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NSB KINGS BAY  
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LETTER FROM NAVY WITH PROJECT TEAM MEETING ATTACHMENTS FOR SITE 11 AS  
PER GEORGIA DEPARTMENT OF NATURAL RESOURCES REQUEST NSB KINGS BAY GA  
5/13/1997  
NSB KINGS BAY

**31547-000**  
**09.01.00.0121**

5090  
Ser FE4/1290

**13 MAY 1997**

CERTIFIED MAIL  
RETURN RECEIPT REQUESTED

Georgia Department of Natural Resources  
Attn: Mr. Bruce Khaleghi, Unit Coordinator  
Environmental Protection Division  
205 Butler Street, SE, Suite 1252  
Atlanta, GA 30334

Dear Mr. Khaleghi:

Per your letter dated April 1, 1997 regarding the Installation Restoration Program Site 11 Project Team Meeting of April 7-8, 1997, you requested that Naval Submarine Base (NSB), Kings Bay provide your office with copies of information furnished at the meeting. In addition, you requested copies of the recent pumping tests, results of the recovery well redevelopment, and analytical data for samples collected during the SCAPS survey.

Enclosure (1) is the Site 11 Project Team Meeting Minutes and associated handouts for the meeting held in Charleston, SC on April 7-8, 1997. Enclosure (2) is the results from the new recovery well installation and performance testing. Enclosure (3) is the results from the existing recovery well redevelopment. Enclosure (4) is the analytical data for the samples collected during the SCAPS survey. In addition to the information that you requested, enclosure (5) is the Interim Measure System Phase II, Treatment System Evaluation report. Enclosure (6) is the Site 11 Risk Assessment Meeting Minutes held in Arlington, VA on April 3, 1997. NSB would like to schedule a meeting between Georgia Department of Natural Resources Risk Assessors, NSB, Naval Facilities Engineering Command (NAVFACENGCOM), and ABB-ES, Inc. to discuss the elements of the human health and ecological risk assessment for site 11. This meeting will allow all parties to be involved in the decision making process rather than learning of the details of the assessment at the review stage. Enclosure (7) is a proposed agenda for the meeting. Please contact the below named point of contact for the scheduling of this requested meeting.

The Restoration Advisory Board Meeting (RAB) was held on April 24, 1997 at 10:00 a.m. at the St. Mary's Library. Handouts and Meeting Minutes from this meeting will be forwarded at a later date. We regret that you were unable to send a representative to this meeting.

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13 MAY 1997

The NSB Kings Bay point of contact on this matter is Ms. Rhonda L. Bath, (912) 673-2001, extension 1217. Please address all correspondence to "Commanding Officer, 1063 USS Tennessee Avenue, Naval Submarine Base, Kings Bay, GA 31547-2606."

Sincerely,

J. W. MCGONAGILL, P.E.  
Lieutenant, CEC, USN  
Facilities & Environmental  
By direction of the  
Commanding Officer

Encls:

- (1) Site 11 Project Team Meeting Minutes (April 7-8, 1997) and Associated Handouts
- (2) New Recovery Well Installation and Performance Testing
- (3) Existing Recovery Well Redevelopment
- (4) Analytical Data for Samples Collected During SCAPS Survey
- (5) Interim Measure System Phase II Upgrades, Treatment System Evaluation Report
- (6) Site 11 Risk Assessment Meeting Minutes (April 3, 1997)
- (7) Proposed Kings Bay Risk Assessment Meeting Agenda

Blind copy to: (w/o encls)  
ABB-ES (Laura Harris)  
NAVFACENGCOM (Anthony Robinson)  
USGS (Chris Leeth)



May 9, 1997

08503-042-97

Southern Division  
Naval Facilities Engineering Command  
ATTN: Mr. Anthony Robinson  
P.O. Box 10068  
2155 Eagle Drive  
North Charleston, SC 29418

Dear Mr. Robinson:

**SUBJECT: Meeting Summary, April 7 and 8, 1997, Project Team Meeting, Naval Submarine Base, Kings Bay, Georgia, Contract Task Order (CTO) 094, Contract No. N62567-89-D-0317**

On April 7 and 8, 1997, the Kings Bay project team met to discuss the status of recent and ongoing activities at Site 11. In attendance were:

Ms. Rhonda Bath, Naval Submarine Base (NSB)  
Mr. Anthony Robinson, Southern Division Naval Facilities Engineering Command (SOUTHNAVFACENGCOM)  
Mr. Chris Leeth, U.S. Geological Survey (USGS)  
Mr. David Hicks, USGS  
Mr. Richard Tringale, ABB Environmental Services, Inc. (ABB-ES)  
Mr. Rick Ryan, ABB-ES  
Mr. Kurt Sichelstiel, ABB-ES  
Ms. Laura Harris, ABB-ES

As part of each project team meeting, the attendees assess the progress that the team is making towards effective communication and developing trust and credibility with one another. During this meeting, attendees felt that the recent team building initiative had been beneficial in removing barriers that had interfered with the functioning of the team. Communication is much improved and the team is functioning well.

Mr. Hicks, the designated meeting coordinator, opened discussions by informing the team that he had received a favorable response from Georgia Environmental Protection Division (GEPD) representatives who were invited to attend this meeting, but who were unfortunately unavailable because of schedule conflicts. Ms. Bath followed up with a similar note, whereby the GEPD had requested that they be included in distribution for technical information regarding Site 11. The team decided that Ms. Bath would coordinate all such submittals as a representative of the regulated facility.

In correspondence to the NSB dated April 1, 1997, GEPD specifically requested deliverables related to the results of the recent pumping tests, recovery well redevelopment, and analytical data for the groundwater samples collected during the direct push program. Letter reports for the step-drawdown test conducted on the new recovery well, RW-6, and the redevelopment of RW-1 through RW-4, have already been prepared and will be forwarded to the GEPD.

Two topics of discussion were identified that were not originally on the agenda. One topic was an update on the meeting that Mr. Robinson had with the ABB-ES risk assessors. The other topic was for the team to discuss possible follow-on activities in response to the results of the direct push groundwater sampling field program.

ABB Environmental Services Inc.

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### Cleanup Review Tiger Team (CURT) Recommendations

Mr. Robinson presented the Navy's CURT recommendations to the project team. Each recommendation was discussed individually. The first recommendation concerned grouting the direct push holes to avoid creating connections between different zones within the aquifer. The USGS pointed out that there was no reason to be concerned about connecting different zones within the surficial aquifer because no confining layers were violated during the work. Additionally, during previous intrusive activities at the site, the formation was observed to readily collapse, closing off any open boreholes up to the top of the water table. During the 1992 direct push program, the collapsed interval was frequently found to be more dense, causing pushes to be refused at depths that had already been penetrated. During the March 1997 field program, the measured depth of open holes remaining after completion of direct pushes were typically 7 to 8 feet and contained no water, indicating that the collapse corresponded to the water table surface. Commercially available sand was used to fill the open portion of the push holes.

Another CURT recommendation was to continue assessing natural attenuation mechanisms operating at the site. Additionally, the October 1995 and April 1996 analytical data should be compared to evaluate the effects that several months of non-pumping had on the contamination characteristics. A letter report for the April 1996 groundwater sampling effort already exists and makes the recommended comparison. Mr. Hicks inquired about Frank Chapelle's, USGS' natural attenuation specialist, involvement in the project. Mr. Robinson indicated that Dr. Chapelle had a very tight schedule and his involvement in Site 11 had not been fully defined. Dr. Chapelle, who is involved in other Navy projects, recently trained two ABB-ES associates on procedures for data collection. These individuals are intended to be used on other projects to disseminate the information and procedures learned during the training. The Kings Bay team still plans to have Dr. Chapelle support the effort to define natural attenuation mechanisms at Site 11.

The CURT recommended that an in-well stripping technology be considered for any hot spots found during the SCAPS program. In follow-up to this recommendation, ABB-ES will develop a detailed cost estimate for a pilot study involving in-well stripping. They also recommended that the direct push analytical data be used to map individual compounds to show containment of contaminant migration. The team, having had the chance to review the chemical maps during this meeting, concluded that the direct push data was not amenable to demonstrating containment because no data points are available downgradient of the IM. Further, during this meeting, the team agreed that concerns about containment would be addressed by increasing the pumping rate at RW-6 to increase drawdown in the aquifer.

The final recommendation of the CURT was to use the Army Corps of Engineers' HELP model to evaluate potential benefits associated with installing a cap on the landfill. The USGS team members did not feel that a modeling effort was needed to evaluate the benefits of a cap, or lack thereof. Based on (1) the aquifer underlying the landfill receiving recharge laterally and (2) the highest levels of contamination at depths of 35 feet below ground surface (bgs), the USGS did not feel that a cap would benefit the cleanup effort. The project team agreed with the USGS' evaluation.

### Hydrogeologic Framework

Mr. Leeth presented an update on progress made on the hydrogeologic framework for Site 11. During March, a borehole was drilled and core obtained to a depth of 310 feet bgs. The boring is located on the east side of the landfill near monitoring wells KBA-11-A,B, and C. A gamma geophysical log was completed over the entire interval drilled. The objective of the drilling and logging program was to verify vertical containment of contaminated groundwater and tie the local stratigraphy into the regional framework.

Mr. Leeth's presentation included a description of the stratigraphy at the boring location and the correlation to regional features or strata. The gamma log showed good correlation between the gamma signatures and stratigraphy observed at the drilling location. Similarly, the onsite gamma log correlated well with logs from 6 other wells located within a 3.5 mile radius of the site. The boring terminated in the top of the upper Brunswick aquifer, confirmed by a distinctive gamma signature that provides a well accepted marker for the horizon. Above the upper Brunswick aquifer three layers identified as likely confining and interbedded with coarse sand layers separate the surficial aquifer from the upper Brunswick aquifer. The uppermost layer that is likely confining is situated approximately 80 to 110 feet bgs. A well was installed in a coarse sand layer beneath the uppermost zone that is suspected of being a confining layer and base of the surficial aquifer. If pumping test results show that the layer is confining, it can then be concluded that the base of the surficial aquifer is approximately 80 feet bgs. Water-level measurements, a pumping test and collection of groundwater samples for determination of major element chemistry are planned later in the month.

#### Results of the Direct Push Program

Ms. Harris presented the results of the direct push program to the team. All the data were presented on individual maps and contour maps were presented for five of seven analytes, including tetrachloroethene, trichloroethene, cis-1,2-dichloroethene, vinyl chloride, and methylene chloride. Benzene and 1,1-dichloroethane data were not amenable to contouring because of sparse, low-level, detections and lack of chemical gradients.

The chlorinated solvents, excluding methylene chloride, are localized vertically and horizontally forming fingers of contaminated groundwater extending from the landfill. Monitoring well KBA-11-13A is located in one finger of contamination that is characterized by the presence of tetrachloroethene and trichloroethene, in addition to cis-1,2-dichloroethene and vinyl chloride. The other finger of contamination is situated to the north of the first and appears to be distinct from the first. The second, or northern finger of contamination, is south of recovery well RW-2 and is primarily comprised of cis-1,2-dichloroethene. Attempts to trace this northern finger into the landfill resulted in identification of trichloroethene, cis-1,2-dichloroethene, and vinyl chloride at a location just inside the western boundary of the landfill. The horizontal extent of both fingers combined is approximately 150 feet. Vertically, the contamination is localized in an interval between 30 and 40 feet bgs.

Since the tetrachloroethene and trichloroethene detections fall along a linear trend, the interpretation of a chemical contour map is fairly straight forward. The contours form the image of a narrow finger of contamination that follows an east to west path. However, the cis-1,2-dichloroethene and vinyl chloride data are amenable to two different interpretations. On the western right-of-way of Spur 40 the highest concentrations of cis-1,2-dichloroethene and vinyl chloride were 1,100 and 150 ug/l, respectively, and are associated with a location adjacent to RW-3. These concentrations near RW-3 could be a combination of material from both fingers of contamination that have been drawn towards the recovery well as a result of pumping. Alternately, the northern finger of contamination may not have reached the western right-of-way. The data do not indicate that the northern finger of contamination was present in the vicinity of PS-7, that is in the path of the contamination if it has not veered to the south under the influence of RW-3.

After much discussion, no single interpretation of how cis-1,2-dichloroethene and vinyl chloride would be contoured was chosen by the team. This resulted in a decision to forego presenting chemical contour maps at the upcoming Remedial Advisory Board (RAB) meeting. The RAB presentation of the direct push results will include maps with concentrations plotted at the location. Discussion points noted during the project team meeting include reduction in cis-1,2-dichloroethene concentration in the vicinity of RW-3 since the 1992 direct push program when 3500 ug/l was found on the western right-of-way. The 1997

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direct push program met the objective of better defining the contamination in the area of the Interim Measure. The detection and delineation of tetrachloroethene and trichloroethene beneath the landfill at concentrations of 3,500 ug/l and 1,200 ug/l appears to have successfully identified the source area for the release. The team is now considering more aggressive approaches to cleaning up the relatively localized areas where the highest concentrations of contaminants were found.

#### Results of RW-6 Pumping Test

Mr. Leeth and Mr. Sichelstiel presented preliminary results of the pumping test conducted on RW-6 in March 1997. Mr. Leeth discussed time versus drawdown relationships. He recommended that all future evaluations of time versus drawdown data should use the Neuman method of data interpretation. Mr. Leeth noted that the storativity estimate for KBA-11-13A of 0.025 is in the range indicative of confined conditions and the value of KBA-11-13B of 0.05 is indicative of unconfined conditions. The similarity of the storativity value for KBA-11-13A to those expected for confined aquifers is somewhat enigmatic because the intermediate aquifer unit is not overlain by a confining layer. The overlying Satilla Formation is suspected of having effects that are reflected in the storativity value for KBA-11-13A even though it is a permeable sand that should not produce confinement.

Mr. Sichelstiel lead the discussion of the pumping test results that relate to well efficiency and distance versus drawdown relationships. The well efficiency of 75% is consistent with the efficiency derived from data from the step-drawdown test conducted in December 1996. Water-level data from piezometers PS-9, PD-8, and PS-10 show a laterally isotropic response to pumping. Potentiometric heads in these piezometers, located to the west of RW-6, indicate a relative change in the hydraulic gradient from the west to east towards RW-6.

Regarding the water chemistry observed during the pumping test, there were no parent compounds detected in samples from RW-6. One sample was collected before the well was shutdown for the direct push work, more than a week before the pumping test. Several other samples were collected and analyzed during the pumping test. The contaminant flow is retarded relative to groundwater flow, so there may not have been enough time for the contaminants to reach RW-6.

#### Follow-on Activities

The team discussed possible follow-on actions to address the contaminant conditions found during the direct push program. The possible actions included installation of additional recovery wells, increasing flow from RW-6, and using in-well stripping. Positives and negatives of each action were identified during discussions.

Increasing the flow from RW-6 is an attractive option because it can be done relatively quickly. This would create a larger capture zone and reduce concerns about containment. A drawback to this option is that one or two recovery wells might have to be turned off in consideration of the treatment system capacity.

The benefit of installing additional recovery wells would be to create a larger capture zone and expedite contaminant removal. The additional wells could be installed at the locations where the highest levels of contaminants were found during the direct push program. Drawbacks to this approach include upgrading the treatment system to accommodate larger volumes of groundwater influent and the possibility of structural damage due to effective stresses created by drawdown in the subdivision.

In-well stripping could be used in the areas where the highest concentrations were found without the need to upgrade the treatment system and install conveyance lines. This could provide containment as well as facilitate cleanup in these areas without the need to upgrade the system. The uncertainties associated with this approach include regulatory buy-in and how the stripping wells will perform. Biological fouling may be a problem.

The team agreed to install a larger pump in RW-6 so that the flowrate can be increased to create at least 1 foot of drawdown at the distal part of the newly-defined hot spots. The treatment system has a maximum design capacity of 60 gpm and is currently operating at approximately 44 gpm. Increasing flow from RW-6 could be accommodated by turning off RW-1 and RW-2, the two wells having the lowest efficiencies. Flow from RW-4 and RW-3 would also be increased, if possible. Additionally, the USGS will design a tracer test to obtain information that will help assess containment.

The team discussed how turning off RW-1 might effect migration of contaminants into the subdivision from the southern part of the IM. Samples of influent from RW-1 have low concentrations of contaminants that suggest it is not in an area that is highly contaminated. Monitoring well KBA-11-16 is situated downgradient of RW-4 and could be used to monitor potential migration of contaminants from the right-of-way into the subdivision. Historically, samples from well KBA-11-16 meet MCLs if the IM system is operating. Contaminant levels increase at KBA-11-16 if the IM system is not operating. A new recovery well in the southern part of the IM could be installed if needed.

The possibility of settlement problems created by drawdown in the aquifer beneath the subdivision was addressed. Drawdown in the aquifer could result in slight compaction of the aquifer matrix. The gravitational force that causes the aquifer matrix to settle when dewatered is referred to as effective stresses. Effective stress could be managed by limiting pumping rates to control drawdown in the subdivision. The screened interval of recovery wells could be reduced to focus groundwater extraction in the interval where the majority of contaminated groundwater resides.

#### Site Management Plan, Project Status Review, Budget and Schedule

The site management plan will be comprised of two elements. One element is provided by the ABB-ES project controls P3 procedures for long-term planning for the project. Short-term activities and scheduling will be done using a 12-month schedule. The P3 and 12-month schedules will be reviewed during project team meetings to track progress and update schedules where necessary. An updated 12-month schedule is included as an attachment to this meeting summary.

Mr. Tringale briefed the team on the project status review that was performed in February. The review was conducted by Mr. Harry Doo, SOUTHNAVFACENCOM Contracts Technical Representative, and Mr. Rich May, ABB-ES CLEAN Program Manager. Both Mr. Doo and Mr. May had received favorable reports regarding the improved functioning of the team.

The P3 schedule and resource procedures provide a means for tracking the budget. There are ongoing revisions to streamline the project and better define how existing funding will be used. The current budget will be sufficient to support the evaluation of natural attenuation and in-well stripping pilot test.

#### Recovery Well Rehabilitation versus Replacement

The discussions that related to installation of new recovery wells are summarized under the section about follow-on activities.

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Next Meeting

The next project team meeting will be either June 17 and 18 or June 24 and 25. The meeting will be from 1:00 to 5:00 PM on the first day and 8:00 AM to 4:00 PM on the second day. The meeting will be held in Knoxville. Meeting facilities will be arranged at a location other than the ABB-ES office. Chris Leeth is the designated coordinator for the meeting.

Agenda items identified for the next meeting include:

- aquifer response to increased flow from RW-6;
- results of pumping test and water chemistry of USGS deep well;
- RAB meeting topics;
- SOUTHNAVFACENGCOM execution plan;
- natural attenuation assessment; and
- in-well stripping.

Action Items

The following action items were identified during this project team meeting:

- ABB-ES to procure and install pump in RW-6 (target 4 to 5 weeks);
- ABB-ES to get the treatment system to maximum capacity (target 5 weeks);
- USGS to design and implement tracer test (target 7 weeks);
- L. Harris to submit draft RAB presentation materials to team on April 16, 1997;
- A. Robinson to update project team on SOUTHNAVFACENGCOM execution plan each meeting;
- A. Robinson to follow-up with technical support branch regarding ABB-ES performing in-well stripping pilot test;
- R. Ryan to provide UVB information sheet to team.

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Sincerely,

ABB Environmental Services, Inc.

Laura B. Harris, P.G.  
Technical Lead

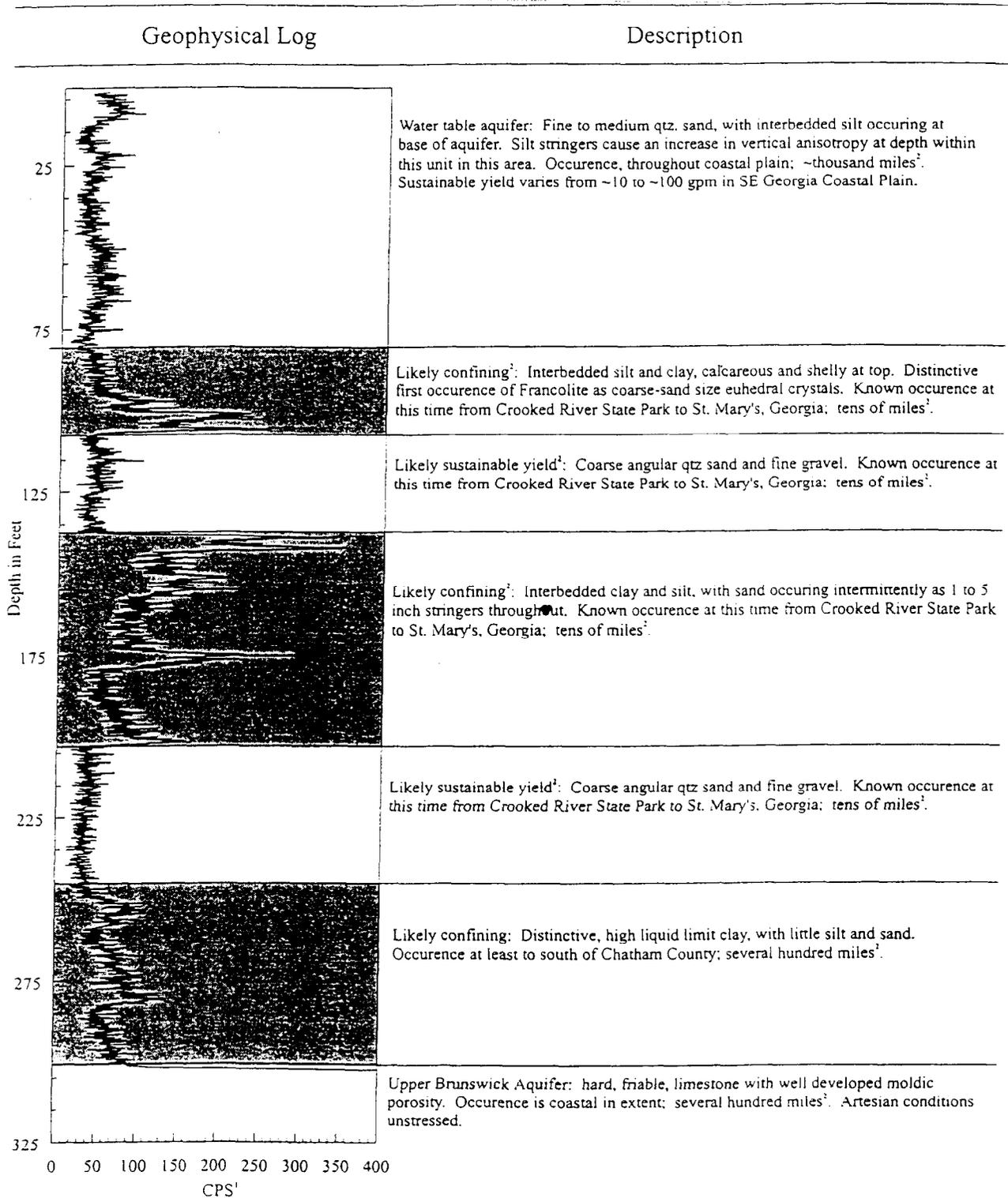
attachment

**12-Month Goals Schedule**  
**Naval Submarine Base**  
**Kings Bay, Georgia**

Action Item	Deadline	Responsible Party
SCAPS Letter Report	6/97	ABB
Deep well pumping testing/water quality	April	USGS
Re-establish budget and schedule (Rich/ABB)	April	Team
Earth Day	April	Rhonda
Re-establish creditability	Ongoing	Team
Sites 5 and 16 planning	8/97	ABB/USGS
Six O&M trips	5/97 - 4/98	ABB
RAB meetings (3 to 4)	4/97 to 4/98	ABB
Publish newsletter	4/97 to 12/97	ABB/Kings Bay
Interface with SouthDiv technical support branch	4/97 to 6/97	Anthony
Framework	6/97	USGS
Telemetry installation	6/97	ABB
Semiannual sampling	6/97	ABB
Implement evaluation plan (PEP)	6/97	ABB/Team ABB/USGS
Biodegradation evaluation	7/97	ABB
Restart CMS	8/97	ABB
Well rehabilitation/abandonment & replacement evaluation	8/97	Team/ABB
Site 11 RFI completion	9/97	ABB
CNO award submittal	10/97	Rhonda
Risk assessment	11/97	ABB
Develop long-term plan - budgets, determining needs	11/97	Team
Project team meetings	Bimonthly	Team
Remediation pilot study	10/97	ABB (Rick)
Revisit team building package at meetings to measure progress towards a more trustful relationship		Team

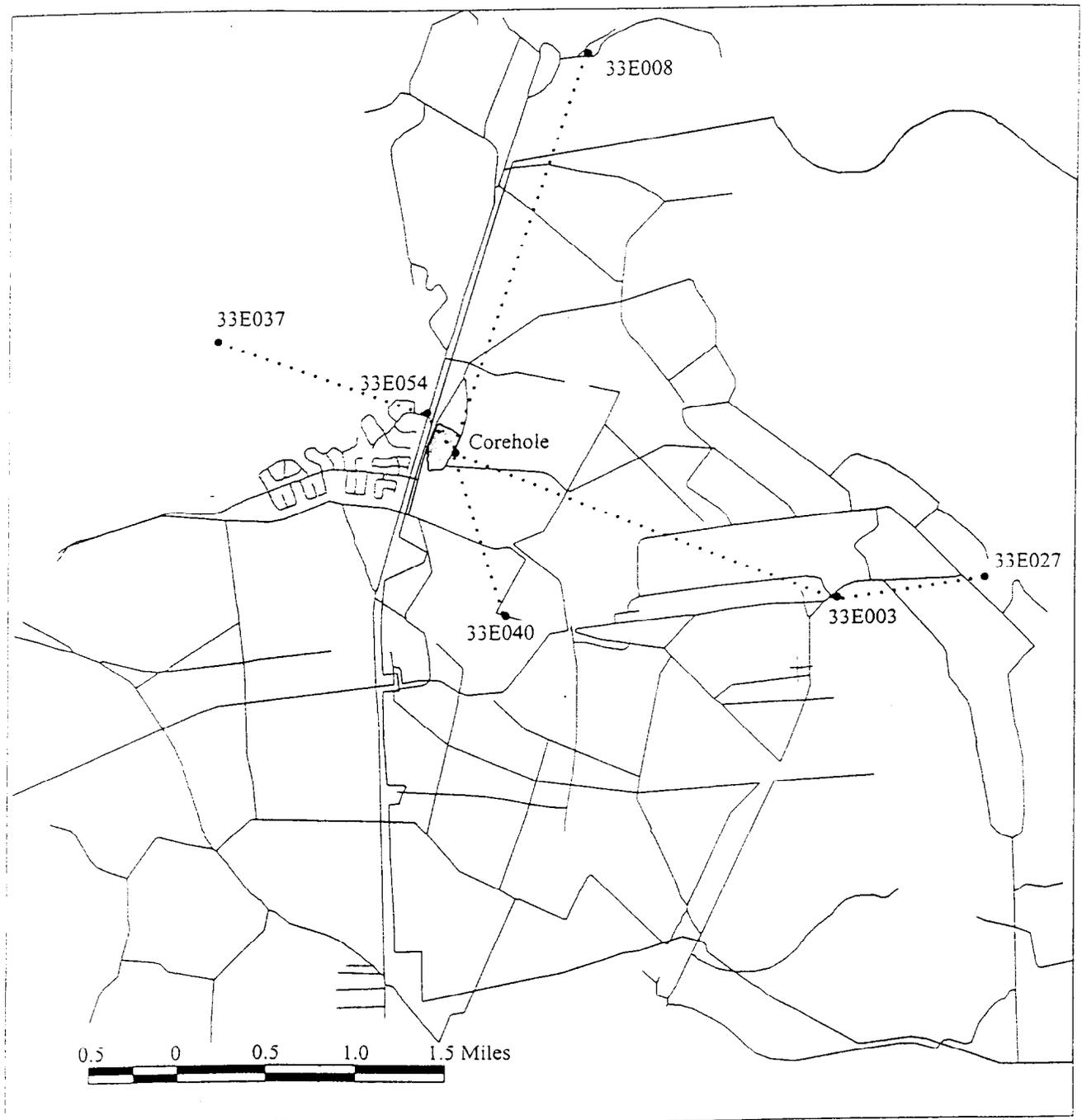
Updated from 4/7-8/97 team meeting.

# Kings Bay, Site 11 Corehole to top of upper Brunswick aquifer.

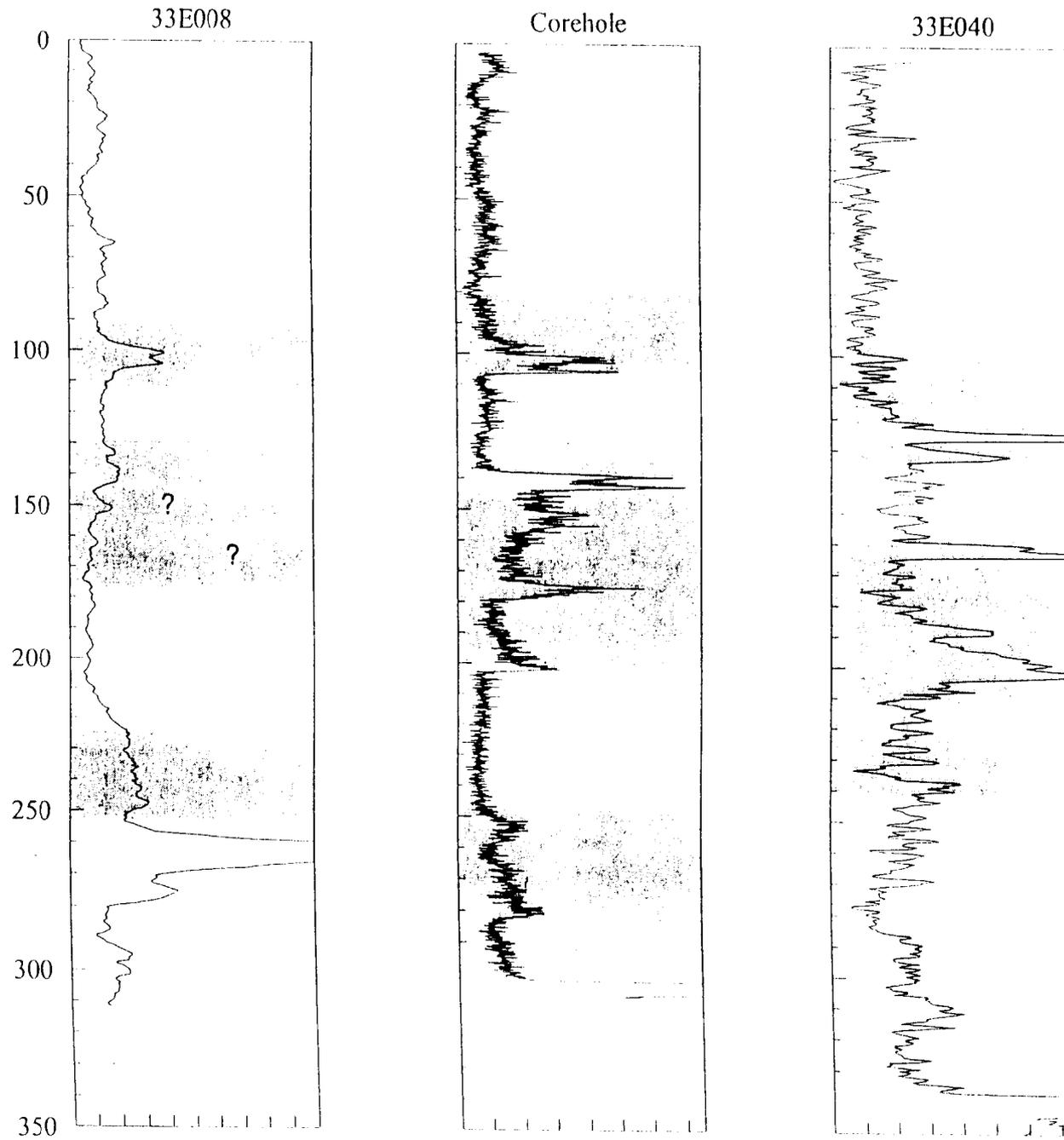


1. Natural gamma values reported in counts per second (CPS)
2. Aquifer properties based on lithology; not verified by hydrologic testing at this time.

# Wells Used to Generate Deep Cross Sections Near Site 11

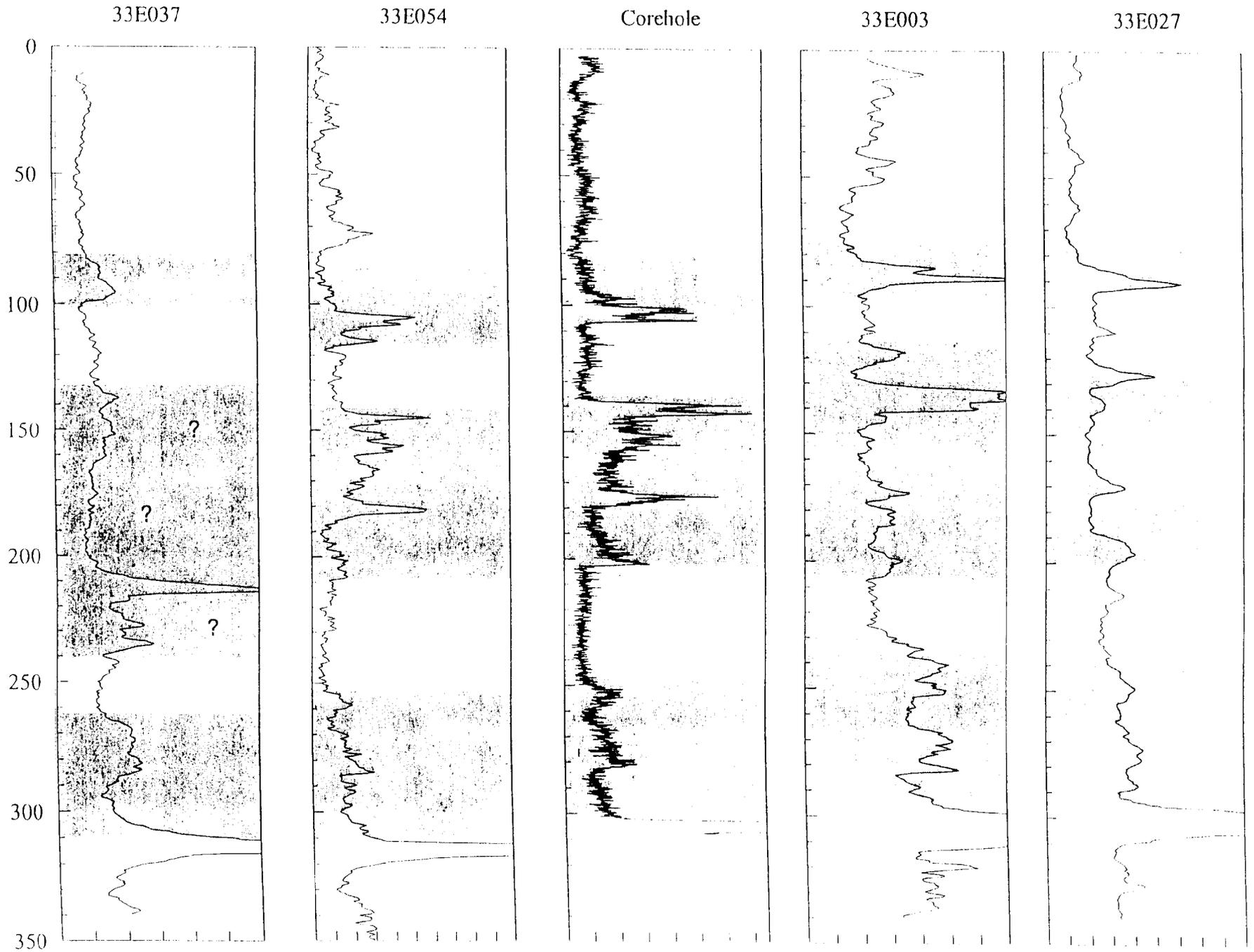


# North to South Geophysical Logs Near Site 11



Note: Logs are not corrected for altitude. Data for 33E008 is poorly documented.

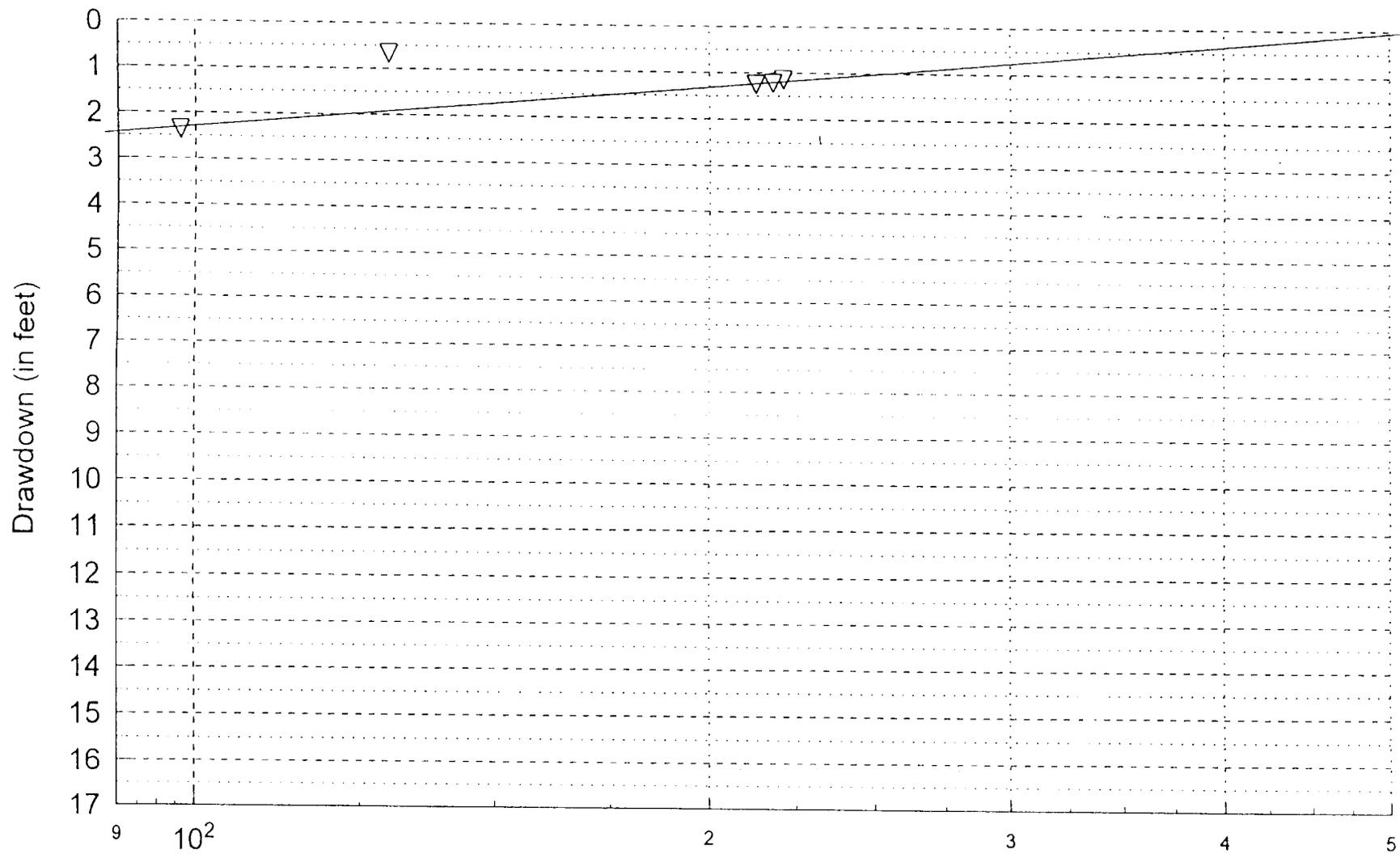
# East to West Geophysical Logs Near Site 11



Note: Logs are not corrected for altit      Data for 33E037 is poorly documented.

# NSB Kings Bay Old Camden County Landfill Site 11 IM System

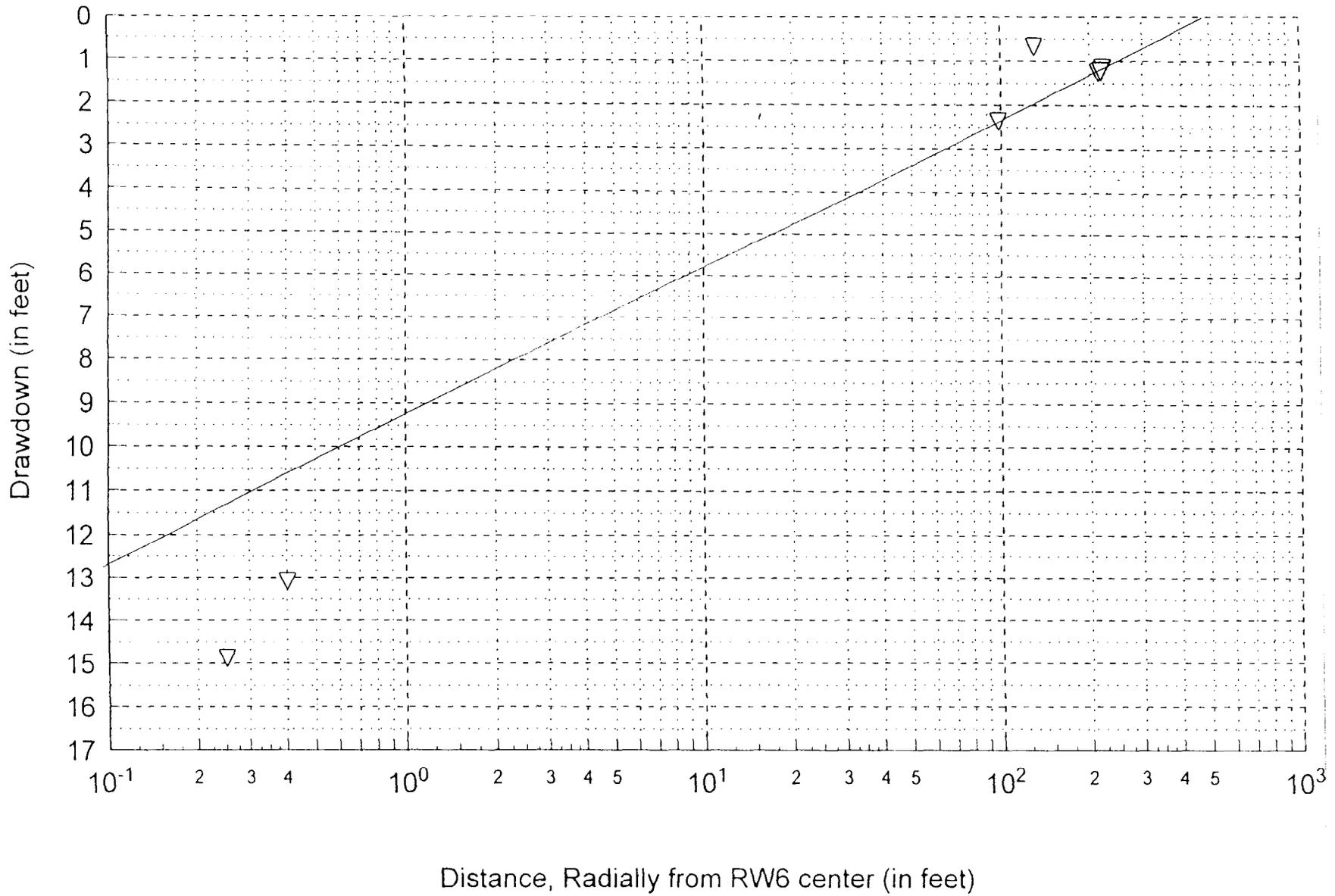
## RW6 Pumping Test -- Distance Drawdown Plot



Distance, Radially from RW6 center (in feet)

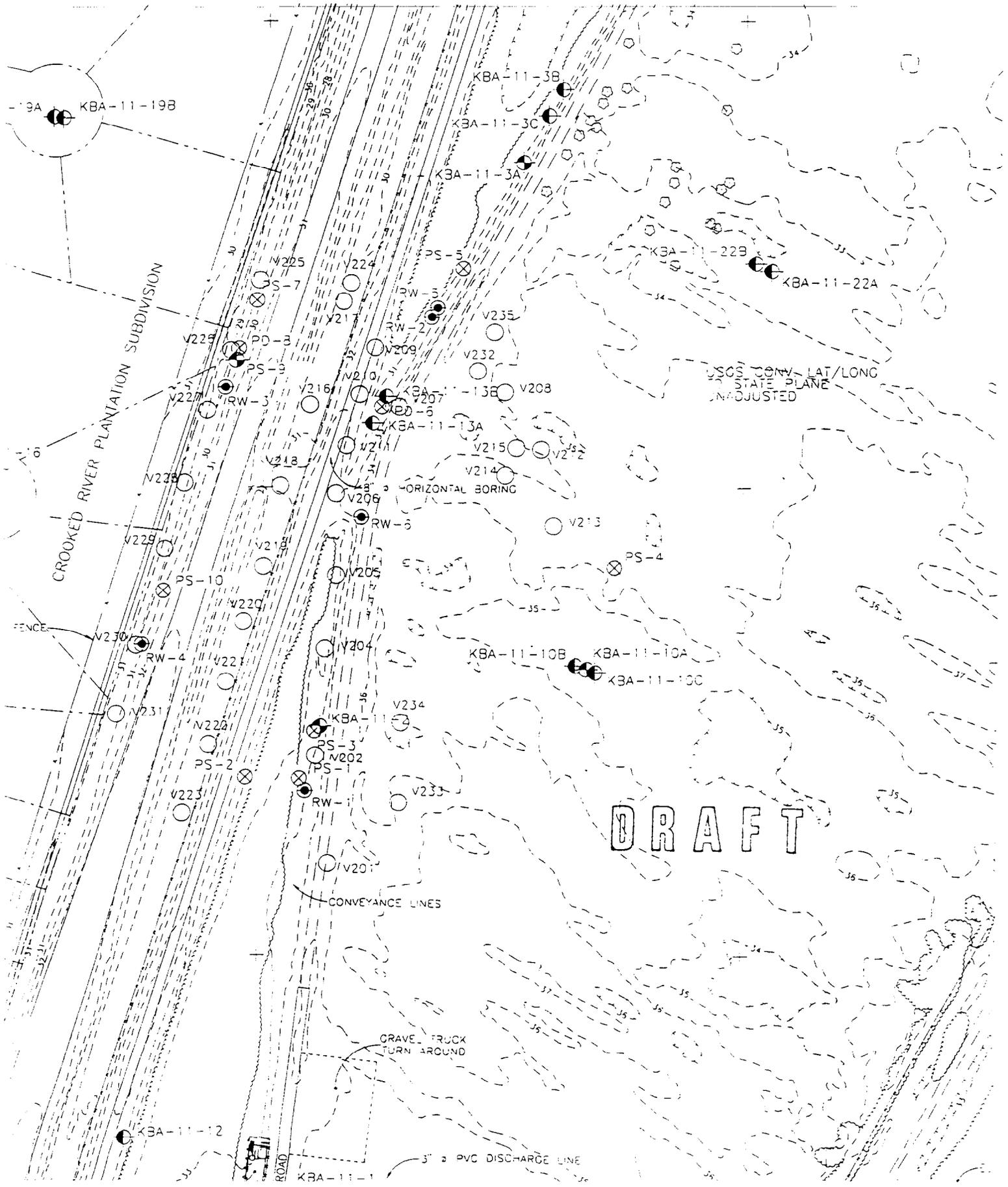
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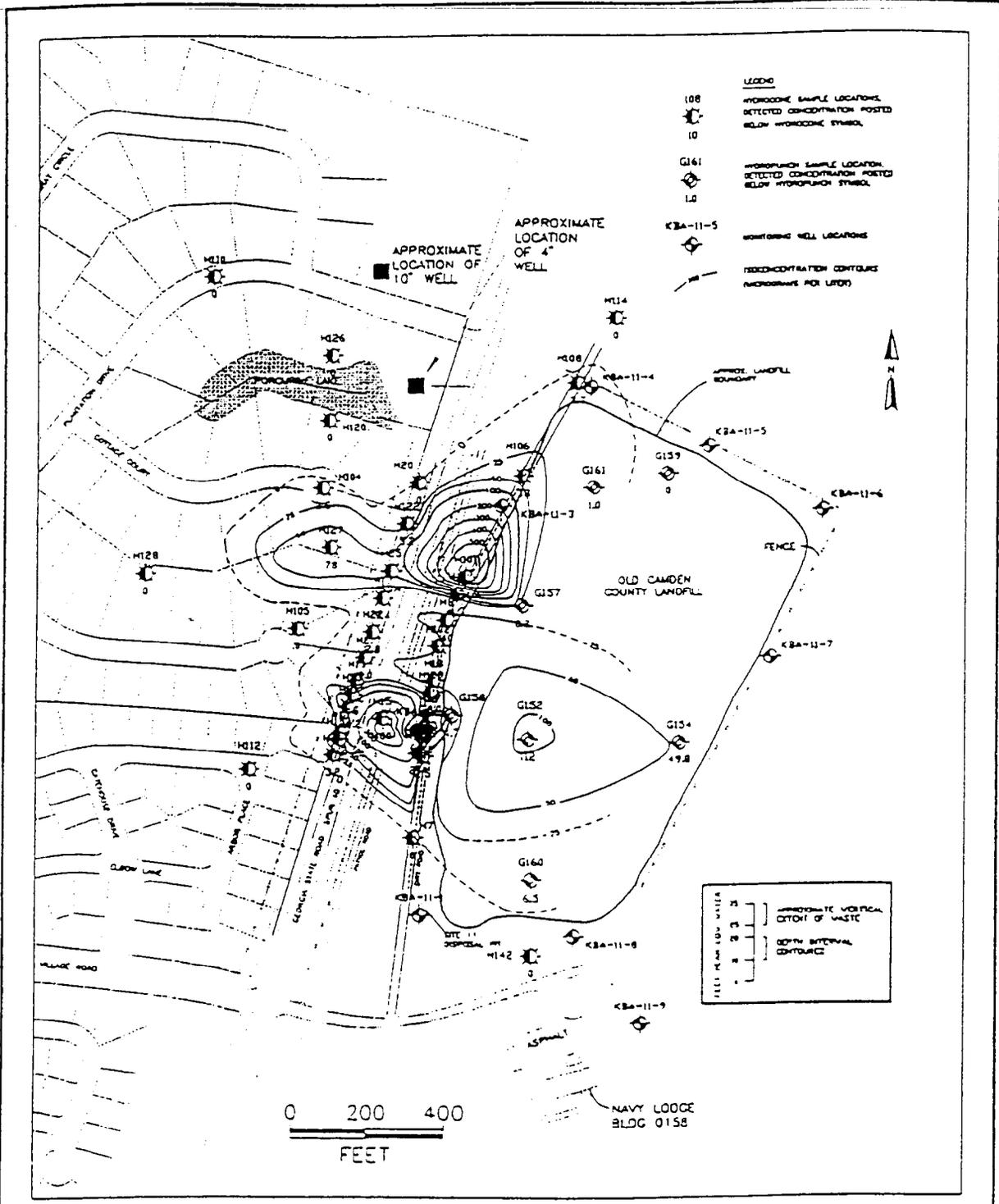
## RW6 Pumping Test -- Distance Drawdown Plot



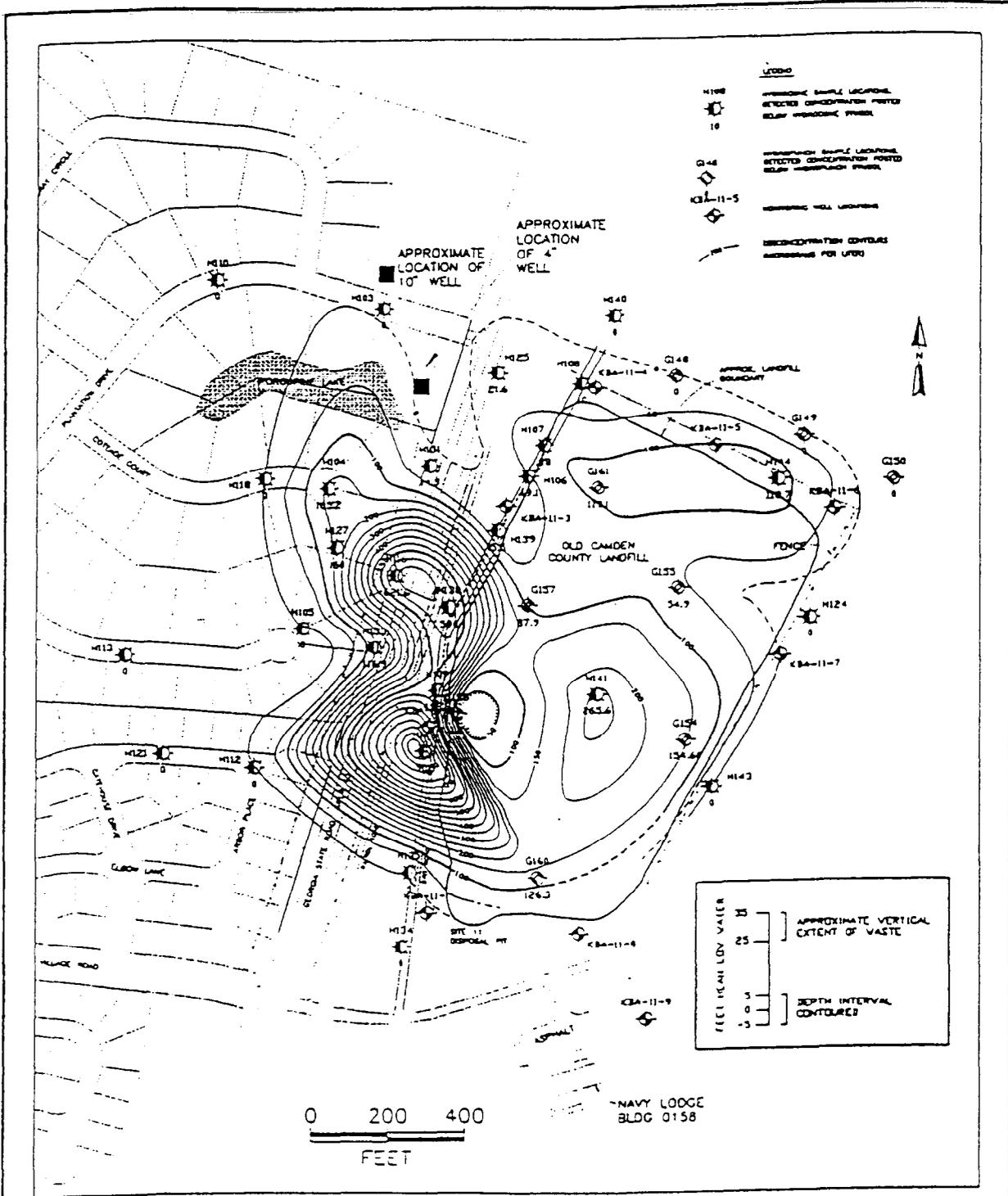




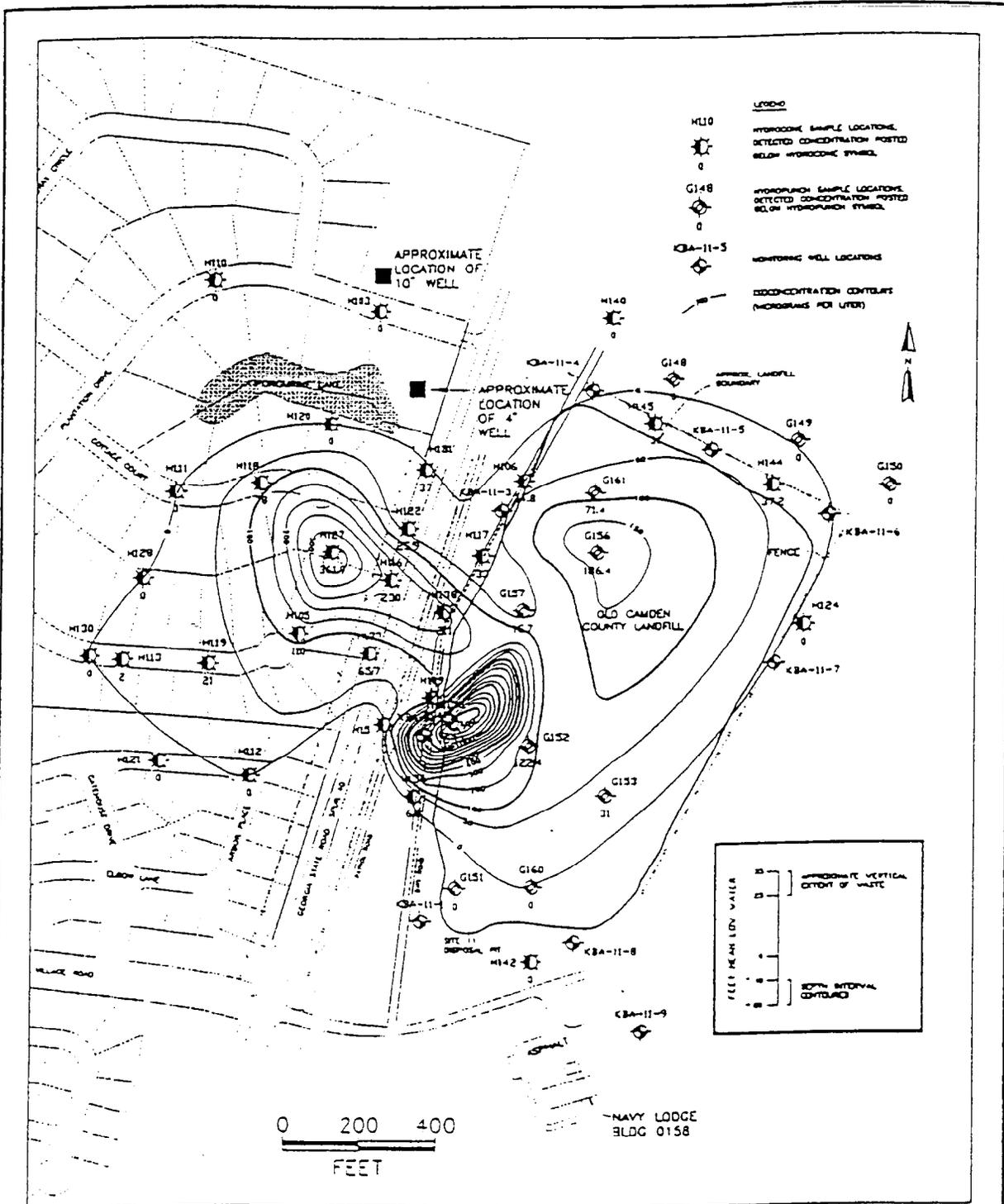




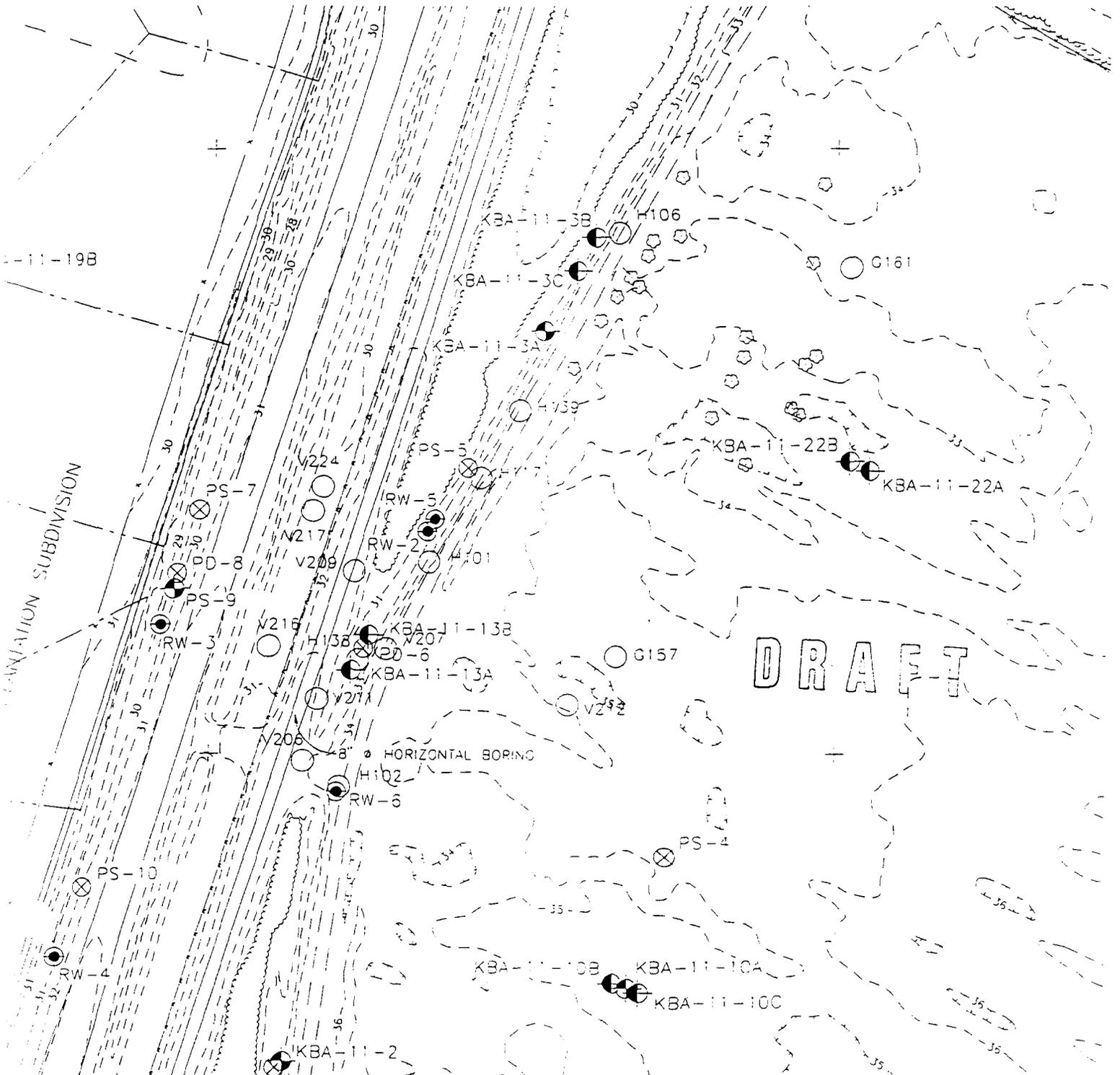
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CHKD: LBH		APPD: LBH		FIGURE NO.: 4-1		
DATE: 6/23/93		REV.: 1.1				

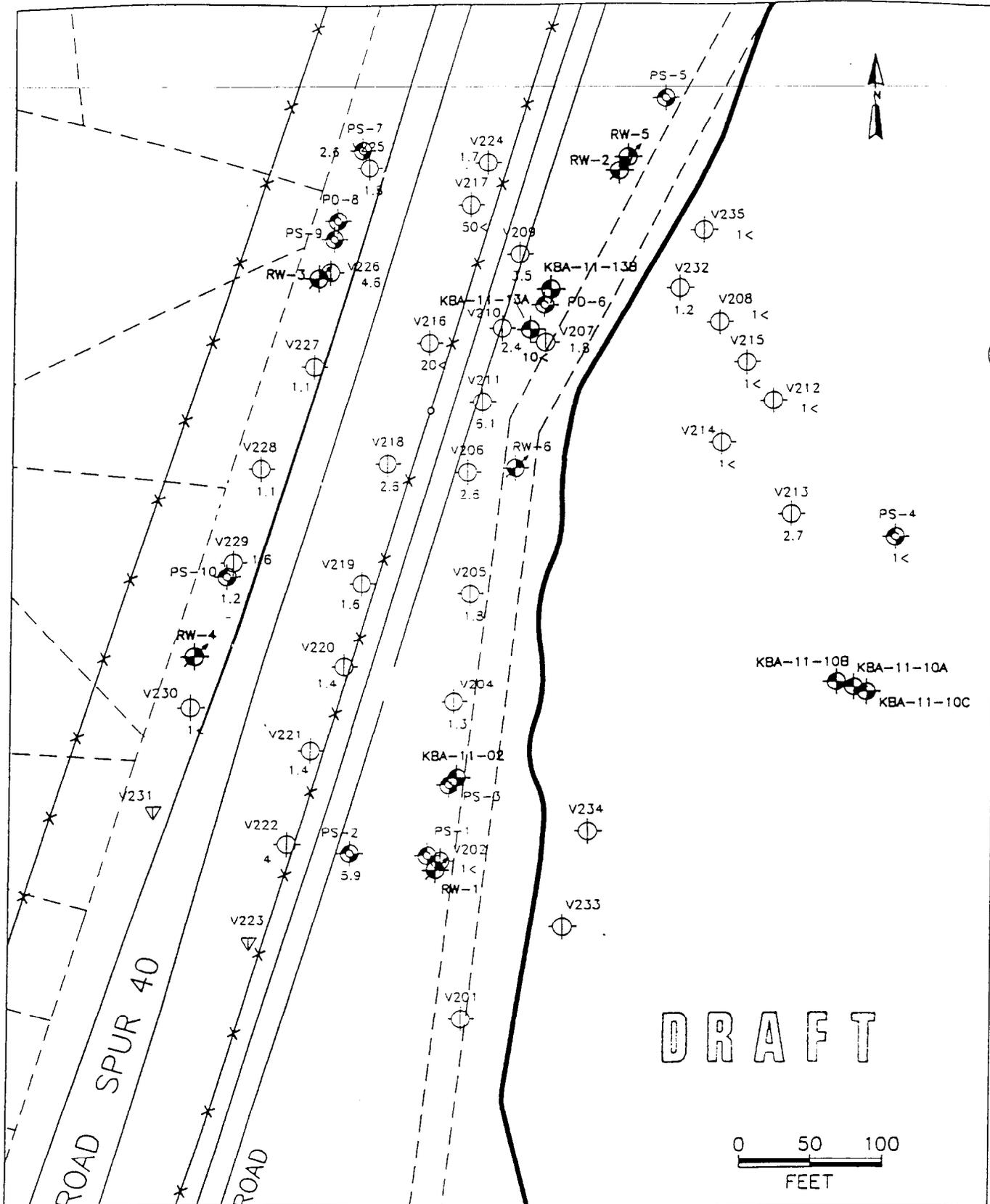


OWN: LGT	DES.: LGT	PROJECT NO.: 7553	TITLE: INTERPRETED PLUME PLAN VIEW S TO -5 FT MEAN LOW WATER TOTAL TARGET VOCs	 KCSB ADDENDUM NAVAL SUBMARINE BASE KINGS BAY, GEORGIA
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DATE: 6/23/93	REV.: 1.1			

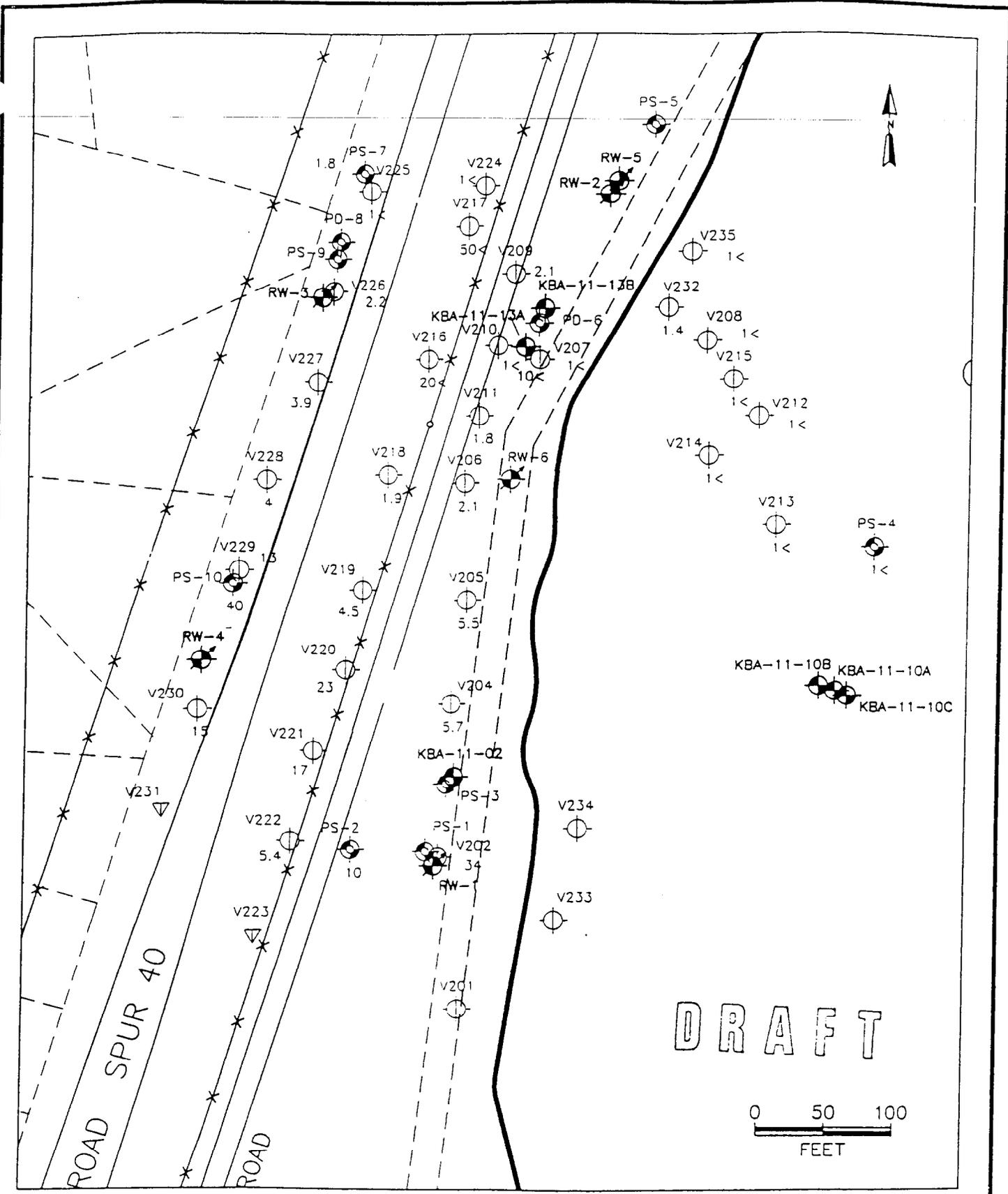


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CHKD: LBH		APPD: LBH	FIGURE NO. 4-3		
DATE: 6/23/93	REV.: 1.1				

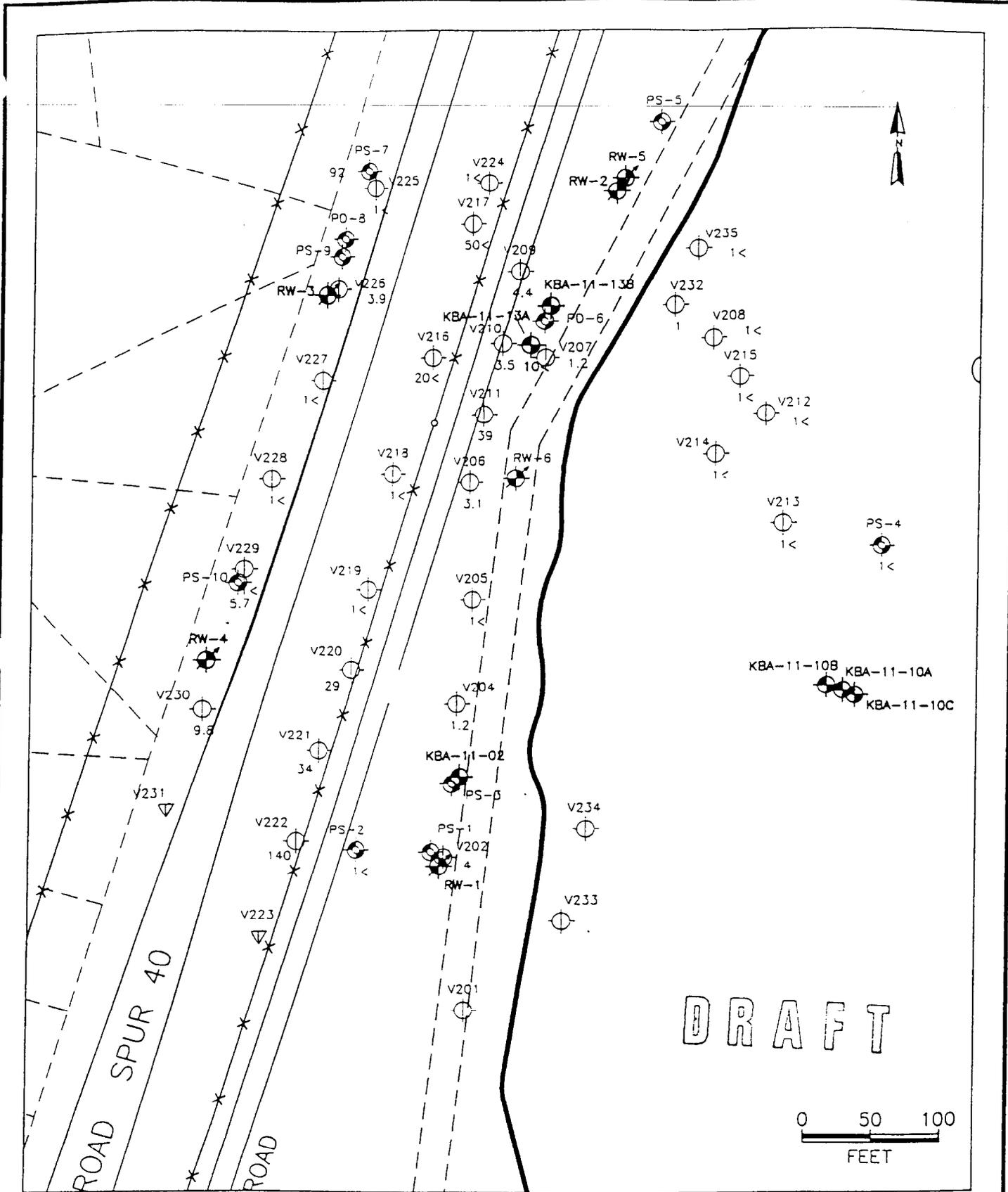




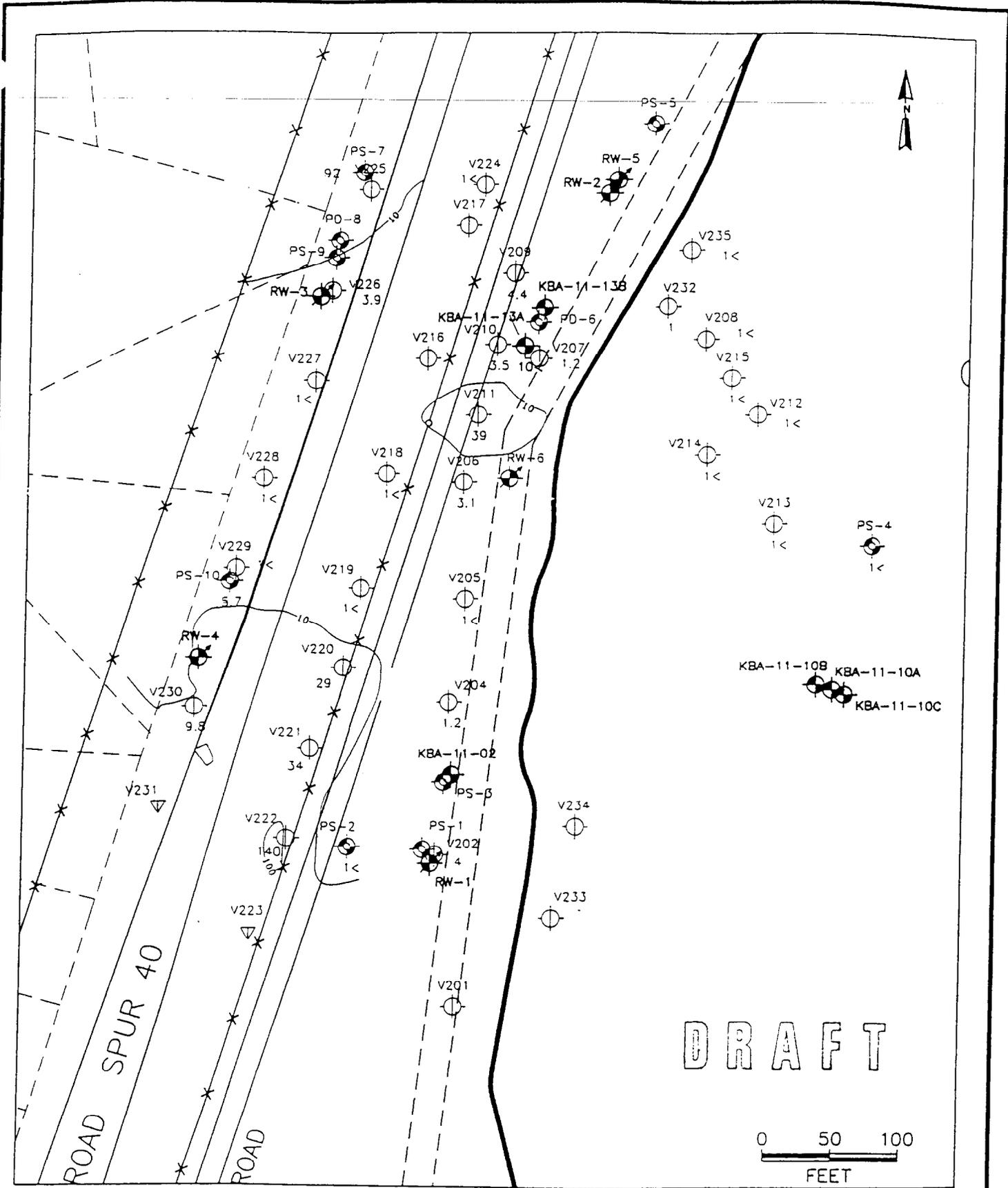
Benzene (ug/l)  
 March 1997 Direct Push Program  
 Site 11, NSB Kings Bay



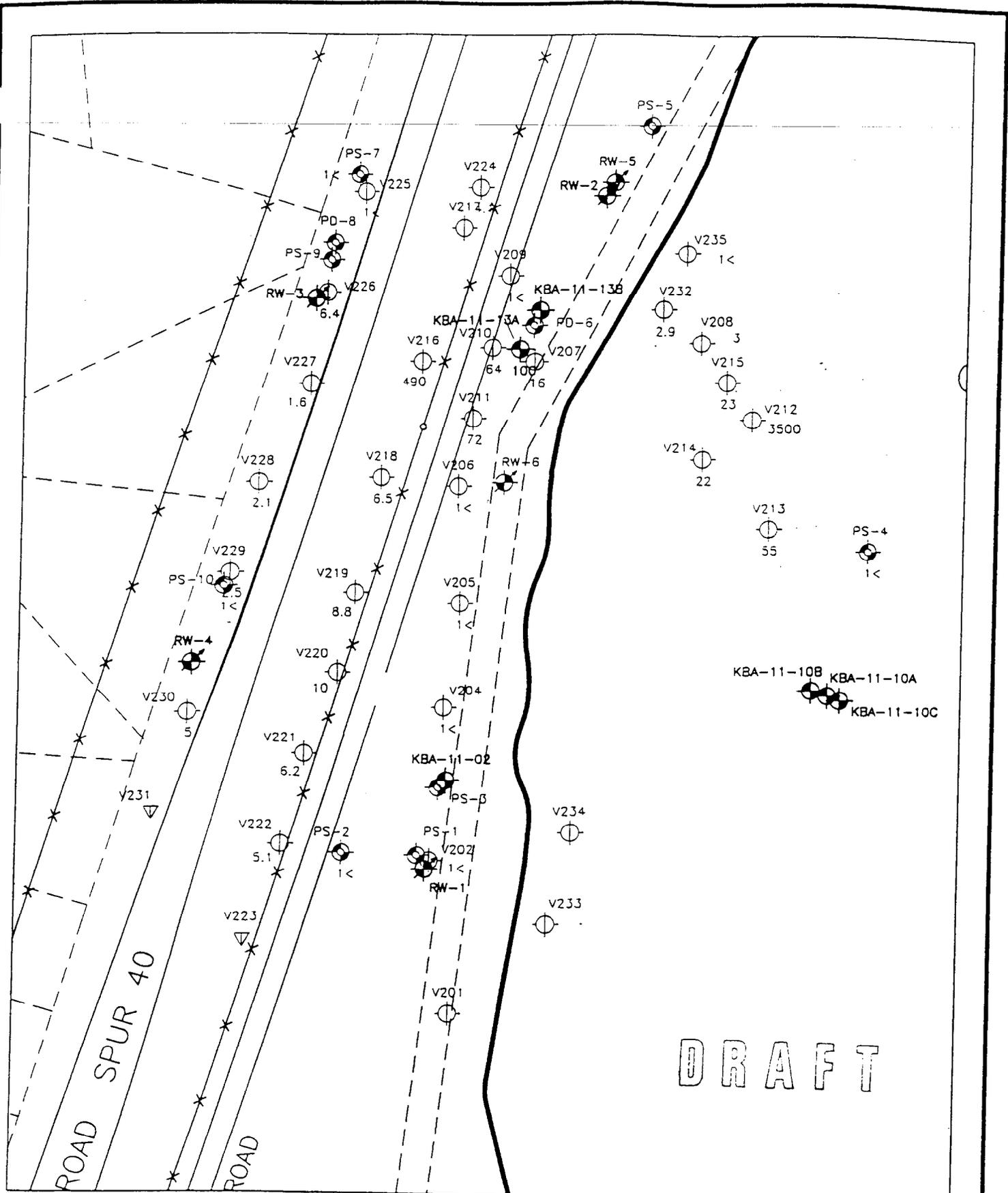
1,1-Dichloroethane (ug/l)  
 March 1997 Direct Push Program  
 Site 11, NSB Kings Bay



Methylene Chloride (ug/l)  
 March 1997 Direct Push Program  
 Site 11, NSB Kings Bay



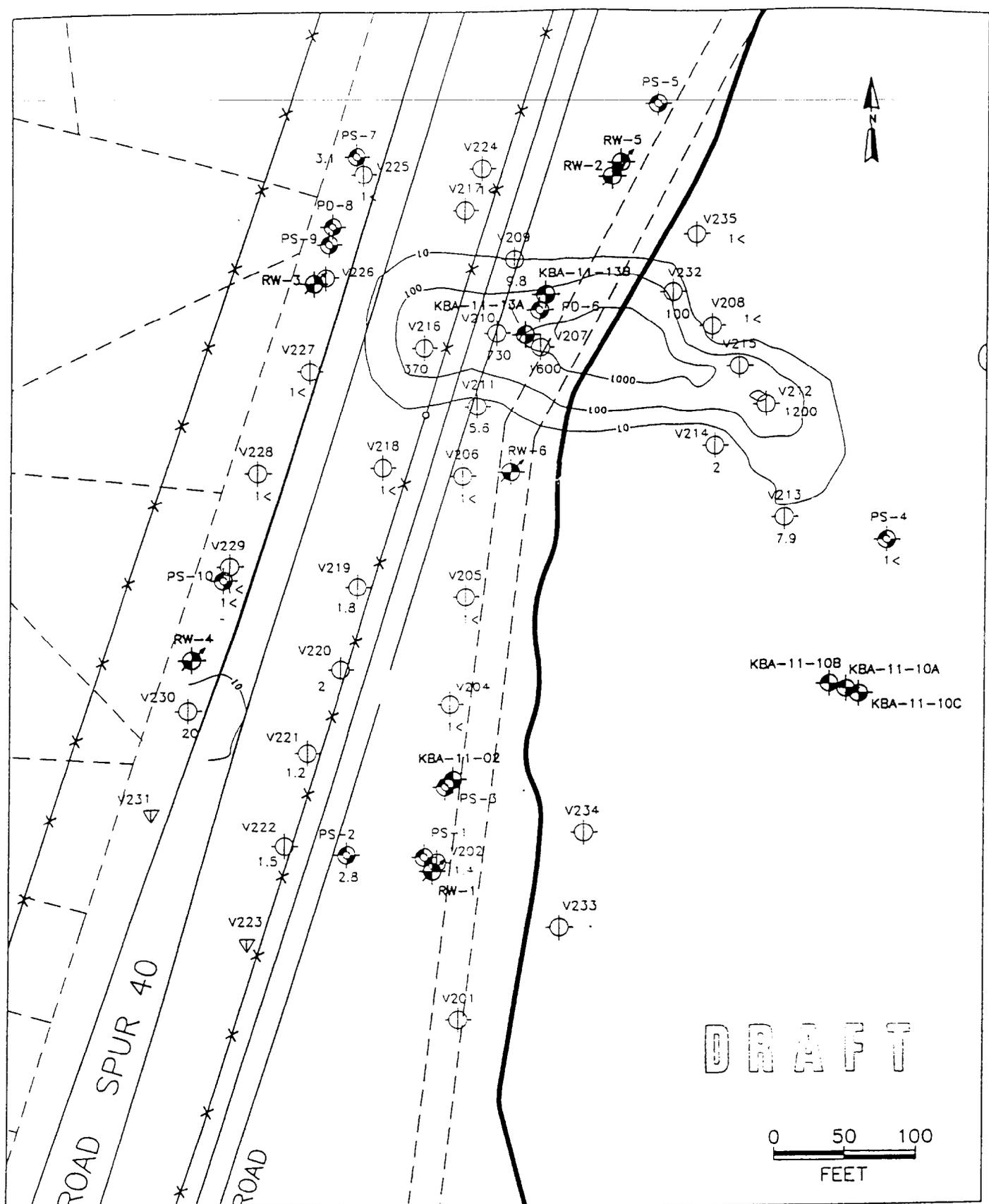
Methylene chloride (ug/l)  
 March 1997 Direct Push Program  
 Site 11, NSB Kings Bay



DRAFT



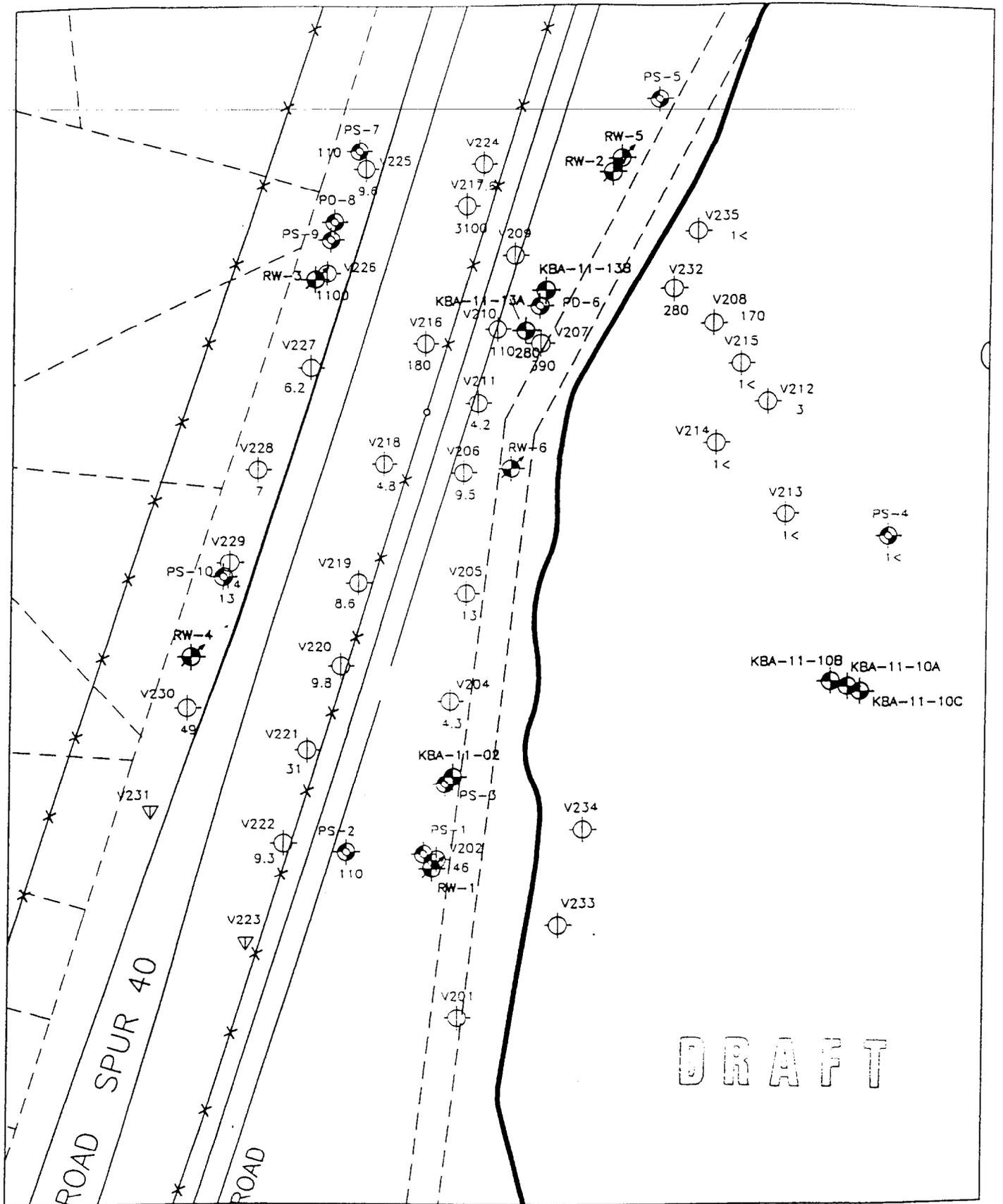




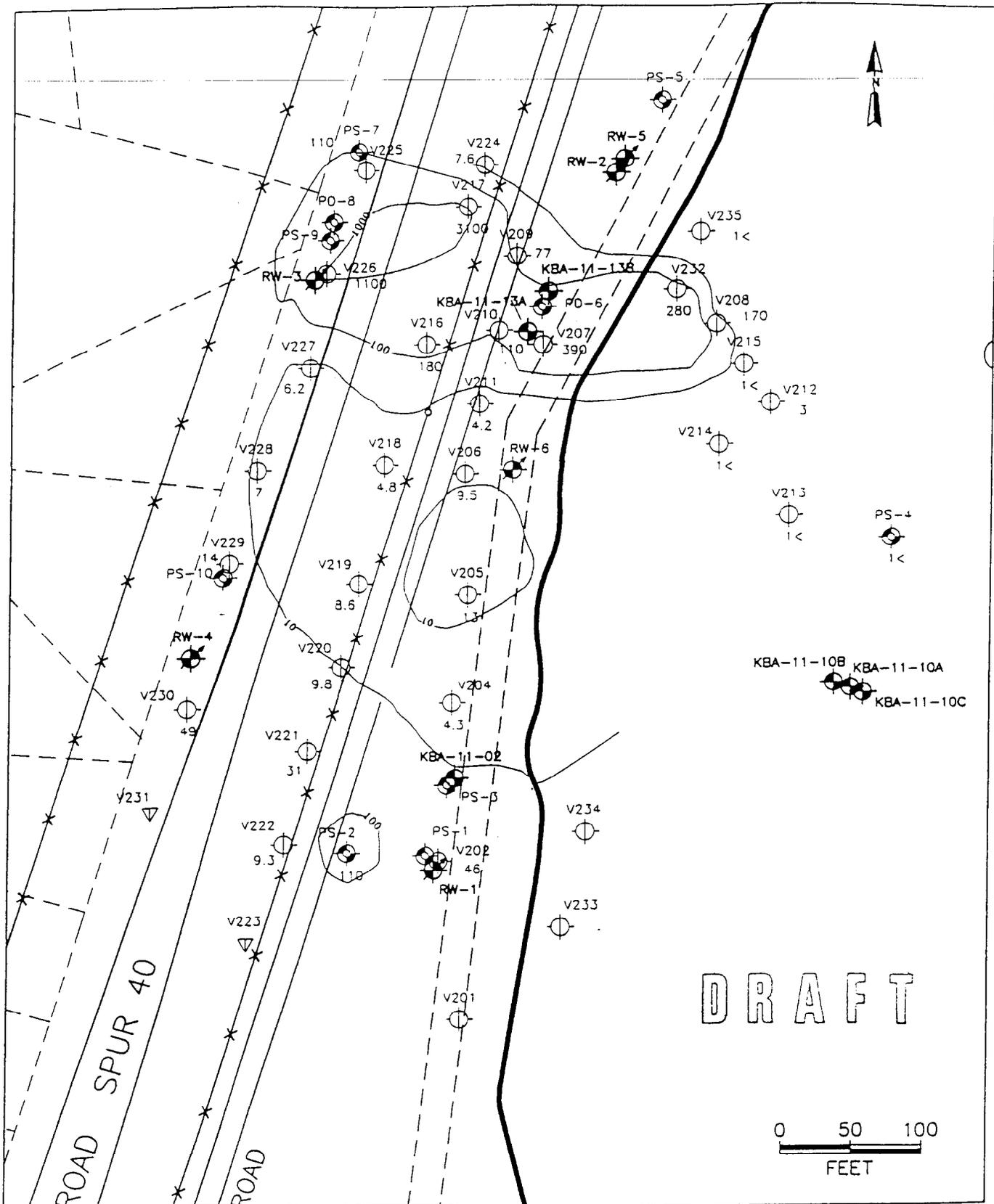
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Trichloroethene  
 March 1997 Direct Push Program  
 Site 11, NSB Kings Bay

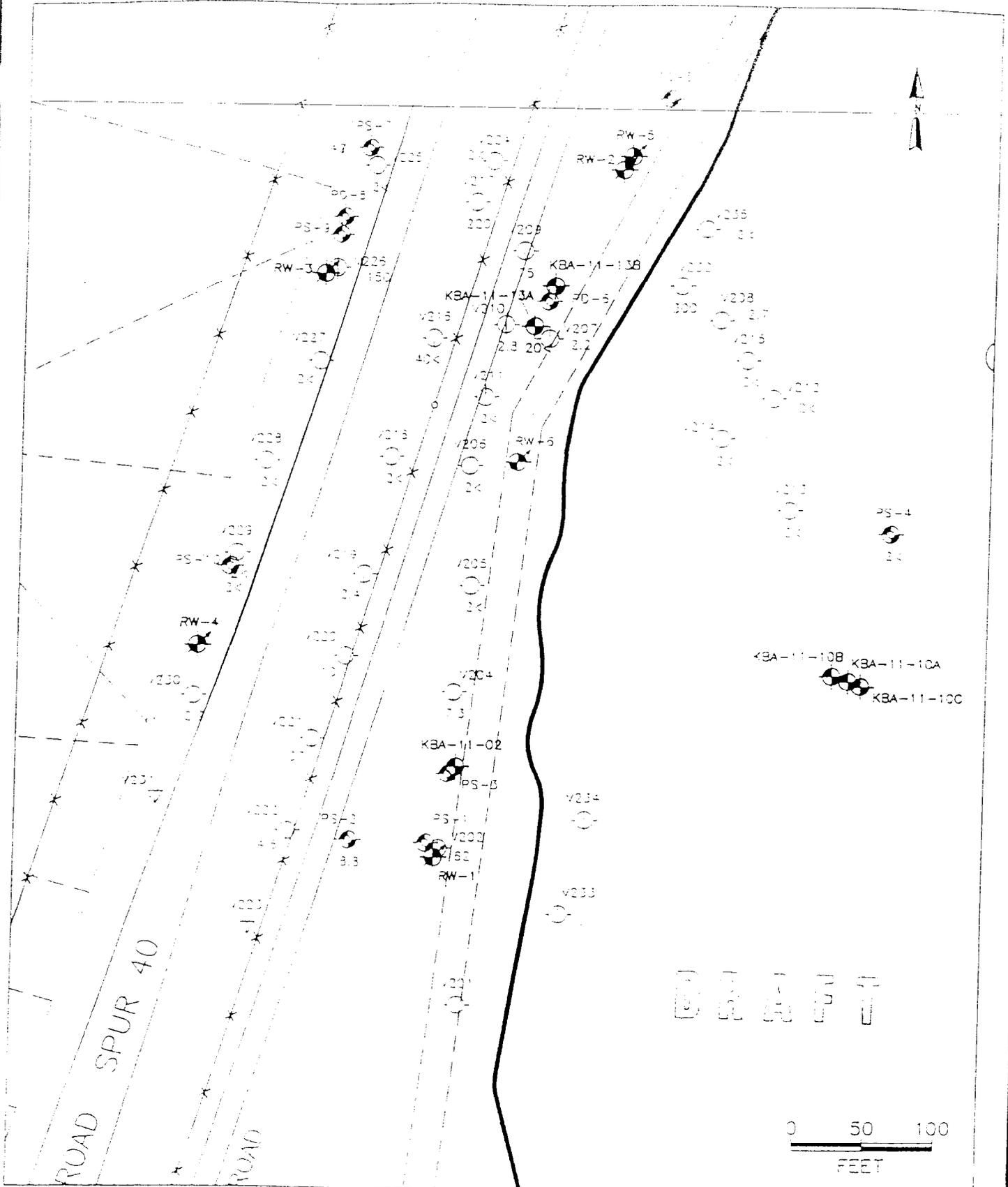


cis-1,2-Dichloroethene (ug/l)  
 March 1997 Direct Push Program  
 Site 11, NSB Kings Bay

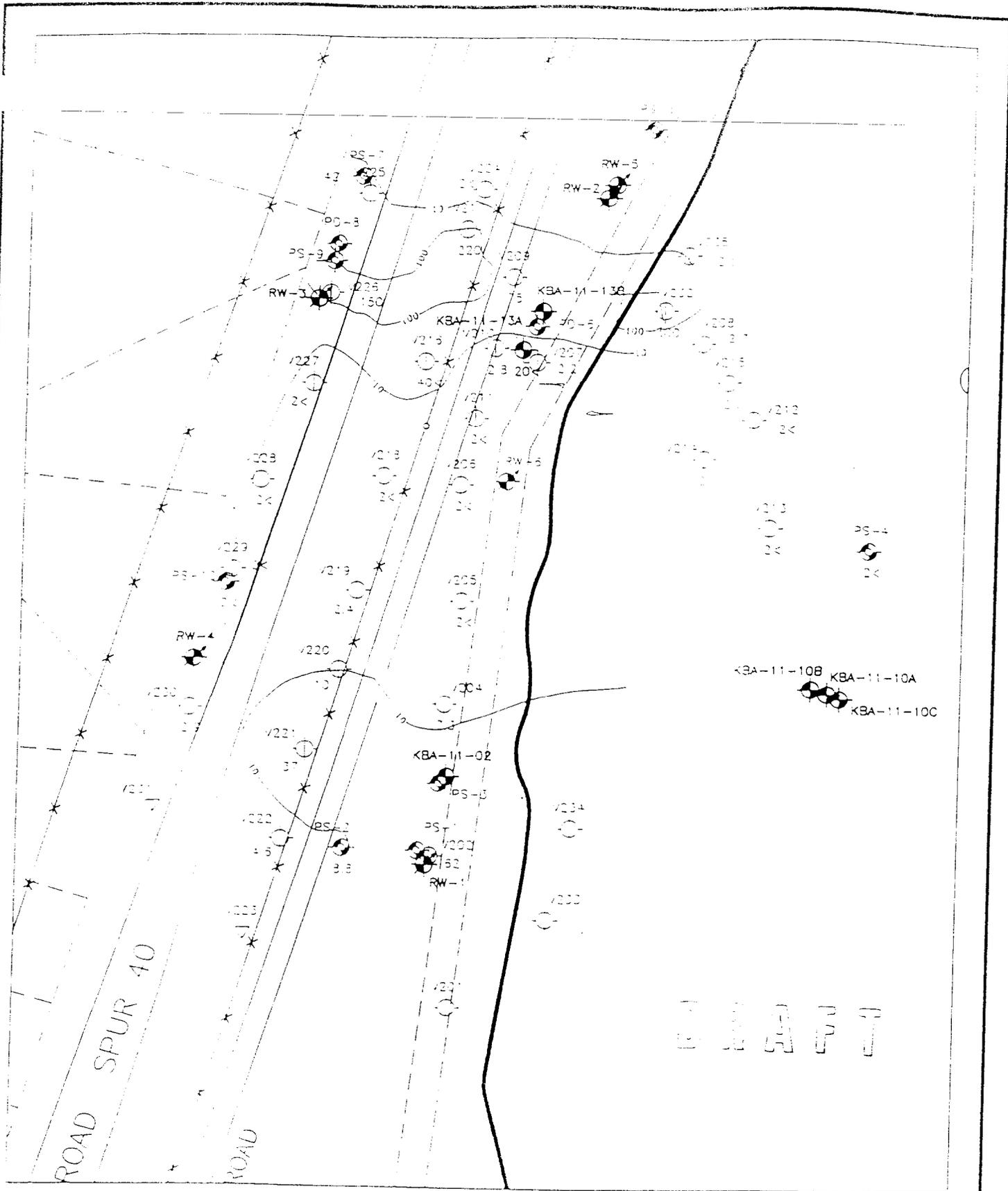


cis-1,2-Dichloroethene (ug/l)  
 March 1997 Direct Push Program  
 Site 11, NSB Kings Bay





Vinyl chloride (ug/l)  
 March 1997 Direct Push Program  
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## Draft Region 4 Approach to Natural Attenuation of Chlorinated Solvents

Much of the Information is Directly from the *Overview of the Draft Technical Protocol for Natural Attenuation of Chlorinated Aliphatic Hydrocarbons in Ground Water* in the Dallas Symposium on Natural Attenuation of Chlorinated Organics in Ground Water

### Introduction

Over the past several years, natural attenuation has become increasingly accepted as a remedial alternative for compounds dissolved in ground water. Region 4 acknowledges that natural attenuation due to advection, adsorption, biological degradation, dispersion, and volatilization can effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem. Natural attenuation in conjunction with source treatment can be the sole remedial alternative for many sites in Region 4. The National Contingency Plan (NCP) citations below are the basis for Natural Attenuation remedy selections made in EPA Region 4.

...Natural attenuation is generally recommended only when active restoration is not practicable, cost effective or warranted because of site-specific conditions (e.g., Class III ground water or ground water which is unlikely to be used in the foreseeable future and there fore can be remediated over an extended period of time) or where natural attenuation is expected to reduce the concentration of contaminants in the ground water to the remediation goals--levels determined to be protective of human health and sensitive ecological environments--in a reasonable time-frame. Further, in situations where there would be little likelihood of exposure due to the remoteness of the site, alternate points of compliance may be considered, provided contamination in the aquifer is controlled from further migrations. The selection of natural attenuation by EPA does not mean that the ground water has been written off and not cleaned up but rather that biodegradation, dispersion, dilution, and adsorption will effectively reduce contaminants in the ground water to concentrations protective of human health in a time frame comparable to that which could be achieved through active restoration (p.8734).

Another NCP citation stating EPA's position on ground water that is not a current source of drinking water but has the ability to be used for drinking water purposes is:

...It is EPA policy to consider the beneficial use of the water and to protect against current and future exposures. Ground water is a **valuable resource** and should be protected and restored if necessary and practicable...(p. 8733)

Institutional controls are required to ensure that such ground waters are not used before levels protective of human health are reached. On DOE and some DoD sites the institutional control issue is more easily provided for, whereas on RCRA and CERCLA sites this poses a considerable problem.

The expectation of EPA in the above citations is that ground water will be restored and when natural attenuation and source treatment are determined to be the appropriate remedial alternative, or part of a remedial alternative for site ground water, the following provisions are understood.

- Measures are taken to "cut off" continued addition of contaminants to ground water and control migration of contaminants in ground water. This embodies removing, remediating, and/or containing the source (see NCP and OSWER Directive No. 9283.1-2).

- All portions of the plume within the area of attainment shall be remediated to the ground water protection standard which are MCL's, non-zero MCLG's and health-based standards for current and potential sources of drinking water. An onsite downgradient compliance boundary will be established beyond which accepted limits cannot be exceeded so that further degradation of large expanses of uncontaminated ground water will be prevented. In other words, the condition in which the property boundary is at a significant distance from the plume the compliance boundary must be located near the existing terminus of the plume. Additionally the area of contamination that exceeds the standards may not be allowed to increase prior to attenuation or discharge into surface water (see NCP and OSWER Directive No. 9283.1-2).

The U.S. Environmental Protection Agency's (EPA) Office of Research and Development and Office of Solid Waste and Emergency Response define natural attenuation as:

The biodegradation, dispersion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

Natural attenuation processes, such as biodegradation, can often be dominant factors in the fate and transport of contaminants. Thus, consideration and quantification of natural attenuation is essential to more thoroughly understand contaminant fate and transport.

This paper presents a technical protocol for data collection and analysis in support of remediation by natural attenuation through biological degradation processes to restore ground water contaminated with chlorinated aliphatic hydrocarbons and ground water contaminated with mixtures of fuels and chlorinated aliphatic hydrocarbons. In some cases, the information collected using this protocol will show that natural attenuation processes, with or without source removal, will reduce the concentrations of these contaminants to below risk-based corrective action criteria or will attain regulatory standards within an acceptable, site-specific time period. This protocol is intended to be used within the established regulatory framework. It is not the intent of this document to replace existing EPA or state-specific guidance on conducting remedial investigations.

## Overview of the Technical Protocol

Natural attenuation in ground-water systems results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Biodegradation is the most important destructive attenuation mechanism. Nondestructive attenuation mechanisms include sorption, dispersion, dilution from recharge, and volatilization. The natural attenuation of fuel hydrocarbons is described in the *Technical Protocol for Implementing Intrinsic Remediation With Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater*, recently published by the U.S. Air Force Center for Environmental Excellence (AFCEE) (1). This document differs from the technical protocol for intrinsic remediation of fuel hydrocarbons because the individual processes of chlorinated aliphatic hydrocarbon biodegradation are fundamentally different from the processes involved in the biodegradation of fuel hydrocarbons.

For example, biodegradation of fuel hydrocarbons, especially benzene, toluene, ethyl benzene, and xylenes (BTEX), is mainly limited by electron acceptor availability, and biodegradation of these compounds generally will proceed until all of the contaminants are destroyed. In the experience of the authors, there appears to be an inexhaustible supply of electron acceptors in most, if not all, hydrogeologic environments. On the other hand, the more highly chlorinated solvents (e.g., perchloroethene and trichloroethene) typically are biodegraded under natural conditions via reductive dechlorination, a process that requires both electron acceptors (the chlorinated aliphatic hydrocarbons) and an adequate supply of electron donors. Electron donors include fuel hydrocarbons or other types of anthropogenic carbon (e.g., land-fill leachate, BTEX, or natural organic carbon). If the subsurface environment is depleted of electron donors before the

chlorinated aliphatic hydrocarbons are removed, reductive dechlorination will cease, and natural attenuation may no longer be protective of human health and the environment. The need of adequate electron donors is the most significant difference between the processes of fuel hydrocarbon and chlorinated aliphatic hydrocarbon biodegradation. For this reason, it is more difficult to predict the long-term behavior of chlorinated aliphatic hydrocarbon plumes than fuel hydrocarbon plumes. Thus, it is important to have a thorough understanding of the operant natural attenuation mechanisms.

In addition to having a better understanding of the processes of advection, dispersion, dilution from recharge, and sorption, it is necessary to better quantify biodegradation. Quantification of biodegradation requires a thorough understanding of the interactions between chlorinated aliphatic hydrocarbons, anthropogenic/natural carbon, and inorganic electron acceptors at the site. Detailed site characterization is required to adequately understand these processes. Compared with conventional engineered remediation technologies, natural attenuation has the following advantages:

The proponent must scientifically demonstrate that biodegradation of site contaminants is occurring at rates sufficient to be protective of human health and the environment in order to support remediation by natural attenuation. Three lines of evidence can be used to support natural attenuation of chlorinated aliphatic hydrocarbons, including:

1. Observed reduction in contaminant concentrations along the flow path downgradient from the source of contamination;
2. Documented loss of contaminant mass at the field scale:
  - Using chemical and geochemical analytical data (e.g., decreasing parent compound concentrations, increasing daughter compound concentrations, depletion of electron acceptors and donors, and increasing metabolic byproduct concentrations);
  - A conservative tracer and a rigorous estimate of residence time along the flow path to document contaminant mass reduction and to calculate biological decay rates at the field scale.
3. Microbiological laboratory data that support the occurrence of biodegradation and give rates of biodegradation.

In an evaluation for the demonstration of biological contaminant degradation, the investigator must obtain either the first two lines of evidence or the first and third lines of evidence. The second and third lines of evidence are crucial to the natural attenuation demonstration of biodegradation because they provide biodegradation rate constants. The biodegradation rate constants are used in conjunction with the other fate-and-transport parameters to predict contaminant concentrations and to assess risk at downgradient points of compliance.

The first line of evidence is simply an observed reduction in the concentration of released contaminants downgradient from the NAPL source area along the groundwater flow path. The observed reduction does not prove that contaminants are being destroyed because the reduction in contaminant concentration could be the result of advection, dispersion, dilution from recharge, sorption, and volatilization with no loss of contaminant mass. Conversely, an increase in the concentrations of some contaminants, most notably degradation products such as vinyl chloride, could be indicative of natural attenuation.

The second line of evidence relies on chemical and physical data to show that contaminant mass is being destroyed via biodegradation, not just diluted. The second line of evidence is divided into two components. The first component is the use of chemical analytical data in mass balance calculations to show that decreases in contaminant and electron acceptor and donor concentrations can be directly correlated to increases in metabolic end products and daughter compounds. The mass balance calculation can be used to show that electron acceptor and donor concentrations in ground water are sufficient to facilitate degradation of dissolved contaminants. Solute fate-and-transport models can be used to aid mass

balance calculations and to collate information on degradation. The second component is the use of measured concentrations of contaminants and/or biologically recalcitrant tracers in conjunction with aquifer hydrogeologic parameters, such as seepage velocity and dilution, to show that a reduction in contaminant mass is occurring at the site and to calculate biodegradation rate constants.

The third line of evidence, microbiological laboratory data, can be used to provide additional evidence that indigenous biota are capable of degrading site contaminants at a particular rate. The most useful type microbiological laboratory data is the microcosm study, because it is necessary to show that biodegradation is occurring and to obtain biodegradation rate constants.

This paper presents a technical course of data gathering that allows converging lines of evidence to be used to scientifically document the occurrence and quantify the rates of natural attenuation. Ideally, the first two lines of evidence should be used in the natural attenuation demonstration. To further document natural attenuation, or at sites with complex hydrogeology, obtaining a field-scale biodegradation rate may not be possible; in this case, microbiological laboratory data can be used. Such a "weight-of-evidence" approach will greatly increase the likelihood of successfully verifying natural attenuation at sites where natural processes are restoring the environmental quality of ground water.

Collection of an adequate database during the iterative site characterization process is an important step in the documentation of natural attenuation. Site characterization should provide data on the location, nature, and extent of contaminant sources. Site characterization also should provide information on the location, extent, and concentrations of dissolved contamination; ground-water geochemical data; geologic information on the type and distribution of subsurface materials; and hydrogeologic parameters such as hydraulic conductivity, hydraulic gradients, and potential contaminant migration pathways to human or ecological receptor exposure points. The data collected during site characterization can be used to simulate the fate and transport of contaminants in the subsurface. Such simulation allows prediction of the future extent and concentrations of the dissolved contaminant plume. Several models can be used to simulate dissolved contaminant transport and attenuation. The natural attenuation modeling effort has three primary objectives: 1) to predict the future extent and concentration of a dissolved contaminant plume by simulating the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the potential for downgradient receptors to be exposed to contaminant concentrations that exceed regulatory or risk-based levels intended to be protective of human health and the environment, and 3) to provide technical support for the natural attenuation remedial option at postmodeling regulatory negotiations to help design a more accurate verification and monitoring strategy and to help identify early source removal strategies.

Upon completion of the fate-and-transport modeling effort, model predictions can be used in an exposure pathways analysis. If natural attenuation is sufficient to mitigate risks to potential receptors, the proponent of natural attenuation has a reasonable basis for negotiating this option with regulators. The exposure pathways analysis allows the proponent to show that potential exposure pathways to receptors will not be completed.

## **Overview of Chlorinated Aliphatic Hydrocarbon Biodegradation**

An accurate estimate of the potential for natural biodegradation is important to obtain when determining whether ground-water contamination presents a substantial threat to human health and the environment, because biodegradation is the most important process acting to remove contaminants from ground water. The information also is useful when selecting the remedial alternative that will be most cost-effective in eliminating or abating these threats should natural attenuation not prove to be sufficient.

Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons and chlorinated solvents (3, 23). Whereas fuel hydrocarbons are biodegraded through use as a primary substrate (electron donor), chlorinated aliphatic hydrocarbons may undergo biodegradation through three different pathways: through use as an electron acceptor, through use as an electron donor, or through co-metabolism, where degradation of the chlorinated organic is fortuitous and there is no benefit to the microorganism. Although at many sites the use of chlorinated aliphatic hydrocarbons as electron acceptors appears to be most important,

under natural conditions at a given site, one or all of these processes may be operating. In general, but in the electron acceptor pathway especially, biodegradation of chlorinated aliphatic hydrocarbons will be an electron-donor-limited process. Conversely, biodegradation of fuel hydrocarbons is an electron-acceptor-limited process.

In a pristine aquifer, native organic carbon is used as an electron donor, and dissolved oxygen (DO) is used first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbon) is present, it also will be used as an electron donor. Following DO consumption, anaerobic microorganisms typically use additional electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron accepting compounds can provide evidence of where and how chlorinated aliphatic hydrocarbon biodegradation is occurring. In addition, because chlorinated aliphatic hydrocarbons may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of the electron acceptor/donor compounds can provide evidence of the mechanisms of biodegradation working. As with BTEX, the driving force behind oxidation-reduction reactions resulting in chlorinated aliphatic hydrocarbon degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in chlorinated aliphatic hydrocarbon reduction and oxidation do not proceed abiotically. Microorganisms are capable of carrying out the reactions, but they will facilitate only those oxidation reduction reactions that have a net yield of energy.

## Mechanisms of Chlorinated Aliphatic Hydrocarbon Biodegradation

### Electron Acceptor Reactions (Reductive Dechlorination)

The most important process for the natural biodegradation of the more highly chlorinated solvents is reductive dechlorination. During the reductive dechlorination, the chlorinated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a chlorine atom is removed and replaced with a hydrogen atom. In general, reductive dechlorination occurs by sequential dechlorination, for example, reductive dechlorination from perchloroethene to trichloroethene to dichloroethene to vinyl chloride to ethene. Depending on environmental conditions, the reductive dechlorination process sequence may be interrupted, with other processes then acting on the products. Reductive dechlorination of chlorinated solvent compounds is associated with all accumulation of daughter products and an increase in the concentration of chloride ions.

Reductive dechlorination affects each of the chlorinated ethenes differently. Of the chlorinated ethene compounds, perchloroethene is the most susceptible to reductive dechlorination because it is the most oxidized. Conversely, vinyl chloride is the least susceptible to reductive dechlorination because it is the least oxidized of these compounds. The rate of reductive dechlorination also has been observed to decrease as the degree of chlorination decreases (24, 25). Murray and Richardson (26) have postulated that this rate decrease may explain the accumulation of vinyl chloride in perchloroethene and trichloroethene plumes that are undergoing reductive dechlorination.

Reductive dechlorination has been demonstrated under nitrate-reducing and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of chlorinated aliphatic hydrocarbons, occur under methanogenic conditions (24). Nitrate/sulfate-reducing condition discussion will be presented in greater detail in subsequent parts of this document. Because chlorinated aliphatic hydrocarbon compounds are used as electron acceptors during reductive dechlorination, there must be an appropriate source of carbon for microbial growth to occur (24). Potential carbon sources include natural organic matter, fuel hydrocarbons, or other organic compounds such as those found in landfill leachate.

### Electron Donor Reactions

Murray and Richardson (26) write that microorganisms are generally believed to be incapable of growth using trichloroethene and perchloroethene as a primary substrate (i.e., electron donor). Under aerobic and some anaerobic conditions, the less-oxidized chlorinated aliphatic hydrocarbons (e.g., vinyl chloride) can be used as the primary substrate in biologically mediated redox reactions (22). In the electron donor reaction, the facilitating microorganism obtains energy and organic carbon from the degraded chlorinated aliphatic hydrocarbon. Fuel hydrocarbons are

biodegraded by the electron donor process.

In contrast to reactions in which the chlorinated aliphatic hydrocarbon is used as an electron acceptor, only the least oxidized chlorinated aliphatic hydrocarbons can be used as electron donors in biologically mediated redox reactions. McCarty and Semprini (22) describe investigations in which vinyl chloride and 1,2-dichloroethane were shown to serve as primary substrates under aerobic conditions. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (27) show evidence of mineralization of vinyl chloride under iron reducing conditions so long as there is sufficient bioavailable iron(III). Aerobic metabolism of vinyl chloride may be characterized by a loss of vinyl chloride mass and a decreasing molar ratio of vinyl chloride to other chlorinated aliphatic hydrocarbon compounds.

### Co-metabolism

When a chlorinated aliphatic hydrocarbon is biodegraded via co-metabolism, the degradation is catalyzed by an enzyme or cofactor that is fortuitously produced by the organisms for other purposes. The organism receives no known benefit from the degradation of the chlorinated aliphatic hydrocarbon; in fact, the co-metabolic degradation of the chlorinated aliphatic hydrocarbon may be harmful to the microorganism responsible for the production of the enzyme or cofactor (22).

Co-metabolism is best documented in aerobic environments, although it could occur under anaerobic conditions. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of perchloroethene, are susceptible to co-metabolic degradation (22, 23, 26). Vogel (23) further elaborates that the co-metabolism rate increases as the degree of dechlorination decreases. During co-metabolism, trichloroethene is indirectly transformed by bacteria as they use BTEX or another substrate to meet their energy requirements. Therefore, trichloroethene does not enhance the degradation of BTEX or other carbon sources, nor will its co-metabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources.

### Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of biologically available organic carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being used. It must be noted that individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below.

#### Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate), and this anthropogenic carbon drives reductive dechlorination. When evaluating natural attenuation of a plume exhibiting Type 1 behavior the following questions must be answered:

1. Is the electron donor supply adequate to allow microbial reduction of the chlorinated organic compounds? In other words, will the microorganisms "strangle" before they "starve", will they run out of chlorinated aliphatic hydrocarbons (electron acceptors) before they run out of electron donors?
2. What is the role of competing electron acceptors (e.g., DO, nitrate, iron(III), and sulfate)?
3. Is vinyl chloride oxidized, or is it reduced?

Type 1 behavior results in the rapid and extensive degradation of the highly chlorinated solvents such as perchloroethene, trichloroethene, and dichloroethene.

## Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high concentrations of biologically available native organic carbon. This natural carbon source drives reductive dechlorination (i.e., is the primary substrate for microorganism growth). When evaluating natural attenuation of a Type 2 chlorinated solvent plume, the same questions as those posed for Type 1 behavior must be answered. Type 2 behavior generally results in slower biodegradation of the highly chlorinated solvents than Type 1 behavior, but under the right conditions (e.g., areas with high natural organic carbon contents) this type of behavior also can result in rapid degradation of chlorinated solvent compounds.

## Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low concentrations of native and/or anthropogenic carbon and by DO concentrations greater than 1.0 milligrams per liter. Under these aerobic conditions, reductive dechlorination will not occur; thus, there is no removal of perchloroethene, trichloroethene, and dichloroethene. Advection, dispersion, and sorption are the most significant natural attenuation mechanisms for perchloroethene, trichloroethene, and dichloroethene in this setting. However, vinyl chloride can be rapidly oxidized under these conditions.

## Mixed Behavior

A single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of chlorinated aliphatic hydrocarbon plumes. For example, Wiedemeier et al. (28) describe a plume at Plattsburgh Air Force Base, New York, that exhibits Type 1 behavior in the source area and Type 3 behavior downgradient from the source. The most fortuitous scenario involves a plume in which perchloroethene, trichloroethene, and dichloroethene are reductively dechlorinated (Type 1 or 2 behavior), then vinyl chloride is oxidized (Type 3 behavior) either aerobically or via iron reduction. Vinyl chloride is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in a plume that exhibits this type of mixed behavior:

Perchloroethene - Trichloroethene -  
Dichloroethene - Vinyl chloride - Carbon dioxide

The trichloroethene, dichloroethene, and vinyl chloride may attenuate at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. Vinyl chloride is removed from the system much faster under these conditions than it is under vinyl chloride-reducing conditions.

A less desirable scenario, but one in which all contaminants may be entirely biodegraded, involves a plume in which all chlorinated aliphatic hydrocarbons are reductively dechlorinated via Type 1 or Type 2 behavior. Vinyl chloride is chemically reduced to ethene, which may be further reduced to ethane or methane. The following sequence of reactions occurs in this type of plume:

Perchloroethene - Trichloroethene -  
Dichloroethene - Vinyl chloride - Ethene - Ethane

This sequence has been investigated by Freedman and Gosseft (13). In this type of plume, vinyl chloride degrades more slowly than trichloroethene and thus vinyl chloride tends to accumulate.

## Protocol for Quantifying Natural Attenuation During the Remedial Investigation Process

The primary objective of the natural attenuation investigation is to show that natural processes of contaminant degradation will reduce contaminant concentrations in ground water to below risk-based corrective action or regulatory levels within an acceptable distance and/or time frame. The natural attenuation investigation requires a prediction of the

potential extent and concentration of the contaminant plume in time and space. The prediction should be based on historic variations in, and the current extent and concentrations of, the contaminant plume, as well as the measured rates of contaminant attenuation. Because of the inherent uncertainty associated with such predictions, the investigator must provide sufficient evidence to demonstrate that the mechanisms of natural attenuation will reduce contaminant concentrations to acceptable levels before potential receptors are reached. The demonstration requires the use of conservative solute fate-and-transport model input parameters and numerous sensitivity analyses so that consideration is given to all plausible contaminant migration scenarios. When possible, both historical data and modeling should be used to provide information that collectively and consistently supports the natural reduction and removal of the dissolved contaminant plume.

Figure 1 outlines the steps involved in the natural attenuation demonstration. Figure 1 also shows the important regulatory decision points in the process of implementing natural attenuation. Predicting the fate of a contaminant plume requires the quantification of solute transport and transformation processes.

Quantification of contaminant migration and attenuation rates and successful implementation of the natural attenuation remedial option requires completion of the following steps:

1. Review available site data, and develop a preliminary conceptual model.
2. Screen the site, and assess the potential for natural attenuation.
3. Collect additional site characterization data to support natural attenuation, as required.
4. Refine the conceptual model, complete premodeling calculations, and document indicators of natural attenuation.
5. Simulate natural attenuation using analytical or numerical solute fate-and-transport models that allow incorporation of a biodegradation term, as necessary.
6. Identify current and future receptors, and conduct an exposure-pathway analysis.
7. Determine whether source treatment will be remediation, removal, containment or a combination of these.
8. If natural attenuation (after source treatment) is acceptable, prepare a long-term monitoring plan.
9. Present findings to regulatory agencies.

#### **Review Available Site Data, and Develop a Preliminary Groundwater Flow and Transport Conceptual Model**

Existing site characterization data should be reviewed and used to develop a site-specific conceptual model. The preliminary conceptual model will help identify any shortcomings in the data and will allow placement of additional data collection points in the most scientifically advantageous and cost-effective manner. A site-specific conceptual model is a three-dimensional representation of the ground-water flow and solute transport system based on available geological, biological, geochemical, hydrological, climatological, and analytical data. This type of conceptual model differs from the conceptual site models that risk assessors commonly use that qualitatively consider the location of contaminant sources, release mechanisms, transport pathways, exposure points, and receptors. The groundwater system conceptual model, however, facilitates identification of these risk-assessment elements for the exposure pathways analysis. After development, the conceptual model can be used to help determine optimal placement of additional data collection points (as necessary) to aid in the natural attenuation investigation and to develop the solute fate-and-transport model.

Contracting and management controls must be flexible enough to allow for the potential for revisions to the conceptual

Figure 1. Natural Attenuation Demonstration Flow Chart for Regulatory Decisions

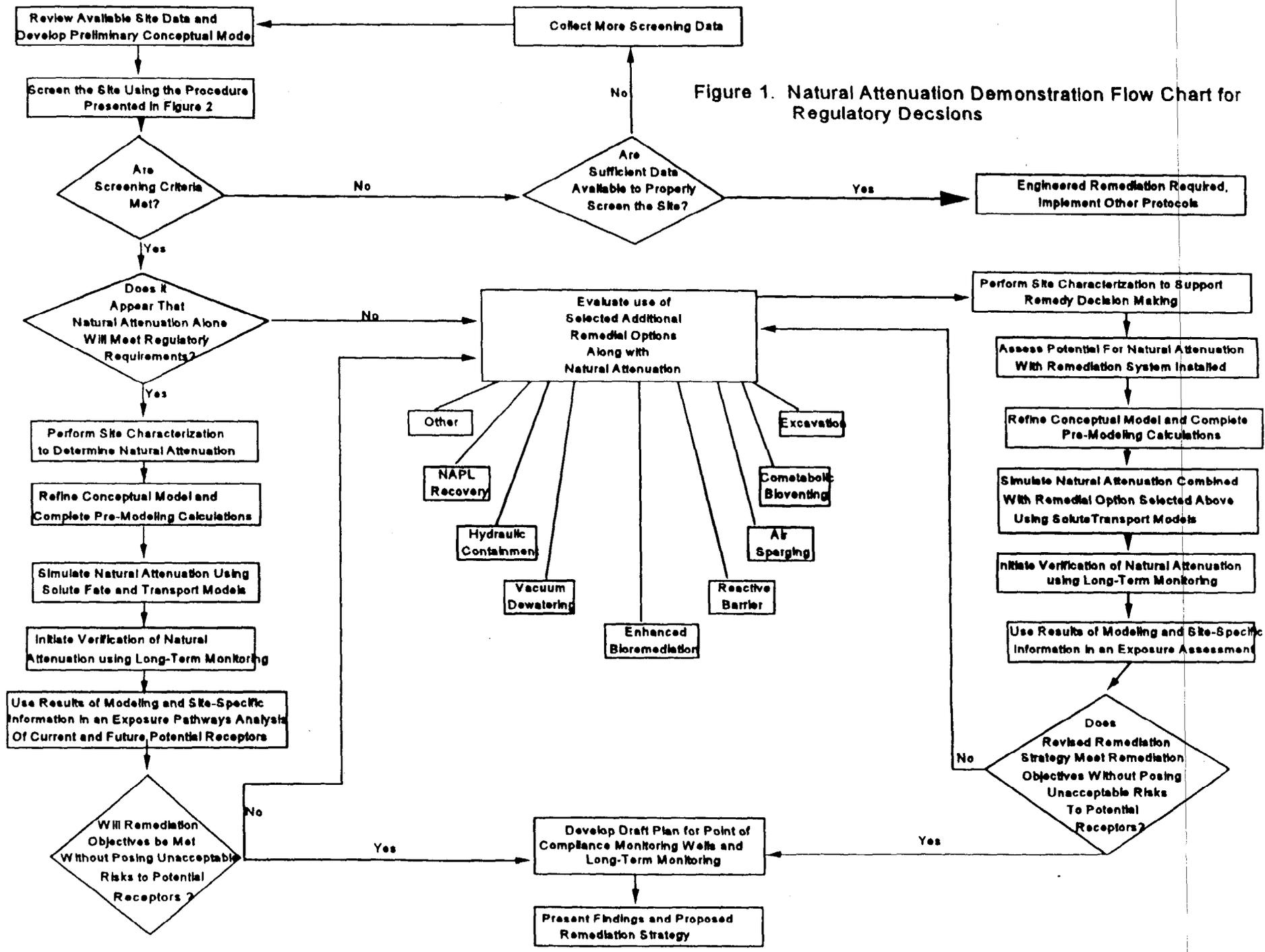


Table 1A. Soil and Ground-Water Analytical Protocol<sup>a</sup>

Matrix	Analysis	Method/Reference <sup>b,c</sup>	Comments <sup>1,9</sup>	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Volatile organic compounds	SW8260A	Handbook method modified for field extraction of soil using methanol	Useful for determining the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW9060, modified for soil samples	Procedure must be accurate over the range of 0.5 to 15% TOC	The amount of TOC in the aquifer matrix influences contaminant migration and biodegradation	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil gas	O <sub>2</sub> , CO <sub>2</sub>	Field soil gas analyzer		Useful for determining bioactivity in the vadose zone	At initial sampling and respiration testing	Reuseable 3-L Tedlar bags	Field
Soil gas	Fuel and chlorinated volatile organic compounds	EPA Method TO-14		Useful for determining the distribution of chlorinated and BTEX compounds in soil	At initial sampling	1-L Summa canister	Fixed-base
Water	Volatile organic compounds	SW8260A	Handbook method; analysis may be extended to higher molecular-weight alkyl benzenes	Method of analysis for BTEX and chlorinated solvents/byproducts	Each sampling round	Collect water samples in a 40-mL volatile organic analysis vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional; intended for diesel and other heavy oils)	Gas chromatography/mass spectroscopy Method SW8270B; high-performance liquid chromatography Method SW8310	Analysis needed only when required for regulatory compliance	PAHs are components of fuel and are typically analyzed for regulatory compliance	As required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base
Water	Oxygen	DO meter	Refer to Method A4500 for a comparable laboratory procedure	Concentrations less than 1 mg/L generally indicate an anaerobic pathway	Each sampling round	Measure DO on site using a flow-through cell	Field
Water	Nitrate	Iron chromatography Method E300; anion method	Method E300 is a handbook method; also provides chloride data	Substrate for microbial respiration if oxygen is depleted	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H <sub>2</sub> SO <sub>4</sub> to pH less than 2; cool to 4°C	Fixed-base
Water	Iron(II) (Fe <sup>+2</sup> )	Colorimetric HACH Method 8146	Filter if turbid	May indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese	Each sampling round	Collect 100 mL of water in a glass container	Field

Table 1A. Soil and Ground-Water Analytical Protocol<sup>a</sup> (Continued)

Matrix	Analysis	Method/Reference <sup>b,c</sup>	Comments <sup>1,g</sup>	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Sulfate (SO <sub>4</sub> -2)	Iron chromatography Method E300 or HACH Method 8051	Method E300 is a handbook method, HACH Method 8051 is a colorimetric method; use one or the other	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	E300 = Fixed-Base HACH Method 8051 = Field
Water	Methane, ethane, and ethene	Kampbell et al. (35) or SW3810, modified	Method published by EPA researchers	The presence of CH <sub>4</sub> suggests biodegradation of organic carbon via methanogenesis; ethane and ethene are produced during reductive dechlorination	Each sampling round	Collect water samples in 50 mL glass serum bottles with butyl gray/Teflon-lined caps; add H <sub>2</sub> SO <sub>4</sub> to pH less than 2; cool to 4°C	Fixed-base
Water	Alkalinity	HACH alkalinity test kit Model AL AP MG-L	Phenolphthalein method	Water quality parameter used to measure the buffering capacity of ground water; can be used to estimate the amount of CO <sub>2</sub> produced during biodegradation	Each sampling round	Collect 100 mL of water in glass container	Field
Water	Oxidation-reduction potential	A2580B	Measurements made with electrodes, results are displayed on a meter, protect samples from exposure to oxygen; report results against a silver/silver chloride reference electrode	The oxidation-reduction potential of ground water influences and is influenced by the nature of the biologically mediated degradation of contaminants; the oxidation-reduction potential of ground water may range from more than 800 mV to less than -400 mV	Each sampling round	Collect 100 to 250 mL of water in a glass container	Field
Water	pH	Field probe with direct reading meter	Field	Aerobic and anaerobic processes are pH-sensitive	Each sampling round	Collect 100 to 250 mL of water in a glass or plastic container; analyze immediately	Field
Water	Temperature	Field probe with direct reading meter	Field only	Well development	Each sampling round	Not applicable	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/ Handbook methods	Water quality parameter used as a marker to verify that site samples are obtained from the same ground-water system	Each sampling round	Collect 100 to 250 mL of water in a glass or plastic container	Field
Water	Chloride	Mercuric nitrate titration A4500-Cl <sup>-</sup> C	Ion chromatography Method E300; Method SW9050 may also be used	Final product of chlorinated solvent reduction; can be used to estimate dilution in calculation of rate constant	Each sampling round	Collect 250 mL of water in a glass container	Fixed-base

Table 1A. Soil and Ground-Water Analytical Protocol<sup>a</sup> (Continued)

Matrix	Analysis	Method/Reference <sup>b,c</sup>	Comments <sup>d,e</sup>	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Chloride (optional; see data use)	HACH chloride test kit Model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Total organic carbon	SW9060	Laboratory	Used to classify plumes and to determine whether anaerobic metabolism of chlorinated solvents is possible in the absence of anthropogenic carbon	Each sampling round	Collect 100 mL of water in a glass container; cool	Laboratory

<sup>a</sup> Analyses other than those listed in this table may be required for regulatory compliance.

<sup>b</sup> "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods* (29).

<sup>c</sup> "E" refers to *Methods for Chemical Analysis of Water and Wastes* (30).

<sup>d</sup> "HACH" refers to the Hach Company catalog (31).

<sup>e</sup> "A" refers to *Standard Methods for the Examination of Water and Wastewater* (32).

<sup>f</sup> "Handbook" refers to the AFCEE *Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS)* (33).

<sup>g</sup> "Protocols" refers to the AFCEE *Environmental Chemistry Function Installation Restoration Program Analytical Protocols* (34).

Table 1B. Soil and Ground-Water Analytical Protocol: Special Analyses Under Development and/or Consideration<sup>a,b</sup>

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Container, Preservation	Field or Fixed-Base Laboratory
Soil	Biologically available iron(III)	Under development	HCl extraction followed by quantification of released iron(III)	To predict the possible extent of iron reduction in an aquifer	One round of sampling in five borings, five cores from each boring	Collect minimum 1-inch diameter core samples into a plastic liner; cap and prevent aeration	Laboratory
Water	Nutritional quality of native organic matter	Under development	Spectrophotometric method	To determine the extent of reductive dechlorination allowed by the supply of electron donor	One round of sampling in two to five wells	Collect 1,000 mL in an amber glass container	Laboratory
Water	Hydrogen (H <sub>2</sub> )	Equilibration with gas in the field; determined with a reducing gas detector	Specialized analysis	To determine the terminal electron accepting process; predicts the possibility for reductive dechlorination	One round of sampling	Sampling at well head requires the production of 100 mL per minute of water for 30 minutes	Field
Water	Oxygenates (including methyl- <i>tert</i> -butyl ether, ethers, acetic acid, methanol, and acetone)	SW8260/8015 <sup>c</sup>	Laboratory	Contaminant or electron donors for dechlorination of solvents	At least one sampling round or as determined by regulators	Collect 1 L of water in a glass container; preserve with HCl	Laboratory

<sup>a</sup> Analyses other than those listed in this table may be required for regulatory compliance.

<sup>b</sup> Site characterization should not be delayed if these methods are unavailable.

<sup>c</sup> "SW" refers to *Test Methods for Evaluating Solid Waste, Physical and Chemical Methods* (29).

model and thus the data collection effort. In cases where little or questionable site-specific data are available, all future site characterization activities should be designed to collect the data necessary to screen the site to determine the potential for remediation by natural attenuation. The data collected in support of natural attenuation can be used to design and support other remedial measures.

Table 1A. lists a standard set of methods, while Table 1B. lists methods that are under development and/or consideration for the soil and ground water analytical protocol for natural attenuation of chlorinated aliphatic hydrocarbons and/or fuel hydrocarbons. Any plan to collect additional ground-water and soil quality data should include targeting the analytes listed in Table 1A., and Table 1B., where the technique is finalized.

### **Screen the Site, and Assess the Potential for Natural Attenuation**

After reviewing available site data and developing a preliminary groundwater flow and transport conceptual model, an assessment of the potential for natural attenuation must be made. As stated previously, existing data can be useful in determining whether natural attenuation will be sufficient to prevent a dissolved contaminant plume from completing exposure pathways, or from reaching a predetermined point of compliance, in concentrations above applicable regulatory or risk-based corrective action standards. Determining the likelihood of exposure pathway completion is an important component of the natural attenuation investigation. The determination is achieved by estimating the migration and future extent of the plume based on contaminant properties, including volatility, sorptive properties, and biodegradability; aquifer properties, including hydraulic gradient, hydraulic conductivity, porosity, and total organic carbon (TOC) content; and the location of the plume and contaminant source relative to potential receptors (i.e., the distance between the leading edge of the plume and the potential receptor exposure points). These parameters (estimated or actual) are used in the example that follows to make a preliminary assessment of the effectiveness of natural attenuation in reducing contaminant concentrations.

If, after completing the steps outlined in this Quantification of biological natural attenuation section, it appears that natural attenuation will be a significant factor in contaminant removal, detailed site characterization activities in support of the natural attenuation remediation is necessary. If exposure pathways have already been completed and contaminant concentrations exceed regulatory levels, or if such completion is likely, other remedial measures should be considered, possibly in conjunction with natural attenuation. Even so, the collection of data in support of the natural attenuation option can be integrated into a comprehensive remedial plan and may help reduce the cost and duration of other remedial measures, such as intensive source removal operations or pump-and-treat technologies. For example, dissolved iron concentrations can have a profound influence on the design of pump-and-treat systems.

The screening process presented in this Quantification of biological natural attenuation section is outlined in Figure 2. The screening process allows the investigator to determine whether natural attenuation is likely to be a viable remedial alternative before additional time and money are expended. The data required to make the preliminary assessment of natural attenuation can also be used to aid the design of an engineered remedial solution, should the screening process suggest that natural attenuation alone is not feasible. The following information is required for the screening process:

- The chemical and geochemical data presented in Table 2 for a minimum of six sample points. Figure 3 shows the approximate location of these data collection points all of which are substantiated in the appropriate flow and contaminant site investigation. If other contaminants are suspected, then data on the concentration and distribution of these compounds also must be obtained.
- Locations of source(s) and receptor(s).
- An estimate of the contaminant transport velocity and direction of ground-water flow.

Once these data have been collected, the screening process can be undertaken. The following steps summarize the screening process:

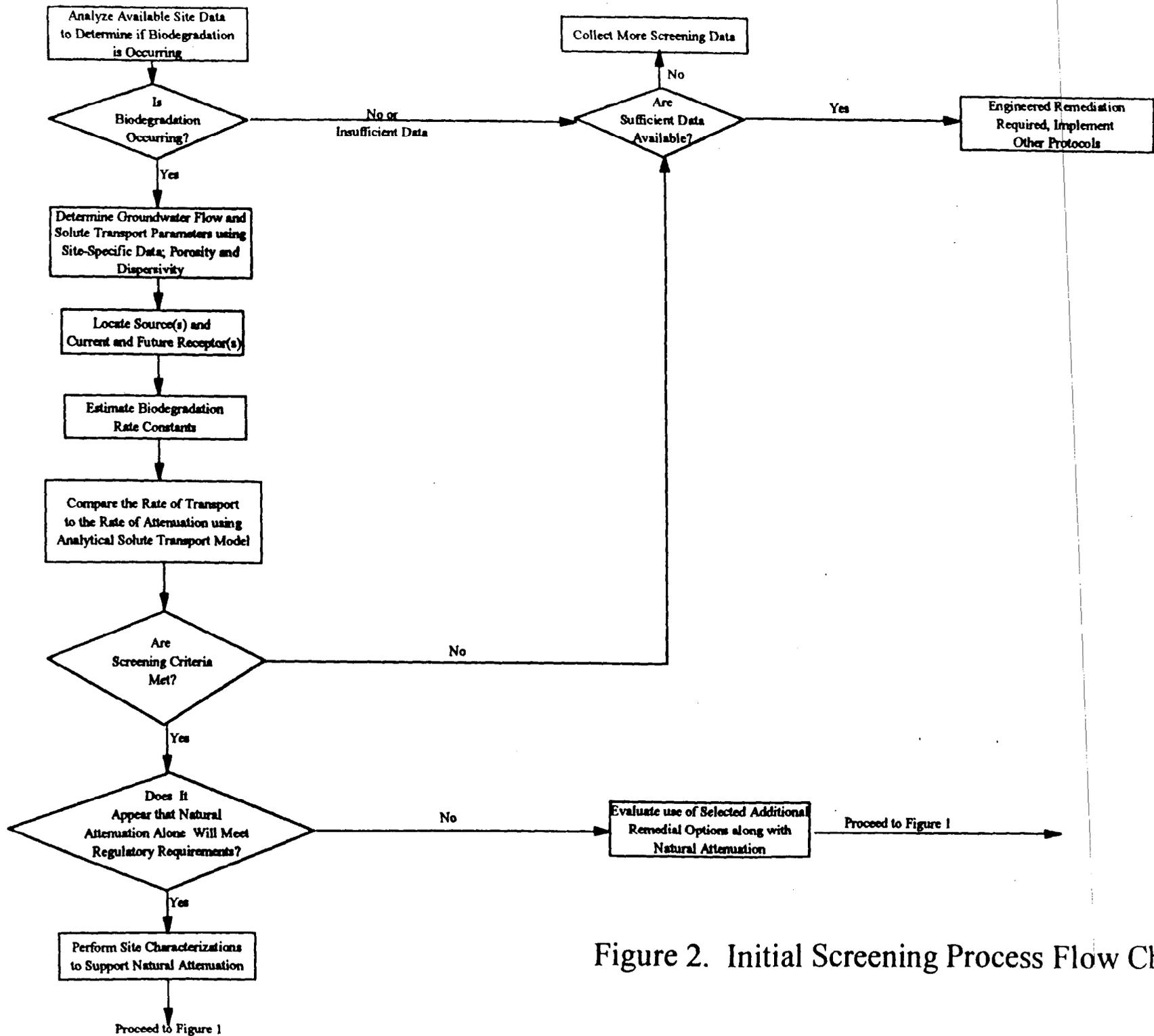


Figure 2. Initial Screening Process Flow Chart

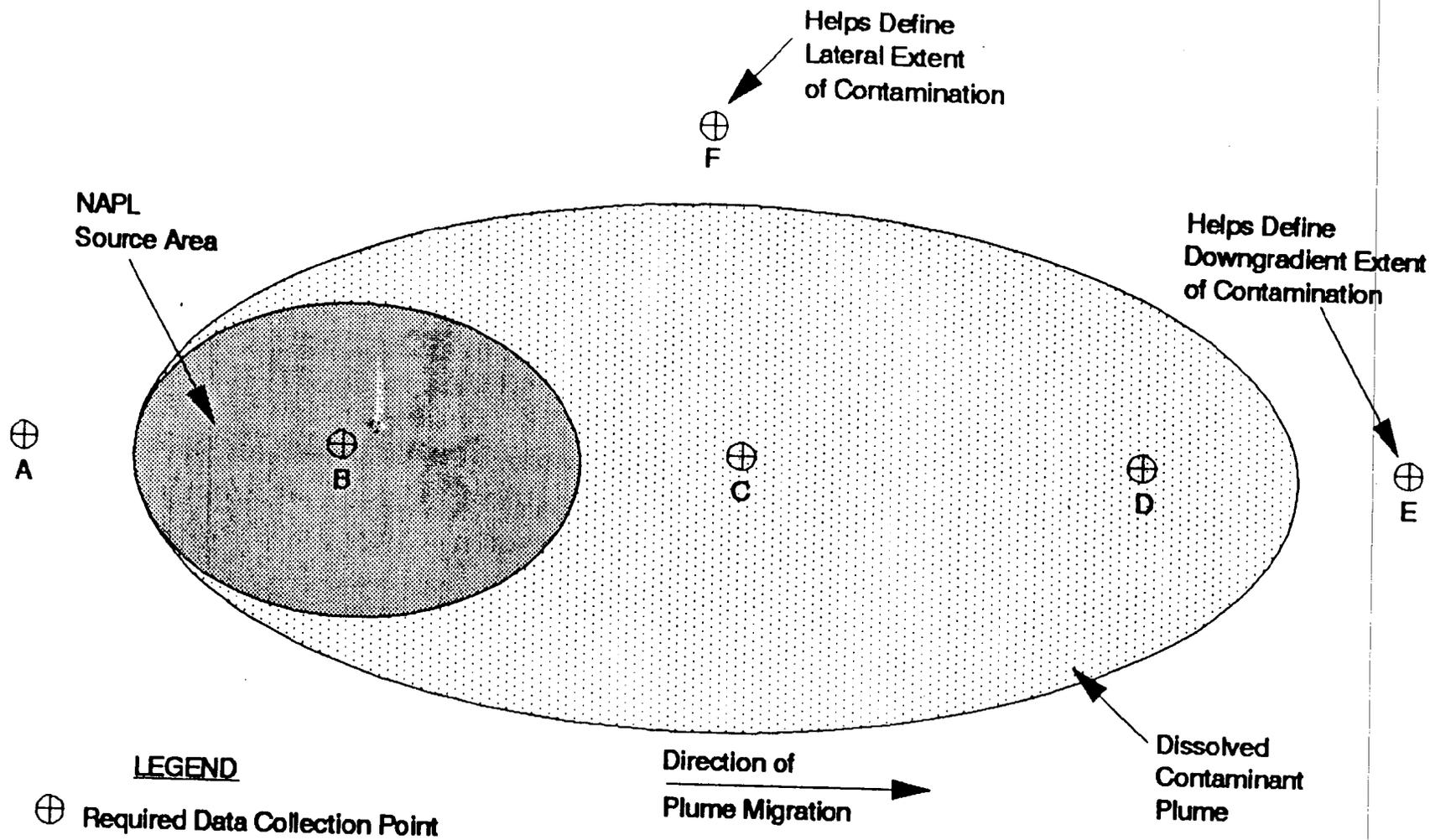


Figure 3. Data collection points required for screening.

1. Determine whether biodegradation is occurring using geochemical data. If biodegradation is occurring, proceed to Step 2. If it is not, assess the amount and types of data available. If data are insufficient to determine whether biodegradation is occurring, collect supplemental data.
2. Determine ground-water flow and solute transport parameters. Hydraulic conductivity and porosity may be estimated, but the ground-water gradient and flow direction may not. The investigator should use the highest hydraulic conductivity measured at the site during the preliminary screening because solute plumes tend to follow the path of least resistance (i.e., highest hydraulic conductivity). This will give the "worst case" estimate of solute migration over a given period.
3. Locate sources and current and future receptor exposure points.
4. Estimate the biodegradation rate constant. In ideal cases, biodegradation rate constants can be estimated using a conservative tracer found co-mingled with the contaminant plume, as described by Wiedemeier et al. (36). When dealing with a plume that contains only chlorinated solvents, this procedure will have to be modified to use chloride as a tracer. Rate constants derived from microcosm studies can also be used. If it is not possible to estimate the biodegradation rate using these procedures, then use a range of accepted literature values for biodegradation of the contaminants of concern.
5. Compare the rate of transport to the rate of attenuation, using analytical solutions or a screening model such as BIOSCREEN.
6. Determine whether the screening criteria are met.

Each step is described in detail below.

### **Step 1: Determine Whether Biodegradation Is Occurring**

The first step in the screening process is to sample a minimum of six wells that are representative of the contaminant flow system and to analyze the samples for the parameters listed in Table 2. Samples should be taken 1) from the most contaminated portion of the aquifer (within or as close to the source area as possible); 2) downgradient from the source area, in the dissolved contaminant plume (2 sample locations); 3) downgradient from the dissolved contaminant plume; and 4) from upgradient and lateral locations that are not affected by the plume.

Samples collected in the Source Area allow determination of the dominant terminal electron-accepting processes at the site. In conjunction with samples collected in the Source Area, samples collected in the Dissolved Contaminant Plume downgradient from the Source Area allow the investigator to determine whether the plume is degrading with distance along the flow path and what the distribution of electron acceptors and donors and metabolic byproducts might be along the flow path. The sample collected downgradient from the Dissolved Contaminant Plume aids in plume delineation and allows the investigator to determine whether metabolic byproducts are present in an area of ground water that has apparently been unaffected by the source. The upgradient and lateral samples allow delineation of the plume and indicate background concentrations of the electron acceptors and donors.

After these samples have been analyzed for the parameters listed in Table 2 (groundwater matrix parameters), the investigator should analyze the data to determine whether biodegradation is occurring. The reason for using the water (groundwater) matrix only in the analysis described in the previous sentence is because the scoring procedure is based on ground water concentrations and parameter data. The right-hand column of Table 2 contains scoring values that can be used for this task. For example, if the DO concentration in the area of the plume with the highest contaminant concentration is less than 0.5 milligrams per liter, this parameter is awarded 3 points. Table 3 summarizes the range of possible scores and gives an interpretation for each score. If the site scores a total of 15 or more points, biodegradation is probably occurring, and the investigator can proceed to Step 2. This method relies on the fact that biodegradation will cause predictable changes in ground-water chemistry.

Table 2. Analytical Parameters and Weighting for Preliminary Screening

Analyte	Concentration in Most Contaminated Zone	Interpretation	Points Awarded
Oxygen <sup>a</sup>	< 0.5 mg/L	Tolerated; suppresses reductive dechlorination at higher concentrations	3
Oxygen <sup>a</sup>	> 1 mg/L	Vinyl chloride may be oxidized aerobically, but reductive dechlorination will not occur	-3
Nitrate <sup>a</sup>	< 1 mg/L	May compete with reductive pathway at higher concentrations	2
Iron (II) <sup>a</sup>	> 1 mg/L	Reductive pathway possible	3
Sulfate <sup>a</sup>	< 20 mg/L	May compete with reductive pathway at higher concentrations	2
Sulfide <sup>a</sup>	> 1 mg/L	Reductive pathway possible	3
Methane <sup>a</sup>	> 0.1 mg/L	Ultimate reductive daughter product	2
	> 1	Vinyl chloride accumulates	3
	< 1	Vinyl chloride oxidizes	
Oxidation reduction potential <sup>a</sup>	< 50 mV against Ag/AgCl	Reductive pathway possible	< 50 mV = 1 < -100 mV = 2
pH <sup>a</sup>	5 < pH < 9	Tolerated range for reductive pathway	
DOC	> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2
Temperature <sup>a</sup>	> 20°C	At T > 20°C, biochemical process is accelerated	1
Carbon dioxide	> 2x background	Ultimate oxidative daughter product	1
Alkalinity	> 2x background	Results from interaction of carbon dioxide with aquifer minerals	1
Chloride <sup>a</sup>	> 2x background	Daughter product of organic chlorine; compare chloride in plume to background conditions	2
Hydrogen	> 1 nM	Reductive pathway possible; vinyl chloride may accumulate	3
Hydrogen	< 1 nM	Vinyl chloride oxidized	
Volatile fatty acids	> 0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	2
BTEX <sup>a</sup>	> 0.1 mg/L	Carbon and energy source; drives dechlorination	2
Perchloroethene <sup>a</sup>		Material released	
Trichloroethene <sup>a</sup>		Material released or daughter product of perchloroethene	2 <sup>b</sup>
Dichloroethene <sup>a</sup>		Material released or daughter product of trichloroethene; if amount of <i>cis</i> -1,2-dichloroethene is greater than 80% of total dichloroethene, it is likely a daughter product of trichloroethene	2 <sup>b</sup>
Vinyl chloride <sup>a</sup>		Material released or daughter product of dichloroethenes	2 <sup>b</sup>
Ethene/Ethane	< 0.1 mg/L	Daughter product of vinyl chloride/ethene	> 0.01 mg/L = 2 > 0.1 = 3
Chloroethane <sup>a</sup>		Daughter product of vinyl chloride under reducing conditions	2
1,1,1-Trichloroethane <sup>a</sup>		Material released	
1,1-dichloroethene <sup>a</sup>		Daughter product of trichloroethene or chemical reaction of 1,1,1-trichloroethane	

<sup>a</sup> Required analysis.

<sup>b</sup> Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

**Table 3. Interpretation of Points Awarded During Screening Step 1**

<u>Score</u>	<u>Interpretation</u>
0 to 5	Inadequate evidence for biodegradation of chlorinated organics
6 to 14	Limited evidence for biodegradation of chlorinated organics
15 to 20	Adequate evidence for biodegradation of chlorinated organics
> 20	Strong evidence for biodegradation of chlorinated organics

Consider the following two examples. Example 1 contains data for a site with strong evidence that reductive dechlorination is occurring. Example 2 contains data for a site with strong evidence that reductive dechlorination is not occurring.

**Example 1. Strong Evidence for Biodegradation of Chlorinated Organics**

<u>Analyte</u>	<u>Concentration in Contaminated Zone</u>	<u>Most points Awarded</u>
DO	0.1 mg/L	3
Nitrate	0.3 mg/L	2
Iron(II)	10 mg/L	3
Sulfate	2 mg/L	2
Methane	5 mg/L	3
Oxidation/ reduction potential	-190 mv	2
Chloride	3x background	2
Perchloroethene (released)	1,000 pg/L	0
Trichloroethene (none released)	1,200 ug/L	2
cis-1,2-DCE (none released)	500 ug/L	2
Vinyl chloride (none released)	50 ug/L	2
Total points awarded	23	

In this example, the investigator can infer that biodegradation is occurring and may proceed to Step 2.

**Example 2. Biodegradation of Chlorinated organics Unlikely**

<u>Analyte</u>	<u>Concentration in Most Contaminated Zone</u>	<u>Points Awarded</u>
DO	3 mg/l	-3
Nitrate	0.3 mg/L	2
Iron(II)	Not detected	0
Sulfate	10 mg/L	2
Methane	ND	0
Oxidation-reduction potential	100 mv	0
Chloride	Background	0
Trichloroethene (released)	1,200 ug/L	0
cis-1,2-Dichloroethene	Not detected	0
Vinyl chloride	ND	0
Total points awarded		1

In this example, the investigator can infer that biodegradation is probably not occurring or is occurring too slowly to be a viable remedial option. In this case, the investigator cannot proceed to Step 2 and will likely have to implement an engineered remediation system.

**Step 2: Determine Groundwater Flow and Solute Transport Parameters**

If the interpretation of the score indicates biodegradation is occurring, it is important to quantify groundwater flow and solute transport parameters. Parameter Quantification will make it possible to use a solute transport model to quantitatively estimate the concentration of the plume and its direction and rate of travel. To use an analytical model, it is necessary to know the hydraulic gradient and hydraulic conductivity for the site and to have estimates of the porosity and dispersivity. The coefficient of retardation also is helpful to know. Quantification of these parameters is discussed by Wiedemeier et al. (1); the textbook Contaminant Hydrogeology (Fetter, 1992) also contains information on these variables.

To make modeling as accurate as possible, the investigator must have site-specific hydraulic gradient and hydraulic conductivity data. To determine the ground-water flow and solute transport direction, the site must have at least three accurately surveyed wells, for the most simplistic site hydrogeologic conditions. The porosity and dispersivity are generally estimated using accepted literature values for the types of sediments found at the site. If the investigator does not have total organic carbon data for soil, the coefficient of retardation can still be estimated using default literature values for total organic carbon, soil bulk density, and the aquifer porosity; however, assuming that the solute transport and ground-water velocities are the same is usually conservative.

### **Step 3: Locate Sources and Receptor Exposure Points**

To determine the length of flow for the predictive modeling conducted in Step 5, it is important to know the distance between the source of contamination, the downgradient end of the dissolved plume, and any potential downgradient or cross-gradient receptors.

### **Step 4: Estimate the Biodegradation Rate Constant**

Estimated biodegradation rates can be used only after biodegradation has been shown to be occurring (see Step 1). The biodegradation rate is one of the most important model input parameters. Biodegradation of chlorinated aliphatic hydrocarbons can commonly be represented as a first-order rate constant. Site-specific biodegradation rates generally are best to use. Calculation of site-specific biodegradation rates is discussed by Wiedemeier et al. (1, 36, 37). If determining site-specific biodegradation rates is impossible, then literature values for the biodegradation rate of the contaminant of interest must be used. It is generally best to start with the average value and then to vary the model input to predict "best case" and "worst case" scenarios. A "reality check" on a literature biodegradation rate constant may be useful, for determining the appropriate value to use.

### **Step 5: Compare the Rate of Transport to the Rate of Attenuation**

At this early stage in the natural attenuation demonstration, comparison of the rate of solute transport to the rate of attenuation is best accomplished using an analytical model. Several analytical models are available, but the BIOSCREEN model is probably the simplest currently available model to use. The model is nonproprietary and is available from the Robert S. Kerr Laboratory's home page on the Internet ([www.epa.gov/ada/kerriab.html](http://www.epa.gov/ada/kerriab.html)). The BIOSCREEN model is based on Domenico's solution to the advection dispersion equation (38), and allows use of either a first-order biodegradation rate or an instantaneous reaction between contaminants and electron acceptors to simulate the effects of biodegradation. To model transport of chlorinated aliphatic hydrocarbons using BIOSCREEN, only the first-order decay rate option should be used. The model BIOCHLOR is under development by the Technology Transfer Division of Air Force Center for Environmental Excellence (AFCEE). The BIOCHLOR model will be geared towards evaluating transport of chlorinated compounds under the influence of biodegradation.

The primary purpose of comparing the rate of transport with the rate of attenuation is to determine whether the residence time along the flow path is adequate to be protective of human health and the environment (i.e., to qualitatively estimate whether the contaminant is attenuating at a rate fast enough to allow degradation of the contaminant to acceptable concentrations before receptors, or potential receptors, are reached). It is important to perform a sensitivity analysis to help evaluate the confidence in the preliminary screening modeling effort. If modeling indicates that natural attenuation may attain remedial action objectives, then the screening criteria are met, and the investigator can proceed with the natural attenuation feasibility study.

### **Step 6: Determine Whether the Screening Criteria Are Met**

Before proceeding with the full-scale natural attenuation feasibility study, the investigator should ensure that the answers to all of the following criteria are "yes":

- Has the plume moved a distance less than expected, based on the known (or estimated) time since the contaminant release and the contaminant velocity, as calculated from site-specific measurements of hydraulic conductivity and hydraulic gradient, as well as estimates of effective porosity and contaminant retardation?
- Is it likely that the contaminant mass is attenuating at rates sufficient to be protective of human health and the environment at a compliance point, or point of discharge to a sensitive environmental receptor?
- Is the plume going to attenuate to concentrations less than risk-based corrective action guidelines or regulatory criteria before reaching potential receptors, or a compliance point?

## Collect Additional Site Characterization Data To Support Natural Attenuation, As Required

Detailed site characterization is necessary to document the potential for natural attenuation. Review of existing site characterization data is particularly useful before initiating site characterization activities. Such review should allow identification of data gaps and guide the most effective placement of additional data collection points. There are two goals during the site characterization phase of a natural attenuation investigation. The first is to collect the data needed to determine whether natural mechanisms of contaminant attenuation are occurring at rates sufficient to protect human health and the environment. The second is to provide sufficient site-specific data to allow prediction of the future extent and concentration of a contaminant plume through solute fate and transport modeling. Because the burden of proof for natural attenuation is on the proponent, detailed site characterization is required to achieve these goals and to support this remedial option. Adequate site characterization in support of natural attenuation requires that the following site-specific parameters be determined:

- The extent and type of soil and ground-water contamination.
- The location and extent of contaminant source area(s) (i.e., areas containing mobile or residual NAPL).
- The potential for a continuing source due to leaking tanks or pipelines.
- Aquifer geochemical parameters.
- Regional hydrogeology, including ground water that is a current or potential source of drinking water or discharges into an ecologically sensitive area and regional confining units.
- Local and site-specific hydrogeology, including local drinking water supplies; location of industrial, agricultural, and domestic water wells; patterns of ground water use (current and future); lithology; site stratigraphy; including identification of transmissive and nontransmissive units; grain-size distribution (sand versus silt versus clay); aquifer hydraulic conductivity; groundwater hydraulic information; preferential flow paths; locations and types of surface water bodies; and areas of local ground-water recharge and discharge.
- Identification of potential exposure pathways and receptors.

The following sections describe the methodologies that should be implemented to allow successful site characterization in support of natural attenuation. Additional information can be obtained from Wiedemeier et al. (1, 37).

### Soil Characterization

To adequately define the subsurface hydrogeologic system and to determine the amount and three-dimensional distribution of contaminant mass that can act as a continuing source of ground-water contamination, extensive soil characterization must be completed. Soil characterization may have been completed during previous remedial investigation activities. The results of soils characterization will be used as input into a solute fate-and-transport model to help define a contaminant source term and to support the natural attenuation investigation.

The analytical protocol to be used for soil sample analysis is presented in Table 1A. and 1B. The analytical protocol includes all of the parameters necessary to document natural attenuation, including the effects of sorption and biodegradation. Knowledge of the location, distribution, concentration, and total mass of contaminants of regulatory concern in soils or present as residual and/or mobile NAPL is required to calculate the mass transfer rate from the contaminant source to the ground water. Knowledge of the TOC content of the aquifer matrix is important for sorption and solute-retardation calculations. TOC samples should be collected from a background location in the stratigraphic horizon(s) where most contaminant transport is expected to occur. Oxygen and carbon dioxide measurements of soil gas can be used to find areas in the unsaturated zone where biodegradation is occurring. Knowledge of the distribution of contaminants in soil gas can be used as a cost-effective way to estimate the extent of soil volatile organic compound

contamination.

### Groundwater Characterization

To adequately determine the amount and three-dimensional distribution of dissolved contamination and to document the occurrence of natural attenuation, ground-water samples must be collected and analyzed. Biodegradation of organic compounds, whether natural or anthropogenic, brings about measurable changes in the chemistry of ground water in the affected area. By measuring these changes, documentation and quantitative evaluation of natural attenuation's importance at a site are possible.

Groundwater sampling is conducted to determine the concentrations and distribution of contaminants, daughter products, and ground-water geochemical parameters. The analytical protocol for ground-water sample analysis is presented in Table 1A. and 1B. The analytical protocol includes all of the parameters necessary to document natural attenuation, including the effects of sorption and biodegradation. Data obtained from the analysis of ground water for these analytes is used to scientifically document natural attenuation and can be used as input into a solute fate-and-transport model. The following paragraphs describe each ground-water analytical parameter and the use of each analyte in the natural attenuation demonstration.

Volatile organic compound analysis (by Method SW8260a) is used to determine the types, concentrations, and distributions of contaminants and daughter products in the aquifer. DO is the electron acceptor most thermodynamically favored by microbes for the biodegradation of organic carbon, whether natural or anthropogenic. Reductive dechlorination will not occur, however, if DO concentrations are above approximately 0.5 milligrams per liter. During aerobic biodegradation of a substrate, DO concentrations decrease because of the microbial oxygen demand. After DO depletion, anaerobic microbes will use nitrate containing compounds as an electron acceptor, followed by iron(III) containing compounds, then sulfate containing compounds, and finally carbon dioxide (methanogenesis). Each sequential reaction drives the oxidation-reduction potential of the ground water further toward conditions that favor reductive dechlorination. The oxidation-reduction potential range of sulfate reduction and methanogenesis is optimal, but reductive dechlorination may occur under nitrate- and iron(III)-reducing conditions as well. Because reductive dechlorination works best in the sulfate reduction and methanogenesis oxidation-reduction potential range, competitive exclusion between microbial sulfate reducers, methanogens, and reductive dechlorinators can occur.

After DO has been depleted in the area of the plume where chlorinated aliphatic compounds are being anaerobically remediated (treatment zone), nitrate-containing compounds may be used as an electron acceptor for anaerobic biodegradation via denitrification. In some cases iron(III)-containing compounds are used as an electron acceptors during anaerobic biodegradation of electron donors. During this process, iron(III) is reduced to the more soluble iron(II). Iron(II) concentrations can thus be used as an indicator of anaerobic degradation of fuel compounds. After DO, nitrate, and bioavailable iron(III) have been depleted in the area of the plume where chlorinated aliphatic compounds are being anaerobically remediated, sulfate-containing compounds may be used as an electron acceptor for anaerobic biodegradation. This process is termed sulfate reduction and results in the production of sulfide-containing compounds. During methanogenesis (an anaerobic biodegradation process), carbon dioxide (or acetate)-containing compounds are used as an electron acceptors, and methane is produced. Methanogenesis generally occurs after oxygen, nitrates, bioavailable iron(III)s, and sulfates have been depleted in the treatment zone. The presence of methane in ground water is indicative of strongly reducing conditions. Because methane is not present in fuel, the presence of methane in ground water above background concentrations in contact with fuels is indicative of microbial degradation of fuel hydrocarbons.

The total alkalinity of a ground-water system is indicative of a water's capacity to neutralize acid. Alkalinity results from the presence of hydroxides, carbonates, and bicarbonates of elements such as calcium, magnesium, sodium, potassium, or ammonia. Alkalinity is important in the maintenance of ground-water pH because it buffers the ground-water system against acids generated during both aerobic and anaerobic biodegradation.

In general, areas contaminated by fuel hydrocarbons exhibit a total alkalinity that is higher than that seen in background areas. This is expected because the microbially mediated reactions causing biodegradation of fuel hydrocarbons cause

an increase in the total alkalinity in the system. Changes in alkalinity are most pronounced during aerobic respiration, denitrification, iron reduction, and sulfate reduction, and are less pronounced during methanogenesis (40). In addition, Willey et al. (41) show that short-chain aliphatic acid ions produced during biodegradation of fuel hydrocarbons can contribute to alkalinity in ground water.

The oxidation-reduction potential of ground water is a measure of electron activity and an indicator of the relative tendency of a solution to accept or transfer electrons. Redox reactions in ground water containing organic compounds (natural or anthropogenic) are usually biologically mediated; therefore, the oxidation-reduction potential of a ground-water system depends on and influences rates of biodegradation. Knowledge of the oxidation-reduction potential of ground water also is important because some biological processes operate only within a prescribed range of redox conditions. The oxidation-reduction potential of ground water generally ranges from -400 to 800 millivolts (mV). Figure 4 shows the typical redox conditions for ground water when different electron acceptors are used.

Oxidation-reduction potential can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. Mapping the oxidation-reduction potential of the ground water while in the field helps the field scientist to determine the approximate location of the contaminant plume. To perform this task, it is important to have at least one redox measurement (preferably more) from a well located upgradient from the plume. Oxidation-reduction potential measurements should be taken during well purging and immediately before and after sample acquisition using a direct-reading meter. Because most well purging techniques can allow aeration of collected ground-water samples (which can affect oxidation-reduction potential measurements), it is important to minimize potential aeration.

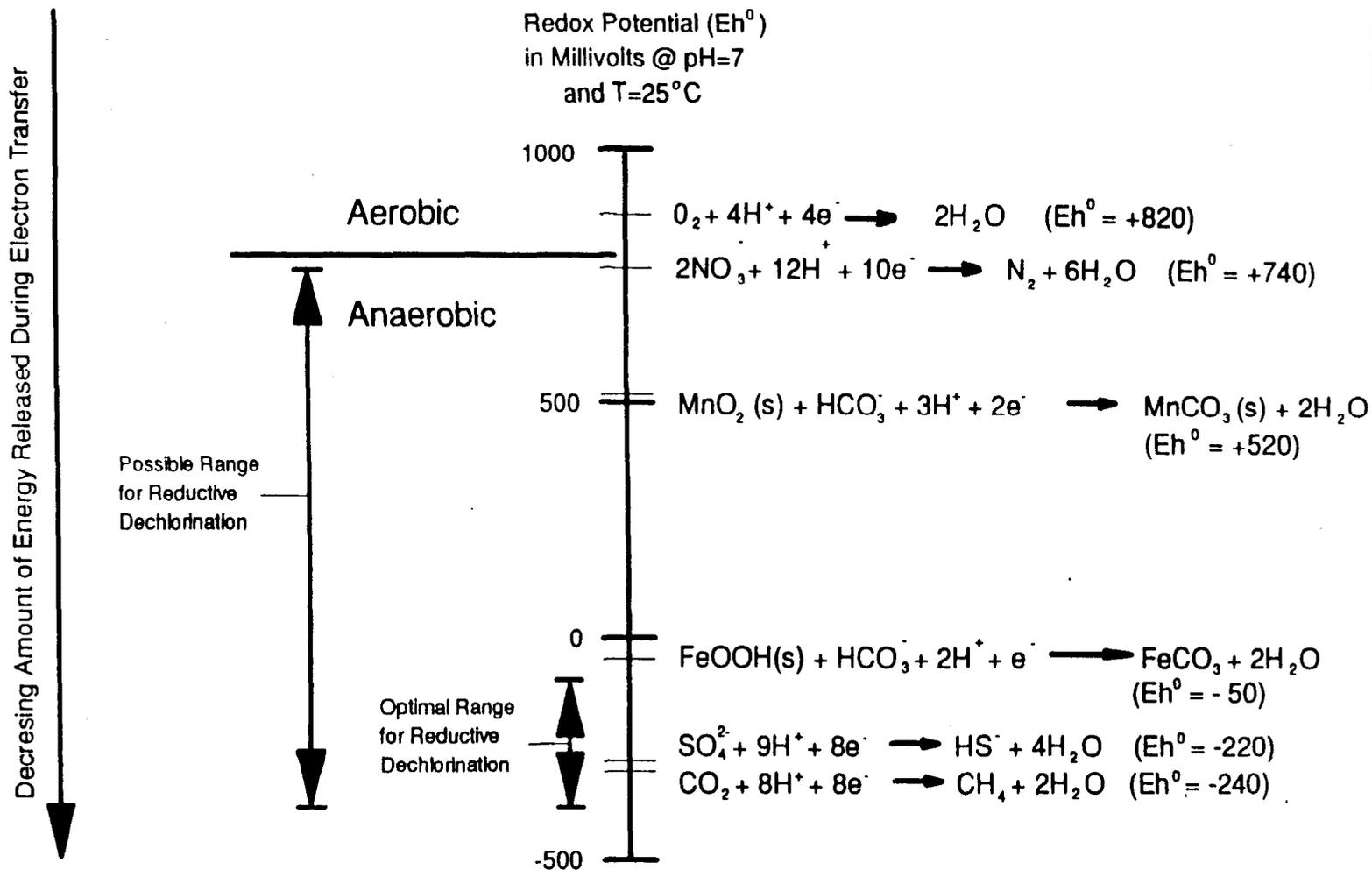
Dissolved hydrogen (gas) concentrations can be used to determine the dominant terminal electron-accepting process in an aquifer. Table 4 presents the range of hydrogen concentrations for a given terminal electron-accepting process. Much research has been done on the topic of using hydrogen measurements to delineate terminal electron-accepting processes (42,44). Because the efficiency of reductive dechlorination differs for methanogenic, sulfate-reducing, iron(III)-reducing, or denitrifying conditions, it is helpful to have hydrogen concentrations to help delineate redox conditions when evaluating the potential for natural attenuation of chlorinated ethenes in ground-water systems. Collection and analysis of ground-water samples for dissolved hydrogen content is not yet commonplace or standardized.

**Table 4. Range of Hydrogen Concentrations for a Given Terminal Electron-Accepting Process**

<b>Terminal Electron-Accepting Process</b>	<b>Hydrogen Concentration (nanomoles per liter)</b>
Denitrification	< 0.1
Iron(III) reduction	0.2 to 0.8
Sulfate reduction	1 to 4
Methanogenesis	> 5

Because the pH, temperature, and conductivity of a ground-water sample can change significantly shortly following sample acquisition, these parameters must be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for DO and redox analyses. The measurements should be made in a clean glass container separate from those intended for laboratory analysis, and the measured values should be recorded in the ground-water sampling record.

The pH of ground water has an effect on the presence and activity of microbial populations in the ground water. This is especially true for methanogens. Microbes capable of degrading chlorinated aliphatic hydrocarbons and petroleum hydrocarbon compounds generally prefer pH values varying from 6 to 8 standard units. Ground-water temperature directly affects the solubility of oxygen and other geochemical species. The solubility of DO is temperature dependent,



Modified From Bouwer (1994)

Figure 4. Redox potential for various electron acceptors.

being more soluble in cold water than in warm water. Ground-water temperature also affects the metabolic activity of bacteria. Rates of hydrocarbon biodegradation roughly double for every 10°C increase in temperature ( $^{\circ}Q_{10}$  rule) over the temperature range between 5°C and 25°C. Ground-water temperatures less than about 5°C tend to inhibit biodegradation, and slow rates of biodegradation are generally observed in such waters.

Conductivity is a measure of the ability of a solution to conduct electricity. The conductivity of ground water is directly related to the concentration of ions in solution; conductivity increases as ion concentration increases. Conductivity measurements are used to ensure that ground water samples collected at a site are representative of the water in the saturated zone containing the dissolved contamination. If the conductivities of samples taken from different sampling points are radically different, the waters may be from different hydrogeologic zones.

Elemental chlorine is the most abundant of the halogens. Although chlorine can occur in oxidation states ranging from  $Cl^{-}$  to  $Cl^{+7}$ , the chloride form ( $Cl^{-}$ ) is the only form of major significance in natural waters (45). Chloride forms ion pairs or complex ions with some of the cations present in natural waters, but these complexes are not strong enough to be of significance in the chemistry of fresh water (45). Chloride ions generally do not enter into oxidation-reduction reactions, form no important solute complexes with other ions unless the chloride concentration is extremely high, do not form salts of low solubility, are not significantly adsorbed on mineral surfaces, and play few vital biochemical roles (45). Thus, physical processes control the migration of chloride ions in the subsurface, and chloride is an effective conservative tracer of ground-water contaminant plume migration.

During biodegradation of chlorinated hydrocarbons dissolved in ground water, chloride is released into the ground water. This process results in chloride concentrations in the ground water of the contaminant plume that are elevated relative to background concentrations. Because of the nonreactive behavior of chloride, it can be used as a conservative tracer to estimate biodegradation rates using methods similar to those discussed by Wiedemeier et al. (36).

#### **Field Measurement of Aquifer Hydraulic Parameters**

The properties of an aquifer that have the greatest impact on contaminant fate and transport include hydraulic conductivity, hydraulic gradient, porosity, and dispersivity. Estimating hydraulic conductivity and gradient in the field is fairly straightforward, but obtaining field-scale information on porosity and dispersivity can be difficult.

Therefore, most investigators rely on field data for hydraulic conductivity and hydraulic gradient and on literature values for porosity and dispersivity for the types of sediments present at the site. Methods for field measurement of aquifer hydraulic parameters are described by Wiedemeier et al. (1, 37).

#### **Microbiological Laboratory Data**

Microcosm studies are used to show that the microorganisms necessary for biodegradation are present and to help quantify rates of biodegradation. If properly designed, implemented, and interpreted, microcosm studies can provide very convincing documentation of the occurrence of biodegradation. Such studies are the only "line of evidence" that allows an unequivocal mass balance determination based on the biodegradation of environmental contaminants. The results of a well-designed microcosm study will be easy for decision-makers with nontechnical backgrounds to interpret. Results of such studies are strongly influenced by the nature of the geological material submitted for study, the physical properties of the microcosm, the sampling strategy, and the duration of the study. Because microcosm studies are time-consuming and expensive, they should be undertaken only at sites where there is considerable skepticism concerning the biodegradation of contaminants.

Biodegradation rate constants determined by microcosm studies often are much greater than rates achieved in the field. Microcosms are most appropriate as indicators of the potential for natural bioremediation and to prove that losses are biological, but it may be inappropriate to use them to generate rate constants. The preferable method of contaminant biodegradation rate-constant determination is in situ field measurement. The collection of material for the microcosm study, the procedures used to set up and analyze the microcosm, and the interpretation of the results of the microcosm

study are presented by Wiedemeier et al. (1).

## **Refine the Conceptual Model, Complete Premodeling Calculations, and Document Indicators of Natural Attenuation**

Site investigation data should first be used to refine the conceptual model and quantify ground-water flow, sorption, dilution, and biodegradation. The results of these calculations are used to scientifically document the occurrence and rates of natural attenuation and to help simulate natural attenuation over time. Because the burden of proof is on the proponent, all available data must be integrated in such a way that the evidence is sufficient to support the conclusion that natural attenuation is occurring.

### **Conceptual Model Refinement**

Conceptual model refinement involves integrating newly gathered site characterization data to refine the preliminary conceptual model that was developed based on previously existing site-specific data. During conceptual model refinement, all available site-specific data should be integrated to develop an accurate three-dimensional representation of the hydrogeologic and contaminant transport system. This conceptual model can then be used for contaminant fate-and-transport modeling. Conceptual model refinement consists of several steps, including preparation of geologic logs, hydrogeologic sections, potentiometric surface/water table maps, contaminant contour (isopleth) maps, and electron acceptor and metabolic byproduct contour (isopleth) maps. Refinement of the conceptual model is described by Wiedemeier et al. (1).

### **Premodeling Calculations**

Several calculations must be made prior to implementation of the solute fate-and-transport model. These calculations include sorption and retardation calculations, NAPL water-partitioning calculations, ground-water flow velocity calculations, and biodegradation rate-constant calculations. Each of these calculations is discussed in the following sections. Most of the specifics of each calculation are presented in the fuel hydrocarbon natural attenuation technical protocol by Wiedemeier et al. (1), and all will be presented in the protocol incorporating chlorinated aliphatic hydrocarbon attenuation (37).

### **Biodegradation Rate Constant Calculations**

Biodegradation rate constants are necessary to simulate accurately the fate and transport of contaminants dissolved in ground water. In many cases, biodegradation of contaminants can be approximated using first-order kinetics. To calculate first-order biodegradation rate constants, the apparent degradation rate must be normalized for the effects of dilution and volatilization. Two methods for determining first-order rate constants are described by Wiedemeier et al. (36). One method involves the use of a biologically recalcitrant compound found in the dissolved contaminant plume that can be used as a conservative tracer. The other method, proposed by Buscheck and Alcantar (47) involves interpretation of a steady-state contaminant plume and is based on the one-dimensional steady-state analytical solution to the advection-dispersion equation presented by Bear (48). The first-order biodegradation rate constants for chlorinated aliphatic hydrocarbons are also presented (J. Wilson et al., Dallas Symposium Notes).

### **Simulate Natural Attenuation Using Solute Fate-and-Transport Models**

Simulating natural attenuation using a solute fate and transport model allows prediction of the migration and attenuation of the contaminant plume through time. Natural attenuation modeling is a tool that allows site-specific data to be used to predict the fate and transport of solutes under governing physical, chemical, and biological processes. Hence, the results of the modeling effort are not in themselves sufficient proof that natural attenuation is occurring at a given site. The results of the modeling effort are only as good as the original data input into the model; therefore, an investment in thorough site characterization will improve the validity of the modeling results. In some cases, straightforward analytical models of contaminant attenuation are adequate to simulate natural attenuation.

Several well-documented and widely accepted solute fate-and-transport models are available for simulating the fate-and-transport of contaminants under the influence of advection, dispersion, sorption, and biodegradation. The use of solute fate-and-transport modeling in the natural attenuation investigation is described by Wiedemeier et al. (1).

### **Identify Potential Receptors, and Conduct an Exposure-Pathway Analysis**

After the rates of natural attenuation have been documented and predictions of the future extent and concentrations of the contaminant plume have been made using the appropriate solute fate-and-transport model, the case for natural attenuation should combine all available data and information to present the basis for using this as a remedial option. Supporting the natural attenuation option generally will involve performing a receptor exposure-pathway analysis. This analysis includes identifying potential human and ecological receptors and points of exposure under current and future land and ground-water use scenarios and the 9 criteria in the Feasibility Study. The results of solute fate-and-transport modeling are central to the exposure pathways analysis. If conservative model input parameters are used, the solute fate-and-transport model should give conservative estimates of contaminant plume migration. From this information, the potential for impacts on human health and the environment from contamination present at the site can be estimated.

### **Evaluate Source Control**

Source removal, treatment or containment will be necessary to reduce plume expansion. Several technologies suitable for source reduction or removal are listed in Figure 1. Other technologies may also be used as dictated by site conditions and local regulatory requirements. Source removal can be very effective at limiting plume migration and decreasing the remediation time frame, especially at sites where biodegradation is contributing to natural attenuation of a dissolved contaminant plume.

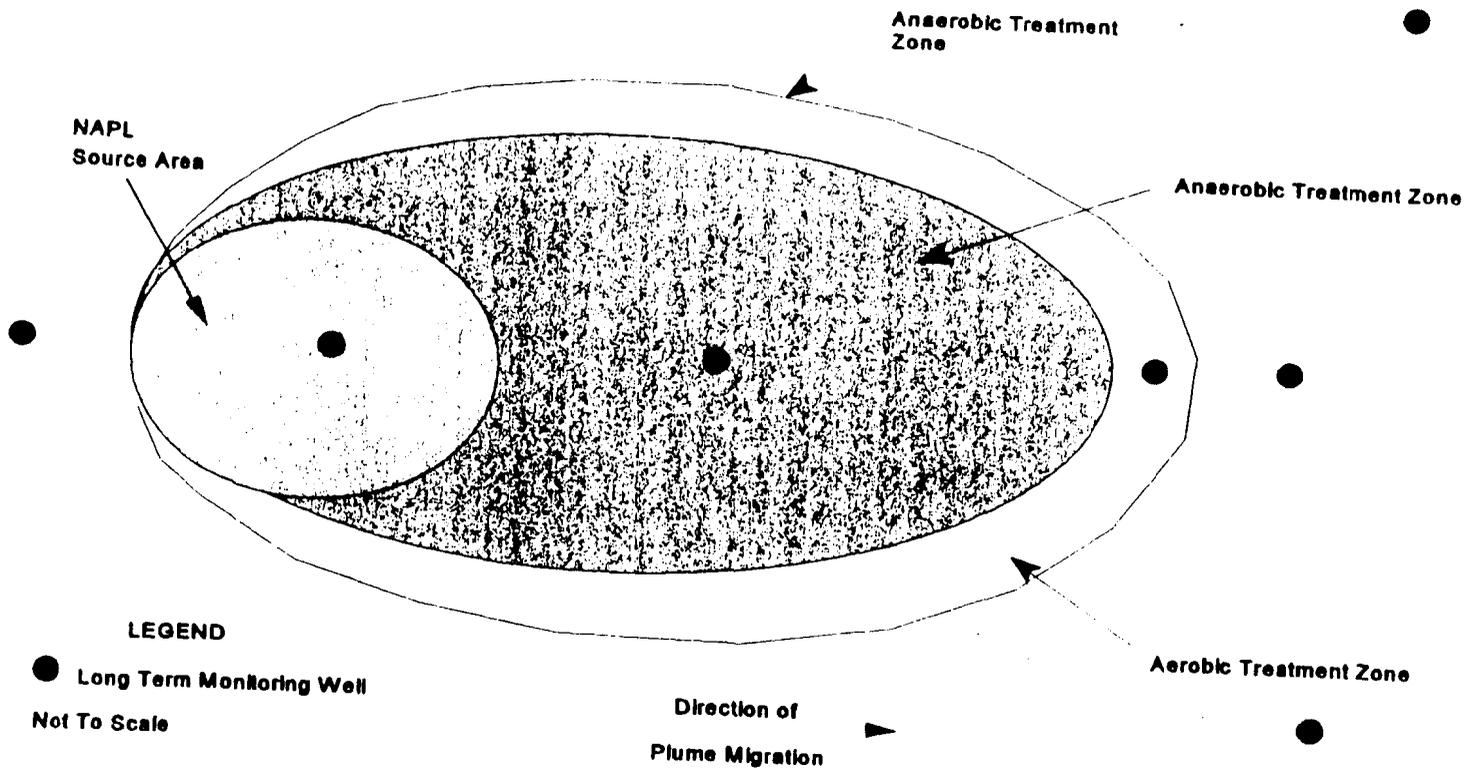
### **Prepare a Long-Term Monitoring Plan**

Experience at 40 Air Force sites contaminated with fuel hydrocarbons using the protocol presented by Wiedemeier et al. (1) suggests that many fuel hydrocarbon plumes are relatively stable or are moving very slowly with respect to ground-water flow. These examples demonstrate the efficacy of long-term monitoring to track plume migration and to validate or refine modeling results. There is not a large enough database available at this time to assess the stability of chlorinated solvent plumes, but in the authors' experience chlorinated solvent plumes are likely to migrate further downgradient than fuel hydrocarbon plumes before reaching steady-state equilibrium or before receding.

The long-term monitoring plan consists of locating ground-water monitoring wells and developing a ground-water sampling and analysis strategy. This plan is used to monitor plume migration over time and to verify that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors. The long-term monitoring plan should be developed based on site characterization data, the results of solute fate and transport modeling, and the results of the exposure pathway analysis.

The long-term monitoring plan includes monitoring wells for long-term monitoring that are intended to determine whether the behavior of the plume is changing; for monitoring additional plume growth and contaminant distribution, and to trigger an action to manage the risk associated with such expansion. Figure 5 depicts 1) an upgradient well in unaffected ground water, 2) a well in a NAPL source area, 3) a well downgradient of the NAPL source area in a zone of anaerobic treatment, 4) a well in the zone of aerobic treatment, along the periphery of the plume, and 5) wells located downgradient from the plume where contaminant concentrations are below regulatory acceptance levels and soluble electron acceptors are depleted with respect to unaffected ground water. The final number and placement of long-term monitoring and point-of-compliance wells is determined through regulatory requirements and may change as conditions at the site change. Locations of long-term monitoring wells are based on the behavior of the plume as revealed during the initial site characterization and on regulatory considerations.

The results of a solute fate-and-transport model can be used to help locate the long-term monitoring wells. To provide a valid monitoring system, all monitoring wells must be screened in the same hydrogeologic unit as the contaminant



**Figure 5. Hypothetical Long Term Monitoring Strategy**

Note: Complex sites may require more wells. The final number and placement should be determined in conjunction with the appropriate regulatory requirements

plume. This generally requires detailed stratigraphic correlation. To facilitate accurate stratigraphic correlation, detailed visual descriptions of all subsurface materials encountered during borehole drilling should be prepared prior to monitoring-well installation.

A ground-water sampling and analysis plan is required in conjunction with long-term monitoring well placement. For long-term monitoring, groundwater analyses should include volatile organic compounds, DO, nitrates, iron(II)s, sulfates, metals and methane. For wells known to be considerably downgradient, groundwater analyses should be limited to determining volatile organic compounds, metals, and DO concentrations. Any site-specific analytical requirements also should be addressed in the sampling and analysis plan to ensure that all data required for regulatory decision-making are collected. Water level and any NAPL thickness measurements must be made during each sampling event. Except at sites with very low hydraulic conductivity and gradients, bi-monthly sampling of long-term monitoring wells is recommended during the first year to help determine the direction of plume migration and to determine baseline data. Monthly precipitation data should also be collected from the nearest Weather Service Center. Based on the results of the first year's sampling, the sampling frequency may be reduced to annual sampling in the quarter showing the greatest extent of the plume. Long-term sampling frequency depends on the final placement of the point-of-compliance monitoring wells and ground-water flow velocity and other regulatory considerations made during risk management decision making.

### **Present Findings and Obtain Consensus for Remediation by Natural Attenuation**

A natural attenuation remedial alternative will be evaluated using the nine criteria used to evaluate other remedial alternatives. All available site-specific data and information developed during the site characterization, conceptual model development, premodeling calculations, biodegradation rate calculation, ground-water modeling, model documentation, and long-term monitoring plan preparation phases of the natural attenuation investigation should be presented in a consistent and complementary manner during the Feasibility Study (FS)/ Corrective Measures Study (CMS) process. Evidence that natural attenuation is occurring at rates sufficient to meet regulatory requirements, and to protect human health and the environment will be presented during the FS/CMS or Remedial Design/Remedial Action (RD/RA) or Corrective Remedial Action (CRA) stage of site work. A "weight-of-evidence" argument is necessary to support this remedial option. For this reason, all model assumptions should be conservative, and all available evidence in support of natural attenuation must be presented with regulatory requirements in mind.

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# SITE Technology Capsule

## Unterdruck-Verdampfer- Brunnen Technology (UVB)

### Vacuum Vaporizing Well

### Introduction

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, committed to protecting human health and the environment from uncontrolled hazardous wastes sites. CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA) in 1986 -- amendments that emphasize the achievement of long-term effectiveness and permanence of remedies at Superfund sites. SARA mandates implementing permanent solutions and using alternative treatment technologies or resource recovery technologies, to the maximum extent possible, to clean up hazardous waste sites.

State and federal agencies, as well as private parties, are now exploring a growing number of innovative technologies for treating hazardous wastes. The sites on the National Priorities List total more than 1,200 and comprise a broad spectrum of physical, chemical, and environmental conditions requiring varying types of remediation. The U.S. Environmental Protection Agency (EPA) has focused on policy, technical, and informational issues related to exploring and applying new remediation technologies applicable to Superfund sites. One such initiative is EPA's Superfund Innovative Technology Evaluation (SITE) program, which was established to accelerate development, demonstration, and use of innovative technologies for site cleanups. EPA SITE Technology Capsules summarize the latest information

available on selected innovative treatment and site remediation technologies and related issues. These capsules are designed to help EPA remedial project managers, EPA on-scene coordinators, contractors, and other site cleanup managers understand the types of data needed to effectively evaluate a technology's applicability for cleaning up Superfund sites.

This capsule provides information on the Unterdruck-Verdampfer-Brunnen (UVB) in situ groundwater remediation technology, a technology developed to remove volatile organic compounds (VOCs) from groundwater. The UVB system is a patented technology. The developer and patent holder is IEG mbH of Germany, and the United States license holder is IEG™ Technologies Corporation (IEG). The UVB process was evaluated under EPA's SITE program between April 1993 and May 1994 at Site 31, March Air Force Base (AFB) California, where groundwater was contaminated with solvents, including trichloroethylene (TCE). Information in this capsule emphasizes specific site characteristics and results of the SITE field demonstration at March AFB. Results obtained independently by the developer at other sites in the United States and Germany are summarized in the Technology Status section. This capsule presents the following information:

- Abstract
- Technology description
- Technology applicability



- Technology limitations
- Process residuals
- Site requirements
- Performance data
- Technology status
- Sources of further information

## Abstract

The UVB technology is an in situ groundwater remediation technology for aquifers contaminated with compounds amenable to air stripping, and is an alternative method to pump-and-treat remediation of groundwater. The UVB technology is designed to remove VOCs from groundwater by transferring the contaminants from the aqueous phase to the gaseous phase and subsequently treating the resulting air stream through carbon adsorption units.

The developer and patent holder is IEG mbH of Germany, the U.S. license holder is IEG® Technologies Corporation.

The UVB system consists of a single well with two hydraulically separated screened intervals installed within a single permeable zone. Pumping in the lower section followed by in situ air stripping and reinfiltration in the upper section creates a recirculation pattern of groundwater in the surrounding aquifer. The continuous flushing of the saturated zone with recirculated treated water facilitates the partitioning of adsorbed, absorbed, and free liquid contaminants to the dissolved phase through increased dissolution, diffusion, and desorption. Increased partitioning through these processes is driven by increased groundwater flow rates within the system's radius of circulation cell and increased concentration gradient established by the reinfiltration and recirculation of treated water in the aquifer.

Where applicable, the UVB technology provides an effective long-term solution to aquifer remediation by removing contaminants in the saturated zone without extracting groundwater, lowering the groundwater table, and generating wastewater typical of pump and treat systems. Additionally, once the UVB treatment system is installed and balanced, it requires minimal support from on-site personnel. The UVB technology was evaluated under the SITE program at Site 31, March AFB, where groundwater was contaminated with solvents including TCE.

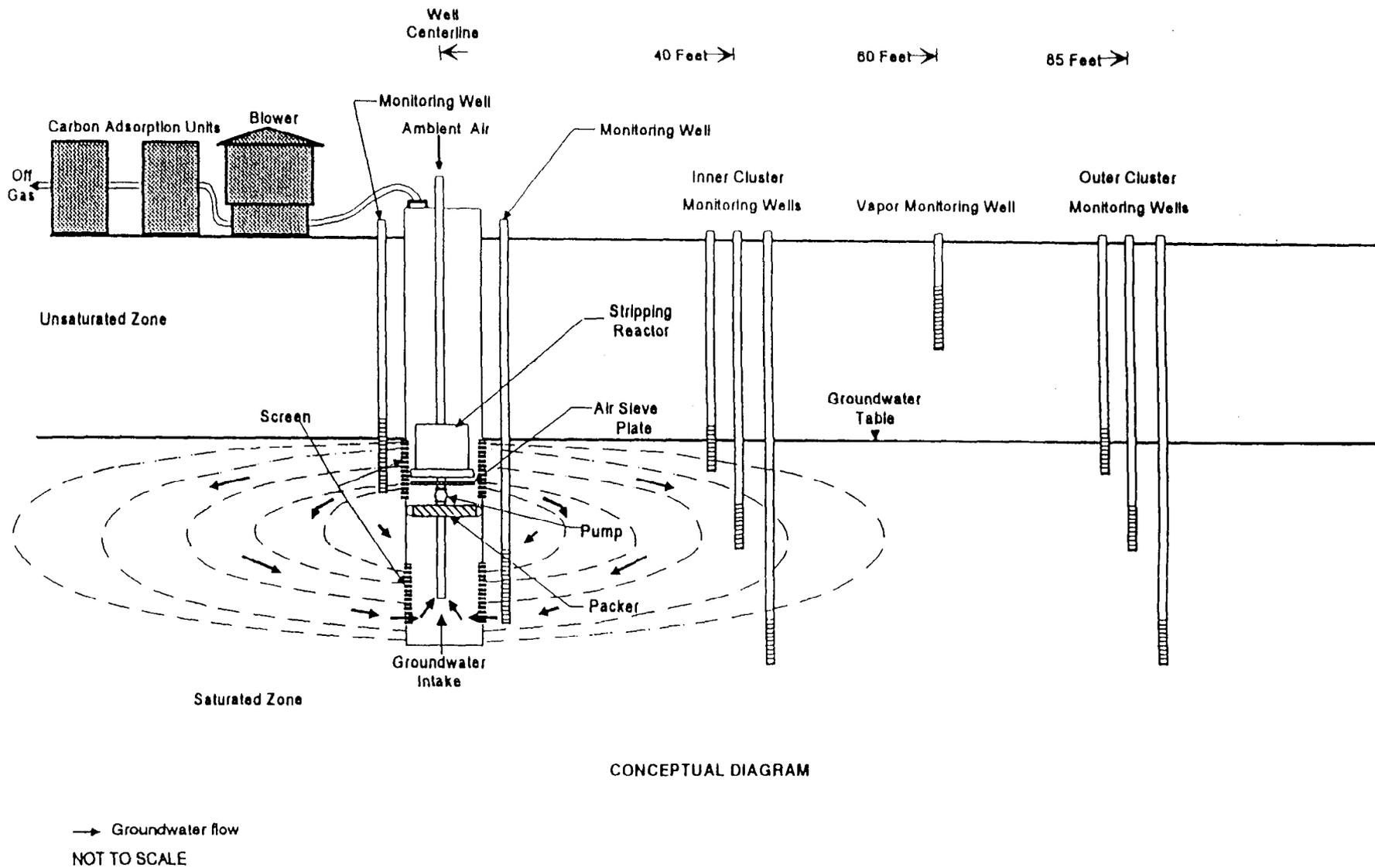
The demonstration evaluated the reduction of TCE concentrations in the groundwater discharged from the

treatment system, the radius of circulation cell of the system, and the reduction of TCE concentrations in the groundwater within the system's radius of circulation cell. The study results showed that the UVB system removed TCE from the groundwater by an average of greater than 94 percent. The mean TCE concentration in water discharged from the system was approximately 3 micrograms per liter ( $\mu\text{g/L}$ ) with the 95 percent upper confidence limit calculated to be approximately 6  $\mu\text{g/L}$ . The study also indicated that the radius of circulation cell was 40 feet in the downgradient direction and may extend as far as 83 feet based on modeling of the radius of circulation cell in the alluvial aquifer at March AFB by the developer. The radius of circulation cell is largely controlled by the hydrogeologic characteristics of the aquifer and, to a lesser extent, UVB system design. TCE concentrations within the aquifer were reduced laterally by approximately 52 percent in the radius of circulation cell during the 12-month pilot study.

## Technology Description

One of the UVB technology designs is an in situ groundwater remediation technology that combines air-lift pumping and air stripping to remove VOCs from groundwater. A properly installed UVB system consists of a single well with two hydraulically separated screened intervals installed within a single permeable zone (Figures 1, 2 and 3). The air-lift pumping occurs in response to negative pressure introduced at the wellhead by a blower. This blower creates a vacuum that draws water into the well through the lower screened portion of the well. Simultaneously, air stripping occurs as ambient air (also flowing in response to the vacuum) is introduced through a sieve plate located within the upper screened section of the well, causing air bubbles to form in the water pulled into the well. The rising air bubbles provide the air-lift pump effect that moves water toward the top of the well and draws water into the lower screened section of the well. This pumping effect is supplemented by a submersible pump that ensures that water flows from bottom to top in the well. As the air bubbles rise through the water column, volatile compounds are transferred from the aqueous to the gaseous phase. The rising air transports volatile compounds to the top of the well casing, where they are removed by the blower. The blower effluent is treated before discharge using a carbon adsorption unit.

The transfer of volatile compounds is further enhanced by a stripping reactor located immediately above the sieve plate. The stripping reactor consists of a fluted and channelized column that facilitates the transfer of volatile compounds to the gas phase by increasing the contact time between the two phases and by minimizing the coalescence of air bubbles. The overall stripping zone of the UVB system extends from the sieve plate to the top



CONCEPTUAL DIAGRAM

Figure 1: The Unterdruck-Verdampfer-Brunnen Well

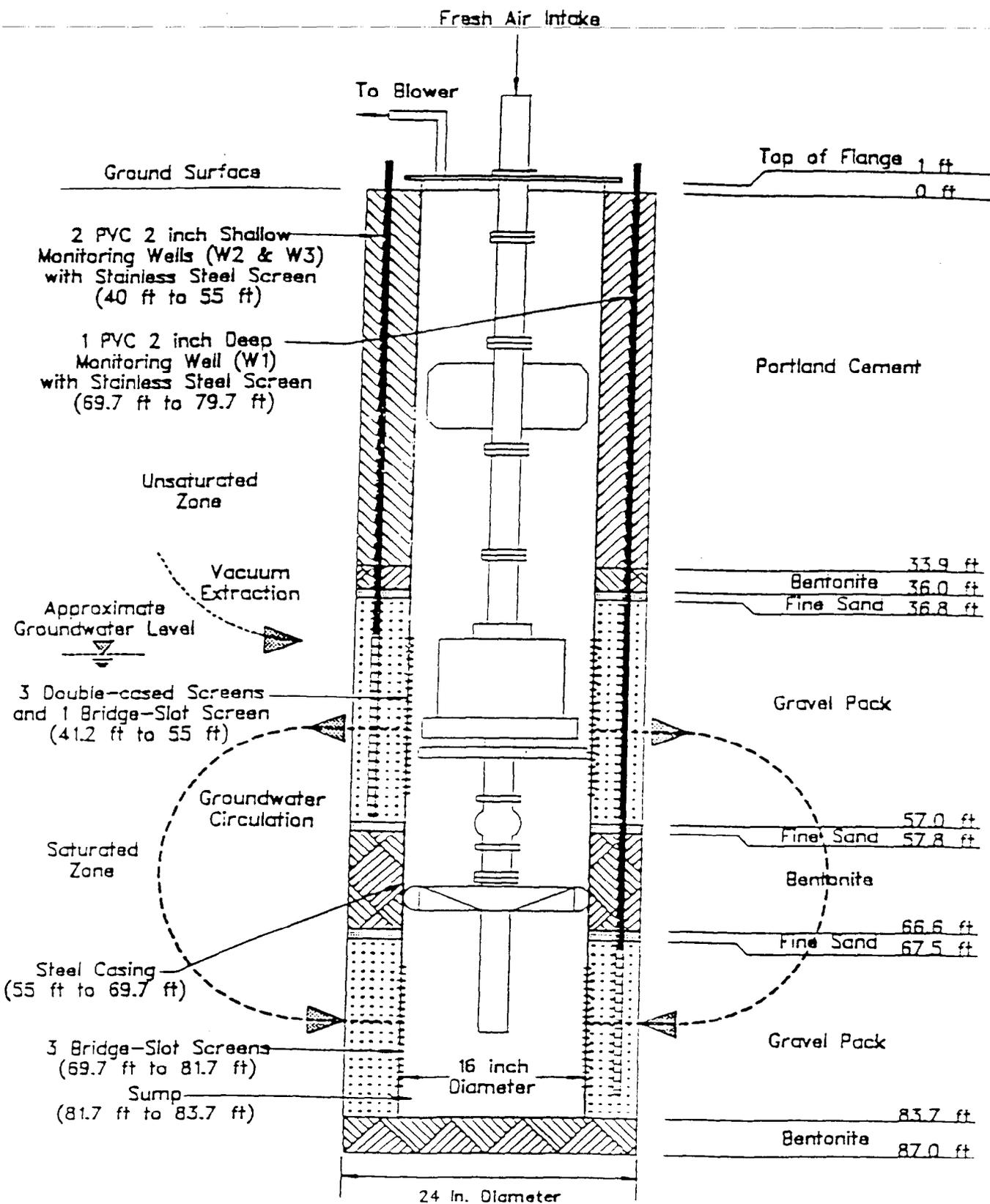
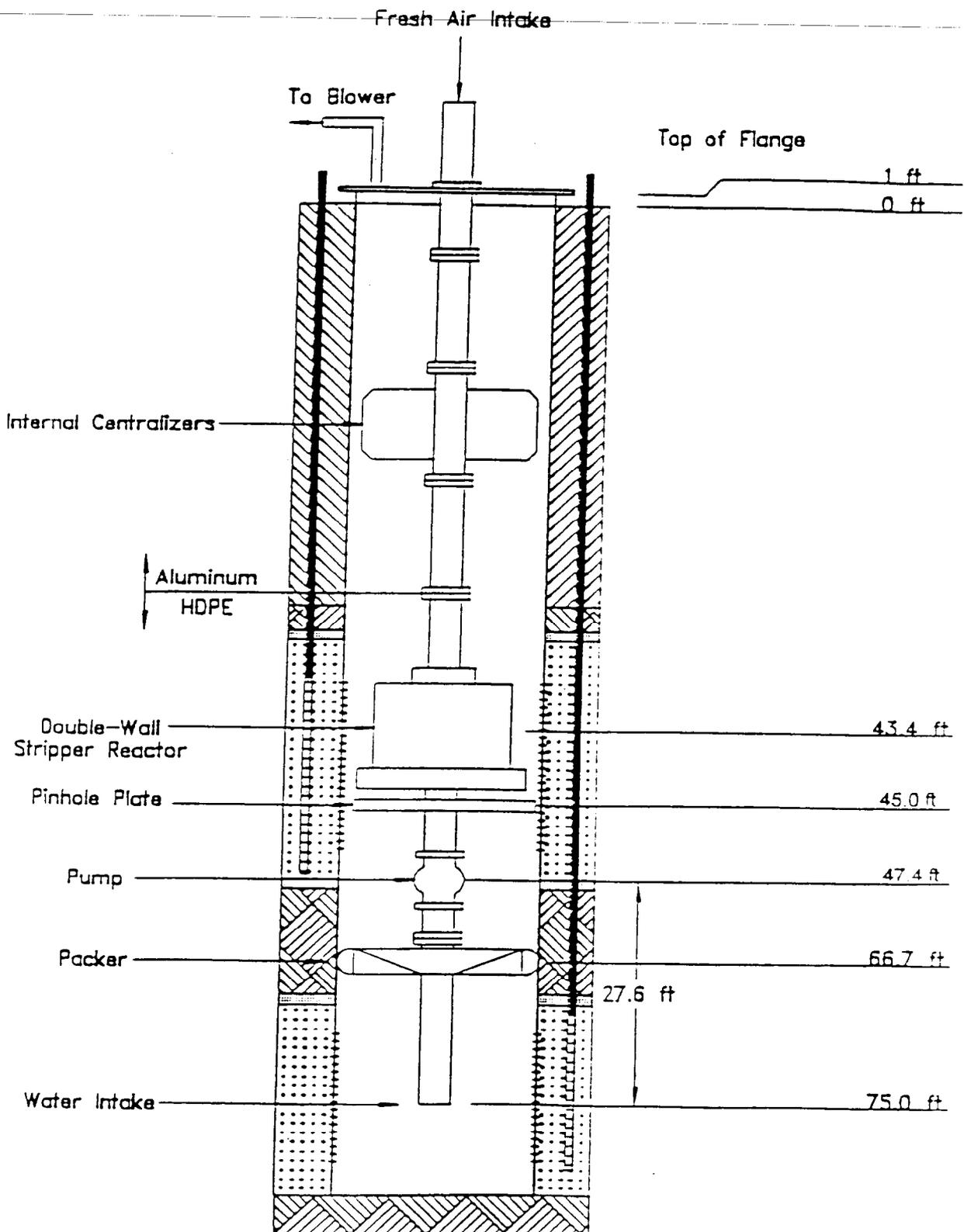


Figure 2: The As-Built Unterdruck-Verdampfer-Brunnen Configuration

NOT TO SCALE



HDPE - High Density Polyethylene

NOT TO SCALE

Figure 3: The As-Built Unterdruck-Verdampfer-Brunnen Internal Components

of the water column. To maximize volatilization in the stripping zone, the sieve plate and stripping reactor are positioned at a depth that optimizes the reach of the stripping zone and the volume of air flow into the system. The down-well components of the UVB system have been designed with leveling ballast that allows the system to be free floating. This feature allows the system to compensate for fluctuations in groundwater elevation during operation and, thereby, maintain maximum volatilization.

Once the upward stream of water leaves the stripping reactor, the water falls back through the well casing and returns to the aquifer through the upper well screen. This return flow to the aquifer, coupled with inflow at the well bottom, circulates groundwater around the UVB well. The extent of the circulation pattern is known as the radius of circulation cell, which determines the volume of water affected by the UVB system.

The radius of circulation cell and the shape of the circulation pattern are directly related to the properties of the aquifer. The circulation pattern is further modified by natural groundwater flow that skews the pattern in the downgradient direction. Numerical simulations of the UVB operation indicates that the radius of circulation cell is largely controlled by anisotropy (horizontal  $[K_h]$  and vertical  $[K_v]$  hydraulic conductivity), heterogeneity, aquifer thickness and, to a lesser extent, well design. In general, changes that favor horizontal flow over vertical flow such as a small ratio of screen length to aquifer thickness, anisotropy, horizontal heterogeneities such as low permeability layers, or increased aquifer thickness will increase the radius of circulation cell. As a general rule, the developer estimates the system's radius of circulation cell to be approximately 2.5 times the distance between the upper and lower screen intervals.

Groundwater within the radius of circulation cell includes both treated and untreated water. A portion of the treated water discharged to the upper screen is recaptured within the circulation cell. Treated water not captured by the system leaves the circulation cell in the downgradient direction. The percentage of treated water recycled within the UVB system (IEG estimates that it can be up to 90 percent) is related to the radius of circulation cell and is a function of the ratio of  $K_h/K_v$ . The larger the radius of circulation cell and the larger the  $K_h$  to  $K_v$  ratio values, the smaller the percentage of recycled water for a given aquifer. The recycled treated water dilutes influent contaminant concentrations.

### Technology Applicability

The UVB technology's applicability was evaluated based on the nine criteria used for decision making in the Superfund feasibility study process. Results of the

evaluation are summarized in Table 1. In general, the UVB technology is applicable for treatment of dissolved phase volatile compounds in groundwater. The developer claims that other UVB system configurations allow for treatment of semi- and non-volatile contaminants and nitrates. In addition, the chemical and physical dynamics established by the recirculation of treated water make this technology suited for remediation of contaminant source areas. The technology employs readily available equipment and materials and the material handling requirements and site support requirements are minimal.

The UVB system demonstrated for the SITE program was designed to remove VOCs from the groundwater, in particular TCE and 1,1-dichloroethene (DCE). The developer claims that the technology can also clean up aquifers contaminated with other organic compounds, including volatile and semivolatile hydrocarbons. According to the developer, the UVB technology in some cases is also capable of simultaneous recovery of soil gas from the vadose zone and treatment of contaminated groundwater from the aquifer as a result of the in situ vacuum. For soil gas recovery, the upper screened portion of the UVB well is completed from below the water table to above the capillary zone. Although the developer claims that the UVB technology reduces VOCs from soil gas in the vadose zone, the technology was evaluated only for its effects in the saturated zone.

### Technology Limitations

The UVB technology has limitations in areas with very shallow groundwater (less than 5 ft.). In such areas, it may be difficult to establish a stripping zone long enough to remove contaminants from the aqueous phase. The technology has further limitations in thin aquifers (less than 10 ft.); the saturated zone must be of sufficient thickness to allow proper installation of the system. In addition, the thickness of the saturated zone affects the radius of circulation cell; the smaller the aquifer thicknesses, the smaller the radius of circulation cell.

The majority of water being drawn from the aquifer into the lower screen section is treated water re-infiltrated from the upper section. This recirculation of cleaned water significantly decreases the contaminant levels in the water treated by the system. As the UVB system continues to operate, the circulation cell grows until a steady state is reached. As the circulation cell grows, the amount of recirculated water increases causing a further decrease of contaminant levels in the water treated by the system.

High concentrations of volatile compounds may require more than one pass through the system to achieve remediation goals. This may initially be a problem since a portion of the treated water is not captured by the system and leaves the circulation cell in the downgradient direction.

**Table 1: Feasibility Study Evaluation Criteria for the UVB Technology**

CRITERION	UVB TECHNOLOGY PERFORMANCE
1 Overall Protection of Human Health and the Environment	The technology eliminates contaminants in groundwater and prevents further migration of those contaminants with minimal exposure to on-site workers and the community. Air emissions are reduced by using carbon adsorption units.
2 Compliance with Federal ARARs	Compliance with chemical-, location-, and action-specific ARARs must be determined on a site-specific basis. Compliance with chemical-specific ARARs depends on (1) treatment efficiency of the UVB system, (2) influent contaminant concentrations, and (3) the amount of treated groundwater recirculated within the system.
3 Long-Term Effectiveness and Permanence	Contaminants are permanently removed from the groundwater. Treatment residuals (for example, activated carbon) require proper off-site treatment and disposal.
4 Reduction of Toxicity, Mobility, or Volume Through Treatment	Contaminant mobility is initially increased, which facilitates the long-term remediation of the groundwater within the system's radius of influence. The movement of contaminants toward the UVB system within the system's capture zone prevents further migration of those contaminants and ultimately reduces the volume of contaminants in the groundwater.
5 Short-Term Effectiveness	During site preparation and installation of the treatment system, no adverse impacts to the community, workers, or the environment are anticipated. Short-term risks to workers, the community, and the environment are presented by increased mobility of contaminants during the initial start-up phase of the system and from the system's air stream. Adverse impacts from the air stream are mitigated by passing the emissions through carbon adsorption units before discharge to the ambient air. The time requirements for treatment using the UVB system depends on site conditions and may require several years.
6 Implementability	The site must be accessible to large trucks. The entire system requires about 100-700 square feet (average 300). Services and supplies required include a drill rig, off-gas treatment system, laboratory analysis, and electrical utilities.
7 Cost	Capital costs for installation of a single unit are estimated to be \$180,000, and annual operation and maintenance costs estimated to be \$72,000.
8 Community Acceptance	The small risks presented to the community along with the permanent removal of the contaminants make public acceptance of the technology likely.
9 State Acceptance	State acceptance is anticipated because the UV system uses well-documented and widely accepted processes for the removal of VOCs from groundwater and for treatment of the process air emissions. State regulatory agencies may require permits to operate the treatment system, for air emissions, and to store contaminated soil cuttings and purge water for greater than 90 days.

ARAR - Applicable or relevant and appropriate requirements

However, as the UVB circulation cell is established, the influent concentrations should be diluted to below levels requiring more than one pass, thereby limiting the potential migration of contaminants above target concentrations from the system.

## Process Residuals

The materials handling requirements for the UVB system include managing spent granular activated carbon, drilling wastes, purge water, and decontamination wastes generated during installation, operation, and monitoring of the treatment system. Spent carbon generated during treatment of the system air effluent will either be disposed of or regenerated by the carbon vendor. The drilling wastes are produced during installation of the system well. The drilling waste can be managed either in 55-gallon drums or in roll-off type debris bins. Disposal options for this waste depend on local requirements and on the presence or absence of contaminants. The options may range from on-site disposal to disposal in a hazardous waste or commercial waste landfill.

Purge water is generated during development and sampling of the groundwater monitoring wells. Purge water can be managed in 55-gallon drums. Disposal options again depend on local restrictions and on the presence or absence of contaminants. Options range from surface discharge through a National Pollutant Discharge Elimination System (NPDES) outfall, to disposal through a Publicly Owned Treatment Works (POTW), to treatment and disposal at a permitted hazardous waste facility.

Decontamination wastes are generated during installation and sampling activities. Decontamination wastes generated during installation include decontamination water and may include a decontamination pad for the drill rig. The solid decontamination wastes can be managed in roll-off type debris boxes, and the liquid wastes can be managed in 55-gallon drums. Disposal options are similar to those for drilling wastes and purge water.

## Site Requirements

A UVB treatment system consists of several major components: an 8, 10, 16, or 24-inch dual screen well, well packer, submersible pump, sieve plate, stripping reactor, blower, and carbon filter units. A drill rig is required to install the system well. Once the well has been completed, the treatment system can be operational within 1 day if all necessary equipment, utilities, and supplies are available.

The site support requirements needed for the UVB system are space to set up the carbon adsorption units and

electricity. The system requires standard 120/240 volts (200 amperes). An electrical pole, a 480-volt transformer, and electrical hookup between the supply lines, pole, and the UVB treatment system are necessary to supply power. The space requirements for the above-ground components of the UVB system including the UVB system well, off-gas treatment units, blower, and piping used during the SITE demonstration are approximately 500 square feet. Other requirements for installation and routine monitoring of the system include access roads for equipment transport, security fencing, and decontamination fluids for drilling and sampling.

## Performance Data

The SITE demonstration for the UVB technology was designed with three primary and seven secondary objectives to provide potential users of the technology with the necessary information to assess the applicability of the UVB system at other contaminated sites. Demonstration program objectives were achieved by collecting groundwater and soil gas samples, as well as UVB system process air stream samples over a 12-month period. To meet the objectives, data were collected in three phases: baseline sampling, long-term sampling, and dye trace sampling. Baseline and long-term sampling included the collection of groundwater samples from eight monitoring wells, a soil gas sample from the soil vapor monitoring well, and air samples from the three UVB process air streams both before UVB system startup and monthly thereafter. In addition, a dye trace study was conducted to evaluate the system's radius of circulation cell. This study included the introduction of fluorescent dye into the groundwater and the subsequent monitoring of 13 groundwater wells for the presence of dye three times a week over a 4-month period.

The conclusions of the UVB SITE demonstration at March AFB are presented below by project objective.

### Primary Objectives:

- P1** *Determine the concentration to which the UVB technology reduces TCE and DCE in groundwater discharged from the treatment system.*

The UVB effectively removed target compounds from the groundwater as indicated by the analytical results presented in Table 2. During the demonstration, TCE concentrations in samples from the influent well ranged from 14 µg/L to 220 µg/L with an arithmetic mean of approximately 56 µg/L. The UVB system reduced TCE in the groundwater discharged from the treatment system to below 5 µg/L in nine out of the 10 monthly monitoring

events and on average by greater than 94 percent during the period in which the system operated without apparent maintenance problems. The mean concentration of TCE in the water discharged from the system was approximately 3 µg/L; however, the 95 percent upper confidence limit for TCE in the treated groundwater was calculated to be approximately 6 µg/L.

The UVB system reduced DCE to less than 1 µg/L in groundwater discharged from the treatment system; however, the system's ability to remove DCE cannot be meaningfully estimated due to the low (less than 4 µg/L) influent concentration of DCE.

**P2** *Estimate the radius of circulation cell of the groundwater treatment system.*

The radius of circulation cell of the groundwater treatment system was estimated by both direct and indirect methods. The radius of circulation cell was directly measured by conducting a dye trace study. Based on the dye trace study, the radius of circulation cell was measured to be at least 40 feet in the downgradient direction. However, no dye was observed in wells located 40 feet upgradient or cross gradient of the UVB system. The radius of circulation cell was indirectly evaluated by (1) modeling the groundwater flow, and (2) analyzing aquifer pump test data. Groundwater flow modeling results conducted by the developer indicate a radius of circulation cell of 83 feet. Analysis of aquifer pump test data indicates a radius of circulation cell of about 60 feet for a traditioned pumping well near this UVB system. An attempt was made to indirectly evaluate the radius of circulation cell using variations of target compound concentrations and fluctuations of dissolved oxygen in surrounding groundwater monitoring wells. However, these methods did not provide a reliable or conclusive estimate of the radius of circulation cell due to variables independent of the UVB system.

**P3** *Determine whether TCE and DCE concentrations have been reduced in groundwater (both vertically and horizontally) within the radius of circulation cell of the UVB system over the course of the pilot study.*

Based on the demonstration results presented in Table 2, TCE concentrations in samples from the shallow and intermediate zone wells were reduced both vertically and laterally except in the intermediate outer cluster well, which showed an increase in concentration. TCE concentrations have been reduced laterally by an average of approximately 52 percent in samples from the shallow and intermediate zones of the aquifer. No reduction of TCE was observed in samples from the deep zone, which could be due to limited duration of monitoring in this zone.

Secondary Objectives:

**S1** *Assess homogenization of the groundwater within the zone of influence.*

A convergence and stabilization of TCE concentrations was observed in samples from the shallow and intermediate zones of the aquifer, which suggest homogenization of contaminant concentrations in the groundwater.

**S2** *Document selected aquifer geochemical characteristics that may be affected by oxygenation and recirculation of treated groundwater.*

No clear trends in the field parameters, general chemistry, or dissolved metals results were observed that would indicate significant precipitation of dissolved metals, changes in dissolved organic carbon, or the presence of dissolved salts caused by the increase in oxygen in groundwater.

**S3** *Determine whether the treatment system induces a vacuum in the vadose zone that suggests vapor transport.*

Although the developer claims that the UVB system has applications to cleanup of both groundwater and soil gas, the system installed at Site 31 was designed to remove halogenated hydrocarbons from the groundwater only. The VOC concentrations and vacuum measurements in the vapor monitoring well indicate that transport of contaminants was not significantly affected by operation of the UVB system as currently designed. Changes in system design and operating parameters may lead to significant transport of contaminants in the vadose zone.

**S4** *Estimate the capital and operating costs of constructing a single treatment unit to remediate groundwater contaminated with TCE and DCE.*

Costs are highly site specific. EPA estimates that one-time capital costs for a single treatment unit are \$180,000; variable annual operation and maintenance costs for the first year were estimated to be \$72,000, and for subsequent years, \$42,000. Based on these estimates, the total cost for operating a single UVB system for 1 year was calculated to be \$260,000. Since the time required to remediate an aquifer is site-specific, costs have been estimated for operation of a UVB system over a range of time for comparison purposes. Therefore, the cost to operate a single UVB system was calculated to be \$340,000 for 3 years, \$440,000 for 5 years, and \$710,000 for 10 years. Additionally, the costs for treatment per 1,000 gallons of

Table 2: Aquifer Trichloroethene Concentration Summary

Well	Description	Trichloroethene Concentration (µg/L)												
		Baseline	1 <sup>ST</sup>	2 <sup>ND</sup>	3 <sup>RD</sup>	4 <sup>TH</sup>	5 <sup>TH</sup>	6 <sup>TH</sup>	7 <sup>TH</sup>	8 <sup>TH</sup>	9 <sup>TH</sup>	10 <sup>TH</sup>	11 <sup>TH</sup>	12 <sup>TH</sup>
W1	Intermediate System Well	22 <sup>a</sup>	57	60	220	35	31	30	22	34	31	14	28	110
W2	Shallow System Well	1 <sup>a</sup>	<1	<1	16	2.4	4	<1	<1	38 <sup>a</sup>	2	1	1	69 <sup>a</sup>
Percent Reduction <sup>b</sup>		NC	>98	>98	93	93	87	>97	>95	12	94	93	95	41
PW1	Shallow Inner Cluster Well	530	500	440	620	608	530	540	600	600	530	300	330	340
PW2	Intermediate Inner Cluster Well	750	1,000	1,900	2,000	1,100	1,200	910	800	620	340	280	240	270
PW3	Deep Inner Cluster Well	100	130	180	310	230	200	250	NA	NA	NA	NA	NA	NA
PW4	Shallow Outer Cluster Well	650	760	760	680	818	980	1,100	1,600	1,400	970	300	340	290
PW5	Intermediate Outer Cluster Well	120	270	310	390	330	350	450	640	380	310	230	210	210
PW6	Deep Outer Cluster Well	110	130	110	130	92	140	150	NA	NA	NA	NA	NA	NA

<sup>a</sup> Concentration affected by water added during drilling and well installation.

<sup>b</sup> Percent reduction =  $[(C_{(w-1)} - C_{(w-2)}) / C_{(w-1)}] \times 100$ ; where  $C_{(w-1)}$  = deep well concentration and  $C_{(w-2)}$  = shallow well concentration

<sup>c</sup> Concentration affected by system maintenance problems; therefore, results were not used to evaluate primary objectives.

µg/L Micrograms per liter

< Less than

> Greater than

NC Not calculated

NA Not analyzed

groundwater were estimated to be \$260 for 1 year, \$110 for 3 years, \$88 for 5 years, and \$71 for 10 years. The cost of treatment per 1,000 gallons refers to the amount of groundwater pumped through the system. Potential users of the treatment technology should be aware that typically 60 to 90 percent of the water pumped through the system is recirculated water. A more detailed document, the Innovative Technology Evaluation Report (ITER) contains information on the assumption for these cost figures.

**S5** *Document pre- and post-treatment off-gas volatile organic contaminant levels.*

The results from air monitoring of the UVB treatment system indicated that low concentrations of TCE were removed from the groundwater. TCE concentrations reduced by the UVB system correlate to trends observed in target compound concentrations in the inner cluster monitoring wells (that is, increasing concentration from the baseline event to the third monthly monitoring event with a subsequent decrease in concentrations).

**S6** *Document system operating parameters.*

The temperature of the internal monitoring ports ranged from 18.5 to 44.7 degrees Celsius; the relative humidity ranged from 27 to 100 percent; the vacuum pressure ranged from 13.81 to 15.03 pounds per square inch absolute; the air flow ranged from 100 to 898 standard cubic feet per minute; the air velocity ranged from 1,109 to 9,999 feet per minute; and the discharge through the UVB system was estimated by the developer to be approximately 22 gallons per minute.

**S7** *Evaluate the presence of aerobic biological activity in the saturated and vadose zones.*

Carbon dioxide concentrations measured in the vapor monitoring well indicate that carbon dioxide has increased by more than 2 percent since baseline monitoring. Several fluctuations in O<sub>2</sub> level were observed; however, there was no evidence of a downward trend of these concentrations. The minor changes in CO<sub>2</sub> and O<sub>2</sub> measured suggest that bioactivity in the soil and groundwater was not significantly enhanced by operation of the UVB system.

Additionally, CO<sub>2</sub> concentrations measured at the UVB system's intake and after the blower reveal minor fluctuations of relative CO<sub>2</sub> concentration. These results also suggest that bioactivity due to increased dissolved oxygen levels in the groundwater was not significantly enhanced by operation of the UVB system.

## Technology Status

Since its introduction in 1986, the UVB technology has been applied at some 80 sites in Europe. No U.S. installation of a UVB system has required an NPDES permit to date. A UVB system was first installed at a U.S. site in September 1992; currently, there are 22 UVB systems operating in eight states.

A more detailed document, the ITER, contains more information on this documentation, the developer has provided four select case studies that document operation of the UVB system at sites in the U.S. and Germany. Two of the cases are from sites in Germany and involve the remediation of chlorinated hydrocarbons (TCE, 1,1,1-trichloroethane, and dichloromethane) in the groundwater. The two cases from the U.S. document the remediation of groundwater contaminated with benzene, toluene, ethylbenzene, and xylene at an underground storage tank site in Troutman, North Carolina, and Weston's interpretation of the data collected during but independent of this SITE demonstration.

## Sources of Further Information

For further information, contact:

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March 7, 1997

Southern Division  
Naval Facilities Engineering Command  
ATTN: Mr. Anthony Robinson  
2155 Eagle Drive  
North Charleston, SC 29418

Dear Mr. Robinson:

**SUBJECT:** Letter Report, Interim Measure (IM) System Phase II Upgrades, New Recovery Well Installation and Performance Testing, Site 11, Old Camden County Landfill, Naval Submarine Base, Kings Bay, Georgia, Contract No. N62467-89-D-0317/094

### INTRODUCTION

This letter report summarizes the installation and performance testing of the new groundwater recovery well (RW-6) at Site 11, Old Camden County Landfill. Installation of this well was part of the Interim Measures System, Phase II Upgrade activities designed to improve operation of the groundwater extraction and treatment system. The work was performed under contract to the U.S. Department of the Navy, Southern Division, Naval Facilities Engineering Command within the Comprehensive Long-term Environmental Action, Navy (CLEAN) program, Contract Task Order No. 94, Contract No. N62467-89-D-0317.

The new well was installed to both improve hydraulic control of the contaminated groundwater plume and to enhance extraction of contaminated groundwater in the area of highest concentrations of volatile organic compounds (VOCs). This new well was installed along the western side of the landfill between existing recovery wells RW-1 and RW-2. The location is 90 feet south of monitoring well KBA-11-13A where the highest concentrations of VOCs have been detected. The purpose of performance testing this new recovery well was to provide baseline estimates of well efficiency ( $E_w$ ) and specific capacity ( $S_c$ ). These estimates also provide a basis to assess well performance and response to alternate extraction rates.

This letter report is divided into three main sections: Field Activities Summary; Data Analysis; followed by Results and Conclusions.

### FIELD ACTIVITIES SUMMARY

Field activities associated with the installation, development, and performance testing of this recovery well were conducted from November 21 through November 27, 1996, and on December 14, 1996. The field activities were comprised of two separate tasks: (1) drilling and well installation and (2) well performance testing. A general overview of these activities and well characteristics are presented in the following subsections.

#### Well Installation

A Bucyrus-Erie cable tool drilling rig was used to advance a 12-inch-diameter borehole to a depth of 75 feet. This drilling method involves the use of driven casing, advanced by a cable-driven hammer. As the casing is advanced, cuttings fill the interior of casing. Cuttings contained within the 11.5-inch inside diameter (ID) casing are removed by lowering a large flap-valve type bailer; surging up and down through the lower part of the casing; and then raising the loaded bailer to the surface. Cuttings collected in the bailer were descriptively logged by the ABB-ES geologist as drilling progressed. This method of drilling agitates the cuttings and generally composites aquifer materials through each 3- to 5-foot zone:

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therefore, sample observations are only useful on a macro, or gross scale. A copy of the field log is provided in Attachment A. Geologic materials encountered were similar to previous exploratory boreholes. Cuttings from the drilling process were retained onsite in a roll-off for later disposal.

A 6-inch-diameter Type 304-stainless steel well was installed in the borehole. The installation was completed by lowering 40 feet of 0.030-inch continuous slot, wire-wrapped well screen through the advanced casing. A schedule 10S 5-foot sump was attached to the bottom, and 30 feet of schedule 10S casing extends up to the surface. Bottom of the well is 74 feet below land surface (bls). The screened zone of this well extends from 29 feet bls to 69 feet bls. A 1-inch piezometer was also installed with in the annular space between the well screen and the borehole wall. The piezometer screen extends from 29 feet bls to 64 feet bls. Filter pack materials, similar in nature to the medium-grained sand used in the other recovery wells, was tremied into the annulus as the casing was withdrawn. The filter pack extends from 74 feet bls up to 27 feet bls. Specification for this 6/20 filter pack material is provided in the Statement of Work for IM Drilling Services at NSB Kings Bay (ABB-ES, 1996). A 2-foot bentonite seal was installed above the sand. The remaining annulus was grouted with a portland cement and bentonite mixture from 25 feet below ground to the invert of a surface vault. Approximately 2 feet of casing was cut-off the top of the well to accommodate the well vault. An as-built of RW-6 is provided in Attachment A to this report.

The well was developed with a Smeal workover rig utilizing a surge block and submersible pump assembly. Development procedures involved swabbing the well screen with the surge block followed by discharge of 3,000 gallons of water over a 2-day period. The entire 40 feet of screen was surged and pumped throughout the development period. The purged water was collected in a polyethylene tank and transported to the Site 11 treatment system for disposal.

An initial estimate of specific capacity ( $S_e$ ) of RW-6 during development was calculated from flow rate and water level data collected using the tank volume (approximately 300 gallons), a stopwatch, and a water level indicator. The initial  $S_e$  value was approximately 3.75 gallons per minute per foot of drawdown (gpm/ft) based on flow estimates of 15 gpm and drawdown estimates of 4 feet during tank fill-up intervals. Due to limited accuracy of the volumetric measurement(s) and the short duration of pumping intervals, this initial  $S_e$  value is provided only as an early estimate and was used for pump selection for the step drawdown test. Groundwater was relatively clear and turbid-free after development.

#### Step Drawdown Test

To collect data for the performance evaluation of this new recovery well, the following activities were performed:

- pump installation: replacement of dedicated pump with test pump;
- monitoring system installation;
- step drawdown test and data collection; and,
- recovery data collection.

The dedicated pump in RW-6 is a Grundfos Model 10S03-9 submersible pump that has an optimum range of 5 to 14 gpm. Based on the initial estimate of  $S_e$  (3.75 gpm/ft) and the Grundfos Model 10S03-9 range, this dedicated pump is limited ( $\pm 4$  feet of drawdown) in its ability to stress the aquifer. In order to create a greater stress on the well and surficial aquifer during this step drawdown test, an alternate pump with greater capacity was selected for use. This pump was a Grundfos Model 40S20-7 submersible unit having an optimum range of 24 to 55 gpm. Accounting for head losses through the system, maximum flow from this test pump was expected to be approximately 45 gpm. The test pump was lowered to the bottom of the well and connected to the existing drop pipe and conveyance line. Power was supplied via the recently installed (Phase II Upgrade activities) underground power, controls, and

discharge conveyance system. Discharge from the pump was then conveyed directly to the Site 11 IM Treatment System, also through this underground system.

Water levels were collected using both electronic pressure transducers and a water level indicator. The transducers were connected to an In-Situ Inc., Hermit 2000 data logger. Only two transducers — both installed in RW-6 (in the well and in the annulus piezometer) — were used during this test. No atmospheric monitoring of barometric influence on water levels was performed during this event. Potential influence of barometric pressure change(s) was assumed to be negligible relative to magnitude of drawdown and the short duration of 6 hours. Nine existing monitoring wells and piezometers in the proximity of RW-6 were selected for observation during this step drawdown test. These wells, listed below, were monitored with a water level indicator. The monitoring wells were: KBA-11-2, KBA-11-13A, KBA-11-13B, PS-3, PS-5, PD-6, KBA-11-10A, KBA-11-10B, and KBA-11-10C. These wells are listed in Table 1 in Attachment B, along with distances from RW-6. Four of these wells, completed in the intermediate aquifer unit were monitored for evaluation of  $E_w$ . The remaining five wells are in the shallow aquifer unit (KBA-11-2 and KBA-11-10A) and the underlying deep unit(s) (PD-6, KBA-11-10C, and KBA-11-13B). These wells were monitored to support evaluation of short-term anisotropic response to RW-6 pumping.

Data were collected during the step drawdown test and evaluated to estimate well performance parameters. This step drawdown test was conducted on December 14, 1996. The test began at 11:00 a.m. and was divided into three 100-minute steps for a total of 300 minutes, or 5 hours. The third step was lengthened by another 60 minutes to provide a 6-hour estimate of  $S_e$ . The average flow rate during the initial step was 9.3 gpm, the intermediate step flow rate was 19.1 gpm, and the final step flow rate was 31.8 gpm. After the 6-hour pumping period, recovery of the well was monitored. Water levels were collected on a logarithmic frequency in RW-6 electronically with the data logger and were collected manually over a periodic (end of each step) basis in the nine observation wells. Data from the transducer installed in RW-6 apparently malfunctioned during the test, so data from the recovery well piezometer (RW-P6) was used for analysis of well performance.

## ANALYSIS OF DATA

Well performance characteristics were evaluated by analysis of the step drawdown test data. Three methods of analysis were applied. Each method has its focus, or purpose. Limitations to these methods are provided after discussion of these methods.

### Methodology

Data from the step drawdown test were analyzed to estimate the  $S_e$  of RW-6. Flow during each of the three steps was evaluated against drawdown in the recovery well.  $S_e$  of any well is inversely proportional to both time and flow rate; therefore,  $S_e$  decreases as time or flow increases until a steady-state condition is achieved. Certain assumptions and limitations are inherent with this method; these are discussed later in this report. The results of the initial specific capacity tests are discussed below and provided in Table 2 in Attachment B.

The Hantush-Bierschenk method of analysis was used to provide well performance characteristics. If certain assumptions provided below are satisfied,  $E_w$  and type of well losses can be addressed. This method was used primarily for evaluation of the distribution of linear (laminar) and nonlinear (turbulent) well losses within the well. The method applies the formula:

$$E_w = \left\{ \frac{B_1 Q}{(B_1 + B_2) Q + C Q^2} \right\} \times 100\%$$

where:       $B_1$  = linear aquifer-loss coefficient  
                $B_2$  = linear well-loss coefficient  
                $C$  = non-linear well-loss coefficient  
                $Q$  = flow rate

Values for the coefficients  $B$  and  $C$  are obtained graphically from the intercept and slope, respectively, of a well-specific graph of the relationship of flow rate versus the inverse of specific capacity ( $1/S_c$ ) for each step. Graphical analysis is provided in Attachment C. Certain assumptions and limitations are inherent with this method, as discussed in the methods limitations section. Results of this analysis are discussed at the end of this report.

$E_w$  was also evaluated by comparison of theoretical and actual drawdown values in the pumping well. This method, as outlined in Groundwater and Wells (Driscoll, 1986), uses the extension of the drawdown curve, plotted on semi-logarithmic graph, to represent the drawdown just outside the well. Theoretical drawdown is represented by the intersection of this curve extension and the intersection with the well's outer radius. In this case, because the RW-6 piezometer was available, a radius of 0.50 feet (from the center of the well) was used.  $E_w$  is calculated as the ratio of theoretical drawdown over actual drawdown multiplied by 100 percent. Certain assumptions inherent with this method are discussed in the methods limitations section.

Aquifer drawdown produced by pumping RW-6 was measured in the nine observation wells. The raw distance-drawdown data for the three steps and the 6-hour test is presented in Table 3 in Attachment B. The distance-drawdown data were used to construct plots of drawdown versus log distance on semi-log paper. The 6-hour plot was used to estimate the well efficiency. The distance-drawdown plot(s) are presented in Attachment C. Results of this analysis are discussed at the end of this report.

No analysis of the recovery phase data was performed.

#### Method Limitations

Calculation of  $S_c$  is generally measured after a period of one day or more. This test period was limited to a 6-hour time frame.  $S_c$  may be slightly lower than reported. It also appears, as discussed later in this report, that RW-6 was still developing and improving productivity during the test period.

Hantush-Bierschenk's method of analysis is applicable if the following assumptions and conditions are satisfied:

1. the aquifer is confined, leaky, or unconfined;
2. the aquifer has a seemingly infinite areal extent;
3. the aquifer is homogenous, isotropic, and of uniform thickness over the area influenced by the test;
4. prior to pumping, the potentiometric surface is horizontal (or nearly so) over the area that will be influenced by the test;
5. the aquifer is pumped step-wise at increased discharge rates;
6. the flow to the well is in an unsteady state; and
7. the non-linear well losses are appreciable and vary according to the expression  $CQ^2$ .

Application of the Hantush-Bierschenk method of analysis does not wholly satisfy all seven of the assumptions and conditions at Site 11. Most notably, items 3 and 7 are not satisfied because the surficial aquifer is neither homogeneous nor isotropic and, as discussed later in this report, non-linear well losses are not appreciable in RW-6.

The distance versus drawdown method of analysis to estimate  $E_w$  is applicable if the following assumptions and conditions are satisfied:

1. The aquifer is confined; leaky; or if unconfined, is not appreciably dewatered;
2. the aquifer has a seemingly infinite areal extent;
3. the aquifer is homogenous, isotropic, and of uniform thickness over the area influenced by the test;
4. prior to pumping, the potentiometric surface is horizontal (or nearly so) over the area that will be influenced by the test;
5. the well is fully developed;
6. the well fully penetrates the aquifer;
7. the aquifer is pumped at a constant discharge rate; and
8. the flow to the well is under quasi-steady-state conditions.

Application of this method of analysis does not wholly satisfy all eight of the assumptions and conditions. Specifically, items 3, 5, 6, 7, and 8 are not satisfied because the surficial aquifer is neither homogeneous or isotropic; the well may not have been fully developed; by design the well does not fully penetrate the surficial aquifer; the well was pumped at steadily increased steps; and steady-state conditions were not achieved due to the short term of the test (6 hours).

## RESULTS AND CONCLUSIONS

$S_c$  for RW-6 ranged from 2.63 gpm/ft to 2.65 gpm/ft during the three 100-minute pumping intervals. An estimate of 2.63 gpm/ft over the 6-hour test is provided herein as a baseline value; a value that can be used for future comparison of well productivity.

A substantial portion of the well losses in RW-6 can be attributed to laminar flow rather than turbulent flow. Because of these circumstances, part of the BQ term in Hantush-Bierschenk's equation includes well losses rather than only aquifer losses. Therefore, estimates of  $E_w$  by their method may be too high if the pumped well has little or negligible turbulent flow (Driscoll, 1986). Calculating  $E_w$  by Hantush-Bierschenk's method of analysis indicates a value of 96.8 percent for RW-6. This value should be considered too high because, as close analysis of the data indicates, 96.8 percent of the well loss is due to laminar flow; a very small portion, 3.2 percent, is due to non-linear flow.

The most representative estimates of  $E_w$  are considered to be from analysis of the distance versus drawdown plot of wells KBA-11-10B, KBA-11-13A, PS-3, and PS-5. The relationship of theoretical drawdown, obtained from the projection of the drawdown "curve," compared to an actual drawdown in RW-6 provides an  $E_w$  of 71.3 percent over the 6-hour pumping period.

### Conclusions

The amount of drawdown required to produce a particular flow rate is controlled by (1) the aquifer characteristics, (2) the well design (screen, filter pack, placement), (3) construction, and (4) development. Drawdown due to friction loss within the aquifer as water flows to a well is unavoidable;

however, substantial head losses sustained as water flows through the disturbed zone around the well (borehole skin, filter pack, and screen) are avoidable. They are caused by residual drilling fluid left in the formation, damage to the formation caused by drilling, a poorly designed filter pack, or use of a well screen with limited open area. Proper drilling and development methods and an effective design to (1) minimize disturbance or damages to the aquifer and (2) provide a suitable filter pack and screen inlet area can minimize head losses in the zone surrounding the well (Driscoll, 1986).

Recovery well RW-6 was designed using the same approach as the previous recovery wells by following established procedures presented in Driscoll, 1986. Conversely, because of suspected damage and/or residual bentonite clogging the formation surrounding the existing recovery wells RW-1 through RW-4, the drilling methodology was changed to cable tool for RW-6.

Clearly, based on a comparison of RW-6 well performance compared to the existing recovery wells (as noted in the ABB-ES well redevelopment report dated December 9, 1996), selection of the cable tool drilling method provides a much improved recovery well. Head losses are minimized; productivity, based on short-term  $S_c$ , is 2 1/2 to 5 times better; and efficiency is increased by approximately 3 to 7 fold.

If you have any questions or comments regarding this information or should you require any additional information, please contact us.

Sincerely,

ABB ENVIRONMENTAL SERVICES, INC.



Kurt D. Sichelstiel  
Engineering Geologist  
Technical Controller, ABB-ES

Attachments

pc: C. Leeth, USGS  
R. Bath, NSB

{08503-035-97}

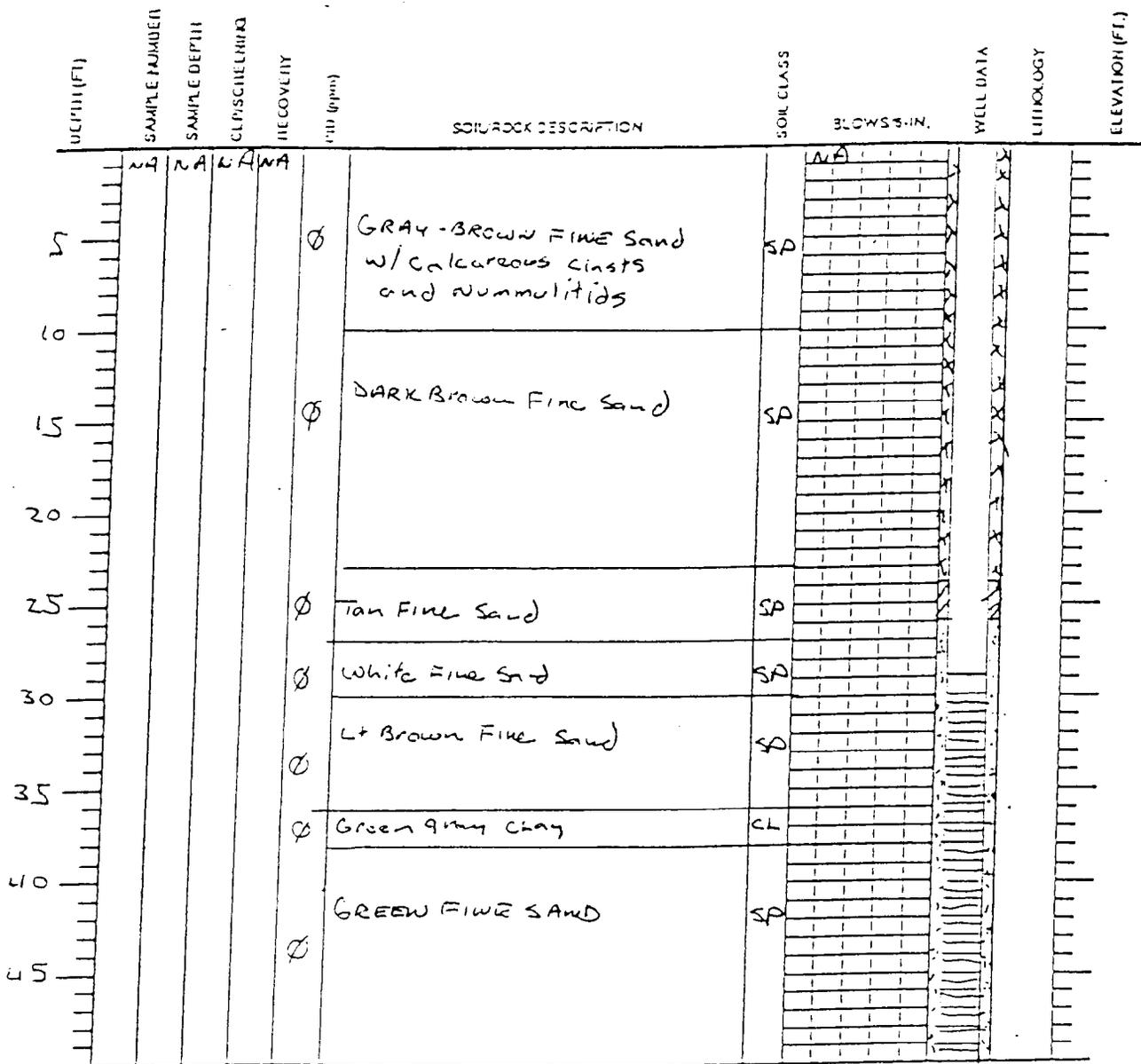
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ATTACHMENT A

FIELD LOGS  
AND AS-BUILT

# SOIL BORING LOG

Client: South DU		Project No. 08543.03	Point of Interest: Site 11
Contractor: AES		Date Started: 11-21-196	Boring No.: RW-6
Method: Cable Tool		Casing Size: 12"	Protection: D
Ground Elev.:		Soil Drilled: 75'	Completed: 11-25/96
Logged by: WDO		Checked by:	PI Meter: Porta FID
Screen: 40 (ft.)		Riser: 30 (ft.)	Diam: 6" (ID)
Material: SS		Page	of: 2
			Total Depth: 75'
			Below Ground: 6'



<b>PROPORTIONS</b>	<b>(-) AMOUNT (-)</b>	<b>ABBREVIATIONS</b>
Trace (T)	0-10%	f = fine
Little (L)	10-20%	m = medium
Some (S)	20-35%	c = coarse
and	25-50%	gr = gray
		br = brown
		bk = black
		MS = Split Spoon
		EW = Screened Auger
		HP = Hydropunch

# SOIL BORING LOG

Point of Interest: Site 11

Boring No.: RW6

Client: South DIV

Project No. 08543.03

Protection: D

Contractor: AES

Date Started: 11-21-96

Completed: 11-25-96

Method: Cable Tool

Casing Size: 12"

PI Meter: Porta FID

Ground Elev.:

Soil Drilled: 75'

Total Depth: 74'

Logged by: WDO

Checked by:

Below Ground: 6'

Screen: 40 (ft.)

Riser: 30 (ft.)

Diam: 6 (ID)

Material: SS

Page 2 of 2

DEPTH (FT)	SAMPLE NUMBER	SAMPLE DEPTH	CLAY/SILT/CHUNK	RECOVERY	PH (ppm)	SOIL/ROCK DESCRIPTION	SOIL CLASS	BLOWS-IN.	WELL DATA	LITHOLOGY	ELEVATION (FT)
55						GREEN FINE SAND	SD				
60						Green clay	CL				
65						Green clayey fine sand	SP/CL				
70											
75						BT @ 75'					

PROPORTIONS	(-) AMOUNT (-)	ABBREVIATIONS
Trace (%)	0-10%	f - fine      gr - gray      MS - Split Spoon
Lite (10)	10-20%	m - medium    br - brown      BW - Screened Auger
Some (30)	20-35%	c - coarse      blk - black      HP - Hydropunch
and	35-50%	

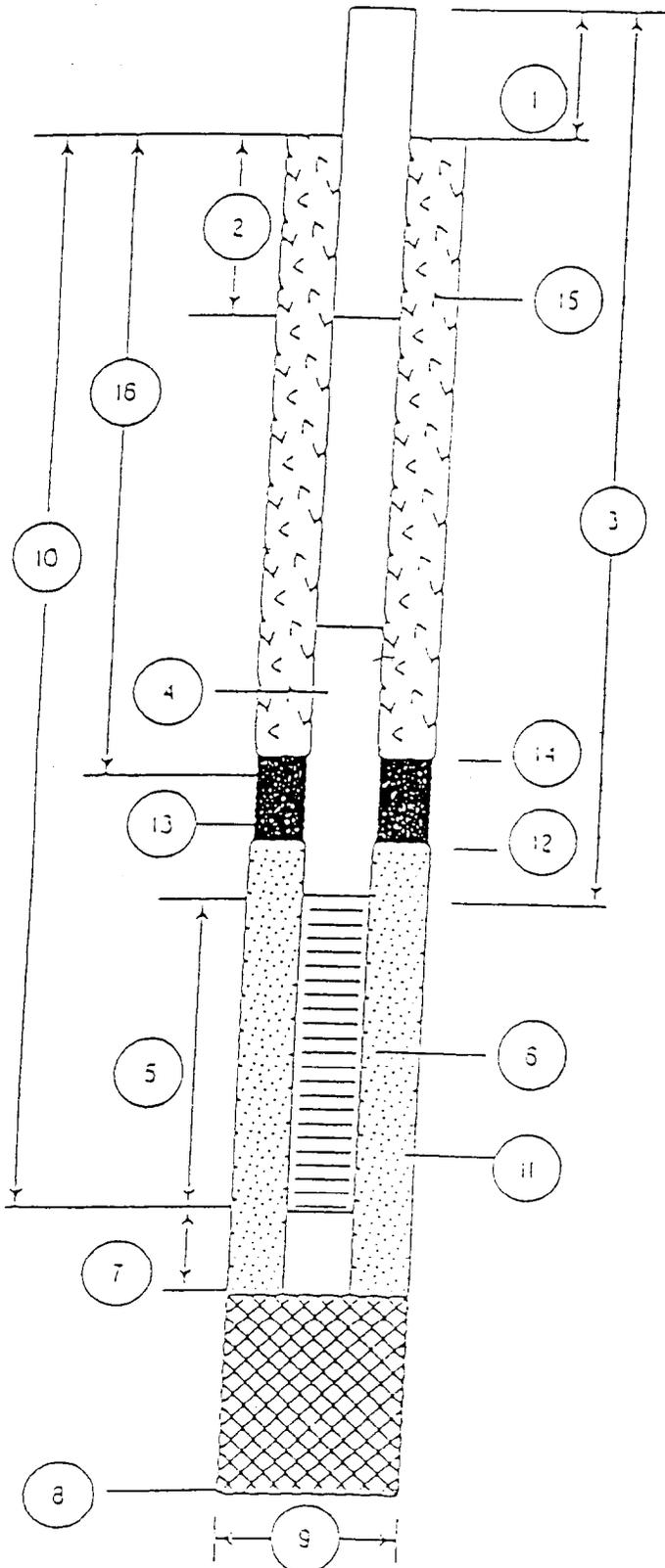
DEPARTMENT OF THE NAVY

WELL CONSTRUCTION DETAIL

SOUTHERN DIVISION  
 NAVAL FACILITIES ENGINEERING COMMAND  
 CHARLESTON, SC.

WELL NUMBER: RW-6

DATE OF INSTALLATION: 11-24/76



1. Height of Casing above ground: 1'2"

2. Depth to first Coupling:     

Coupling Interval Depths: 10

3. Total Length of Riser Pipe: 30

4. Type of Riser Pipe: 6" SS

5. Length of Screens: 40

6. Type of Screen: 0.30 slot 6" SS

7. Length of Sump: 5

8. Total Depth of Boring: 75

9. Diameter of Boring: 12"

10. Depth to Bottom of Screen: 69'

11. Type of Screen Filter: Silica sand

Quantity Used: 2900 lb

Size: 6/20

12. Depth to Top of Filter: 26

13. Type of Seal: Bentonite chips

Quantity Used: 100 lb

14. Depth to Top of Seal: 24'

15. Type of Grout: Portland cement

Grout Mixture: 800 lb cement / 16 lb bentonite  
Legal Potable water

Method of Placement: tremie

16. Tot. Depth of 6 in. Steel Casing: NA

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**ATTACHMENT B**

**TABLES**

**Table 1: Selected Monitoring Wells and Piezometers**

**Table 2: Specific Capacity Results**

**Table 3: Distance Drawdown Data**

**Table 1**  
**Selected Monitoring Wells and Piezometers**

Site 11, IM Phase II Upgrade Activities  
RW-6 Step Drawdown Test: Selected Monitoring Wells  
Naval Submarine Base  
Kings Bay, Georgia

Well	Position Relative to RW-6		Representing Aquifer	Screen	
	Distance (feet)	Orientation		Depth (bls)	Elevation (mlw)
KBA-11-13A	90	North	Intermediate	30.5 to 40.5	1.7 to -8.3
KBA-11-13B	130	North	Deep	78.0 to 88.0	-45.8 to -55.8
KBA-11-2	230	South	Shallow	2.8 to 12.8	30.3 to 20.3
PS-3	236	South	Intermediate	30.7 to 34.7	3.0 to -2.0
KBA-11-10A	286	Southeast	Shallow	9.8 to 19.8	25.3 to 15.3
KBA-11-10B	274	Southeast	Intermediate	39.2 to 49.2	-3.7 to -13.7
KBA-11-10C	296	Southeast	Deep	77.3 to 87.3	-41.7 to -51.7
PS-5	286	North-northeast	Intermediate	31.0 to 35.0	4.2 to -0.8
PD-6	118	North	Deep	61.7 to 65.7	-27.7 to -32.7
RW-6	0	---	Intermediate/Deep	29.0 to 69.0	4.8 to -35.2

Notes: IM = interim measure.  
bls = below land surface.  
msl = mean low water.  
--- = no data.

**Table 2**  
**Specific Capacity Results**

Site 11, IM Phase II Upgrade Activities  
RW-6 Step Drawdown Test: Specific Capacity Results  
Naval Submarine Base  
Kings Bay, Georgia

Step No.	Q <sub>n</sub> (gpm)	Drawdown (feet)	S <sub>e</sub> (gpm/ft)
1	9.29	3.53	2.63
2	19.05	7.20	2.65
3	31.33	12.04	2.64
3 +	31.33	12.11	2.63

Notes: IM = interim measure.  
Q<sub>n</sub> = flow rate  
gpm = gallons per minute.  
S<sub>e</sub> = specific capacity.  
gpm/ft = gallons per minute per foot.  
+ = additional 50 minutes of pumping beyond Step No. 3.

**Table 3**  
**Distance Drawdown Data**

Site 11, IM Phase II Upgrade Activities  
RW-6 Step Drawdown Test  
Naval Submarine Base  
Kings Bay, Georgia

Well Name	Distance	Drawdown	Drawdown Step 1	Drawdown Step 2	Drawdown Step 3
PS-5	286	0.67	0.15	0.35	0.63
PD-6	118	1.31	0.2	0.57	1.16
KBA-11-13A	90	2.14	0.59	1.2	2.09
KBA-11-13B	130	0.17	0	0.03	0.13
KBA-11-10A	286	0.02	0.02	0	0.02
KBA-11-10B	274	0.78	0.16	0.39	0.7
KBA-11-10C	296	0.14	-0.01	0.03	0.1
KBA-11-2	230	0	-0.01	0	-0.03
PS-3	236	0.92	0.2	0.15	0.86

All results are in feet.

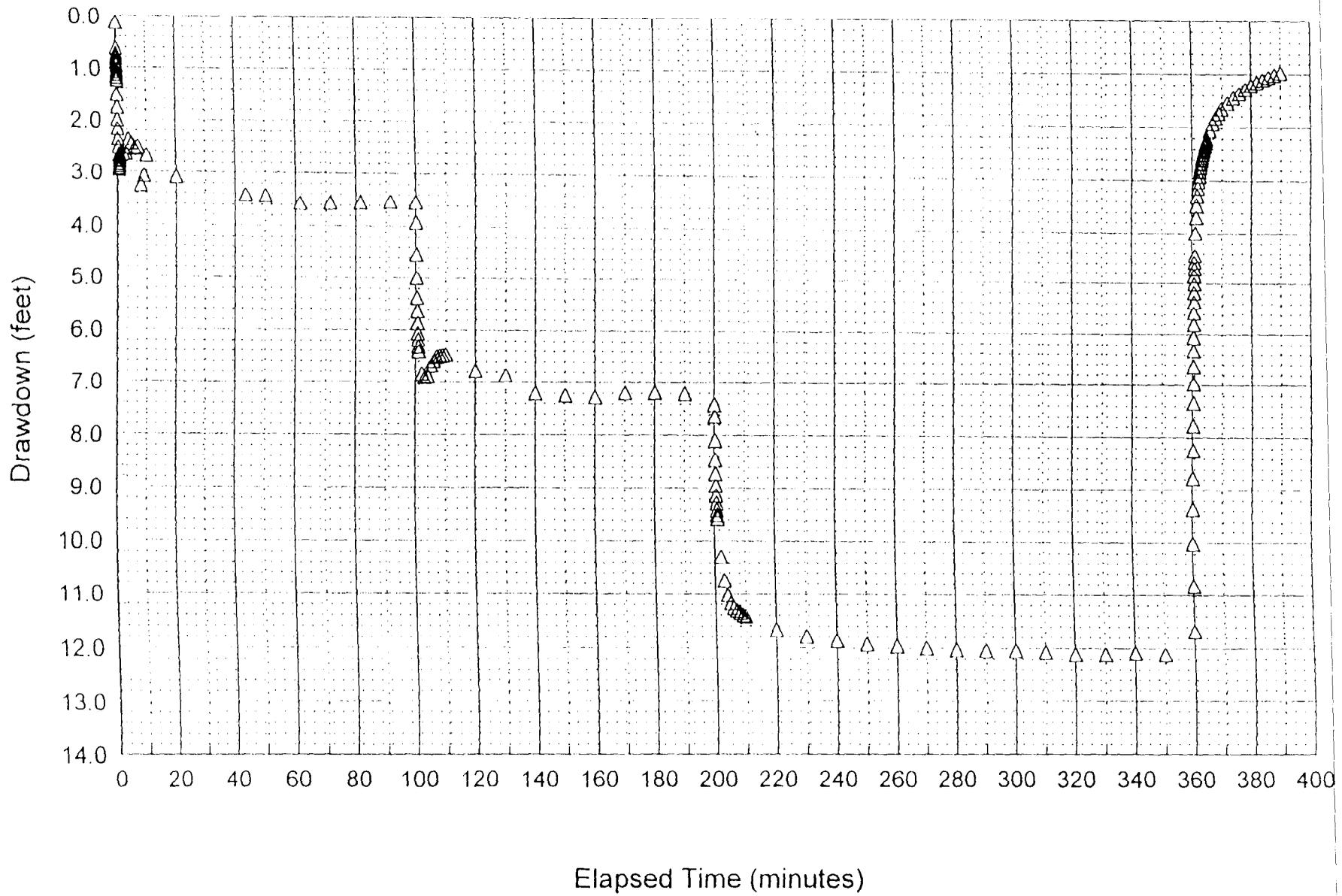
Note: IM = interim measure.

## ATTACHMENT C

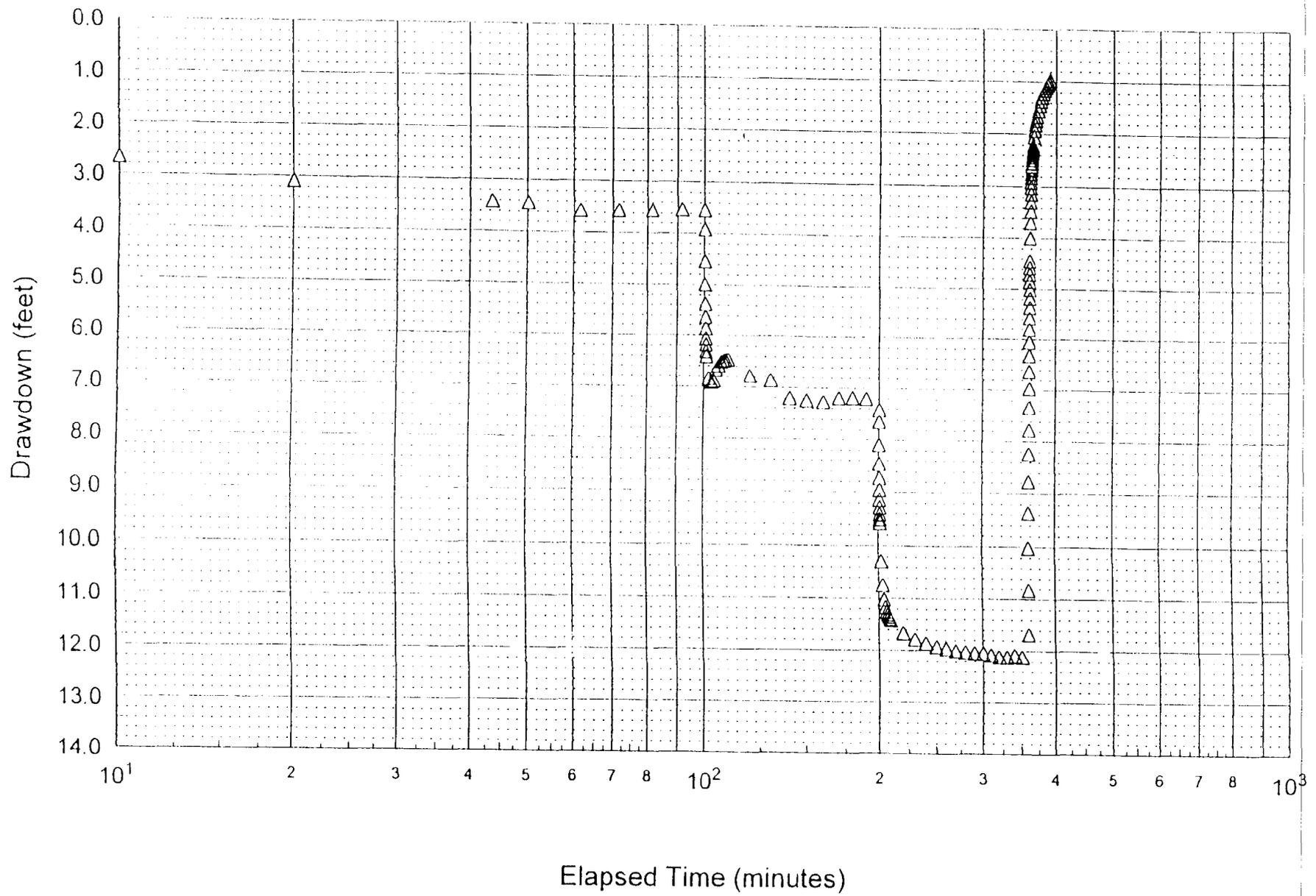
### GRAPHICAL ANALYSES

- Hantush-Bierschenk Analysis Plot
  - Arithmetic Scale, Time Versus Drawdown
  - Semilog, Time Versus Drawdown Plots
  - Arithmetic Scale, Flow Versus Drawdown/Flow Plots
- Distance Versus Drawdown Plots for  $E_w$  Estimate

NSB Kings Bay, Site 11: IM Phase II Upgrade Activities  
RW6 Step Drawdown Test

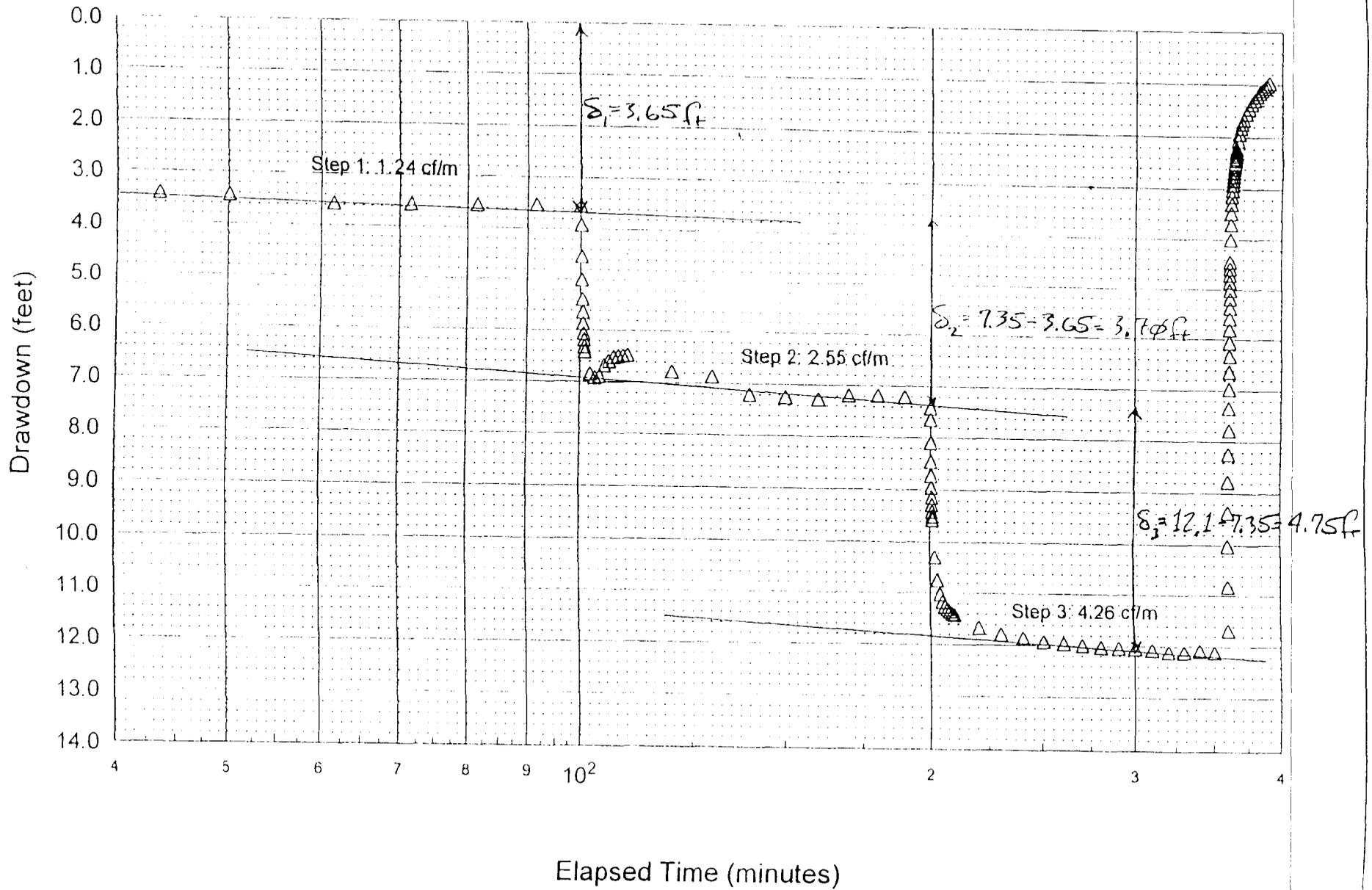


NSB Kings Bay, Site 11: IM Phase II Upgrade Activities  
RW6 Step Drawdown Test



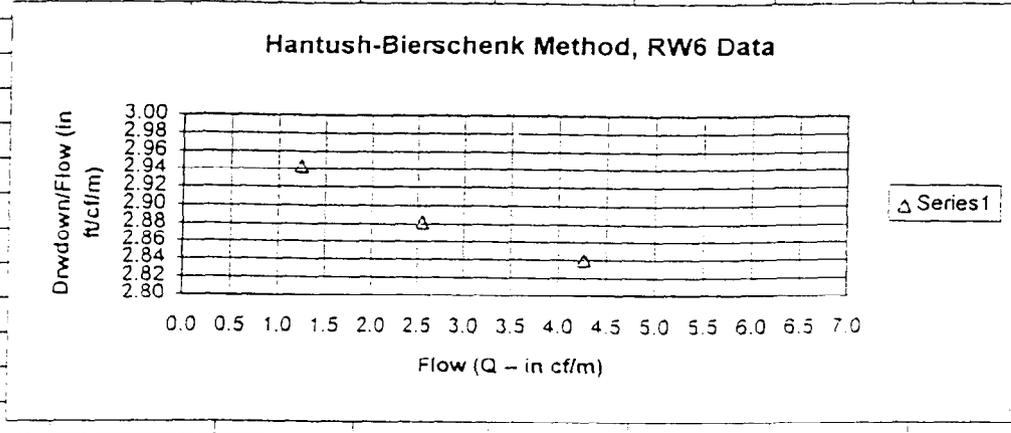
# NSB Kings Bay, Site 11: IM Phase II Upgrade Activities

## RW6 Step Drawdown Test



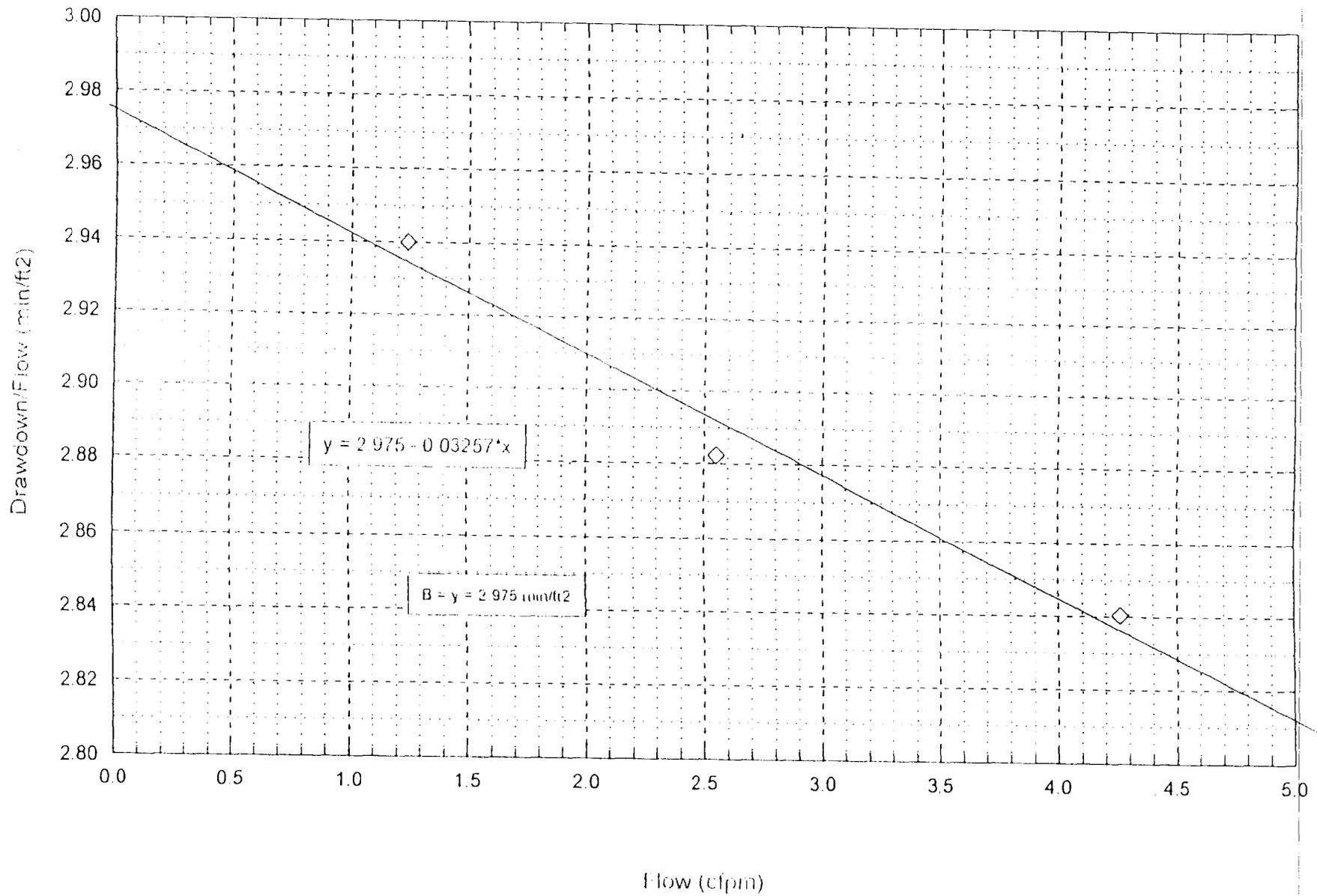
NSB Kings Bay, Site 11  
IM Phase II Upgrade Activities

Step_Number	delta_ddw(n)	ddw(n)	Qn	ddw(n)/Qn
Step 1	3.65	3.65	1.24	2.94
Step 2	3.70	7.35	2.55	2.88
Step 3	4.75	12.10	4.26	2.84



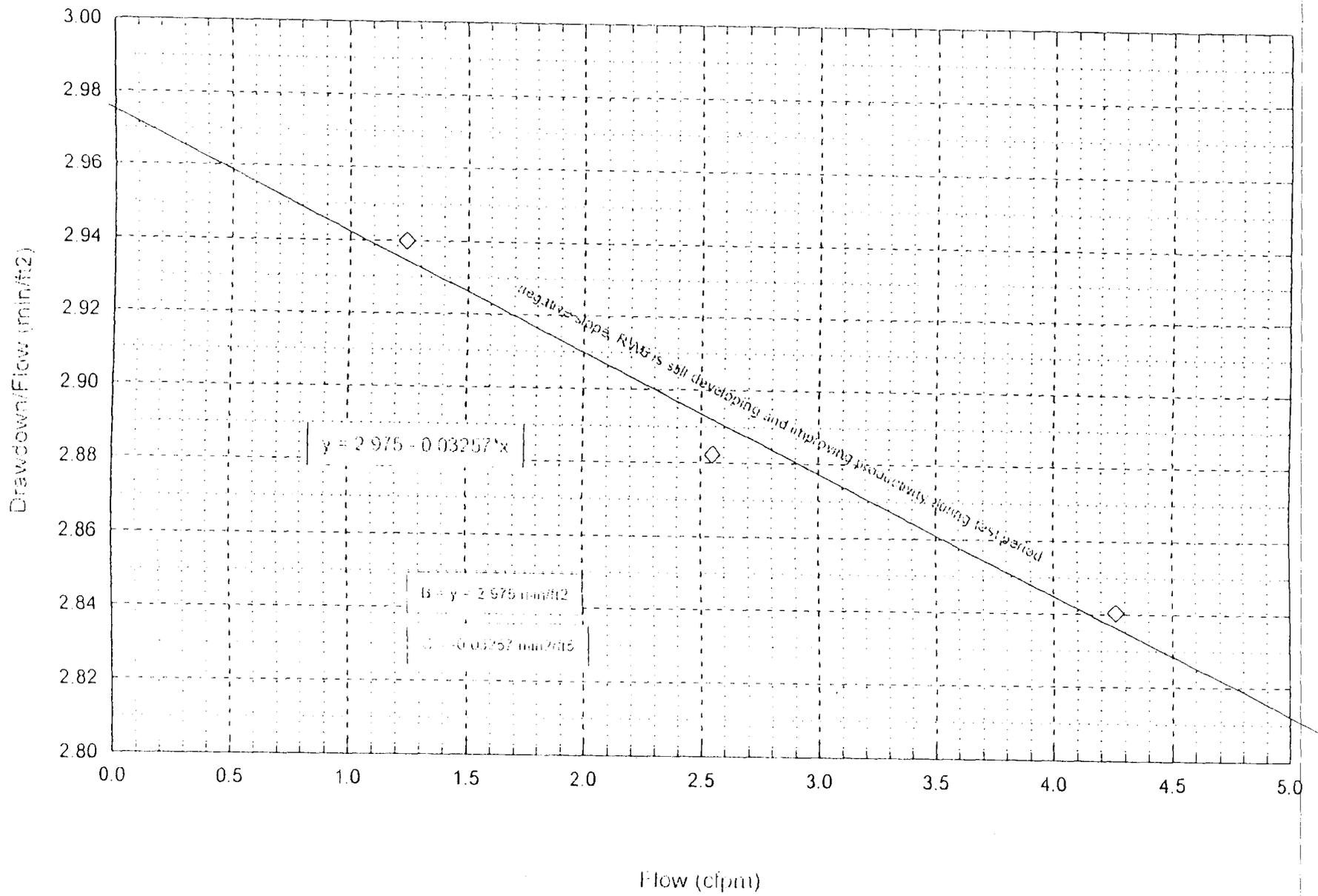
# NSB Kings Bay, Site 11: IM Phase II Upgrade Activities

## Hantush-Bierschenk Method of Analysis



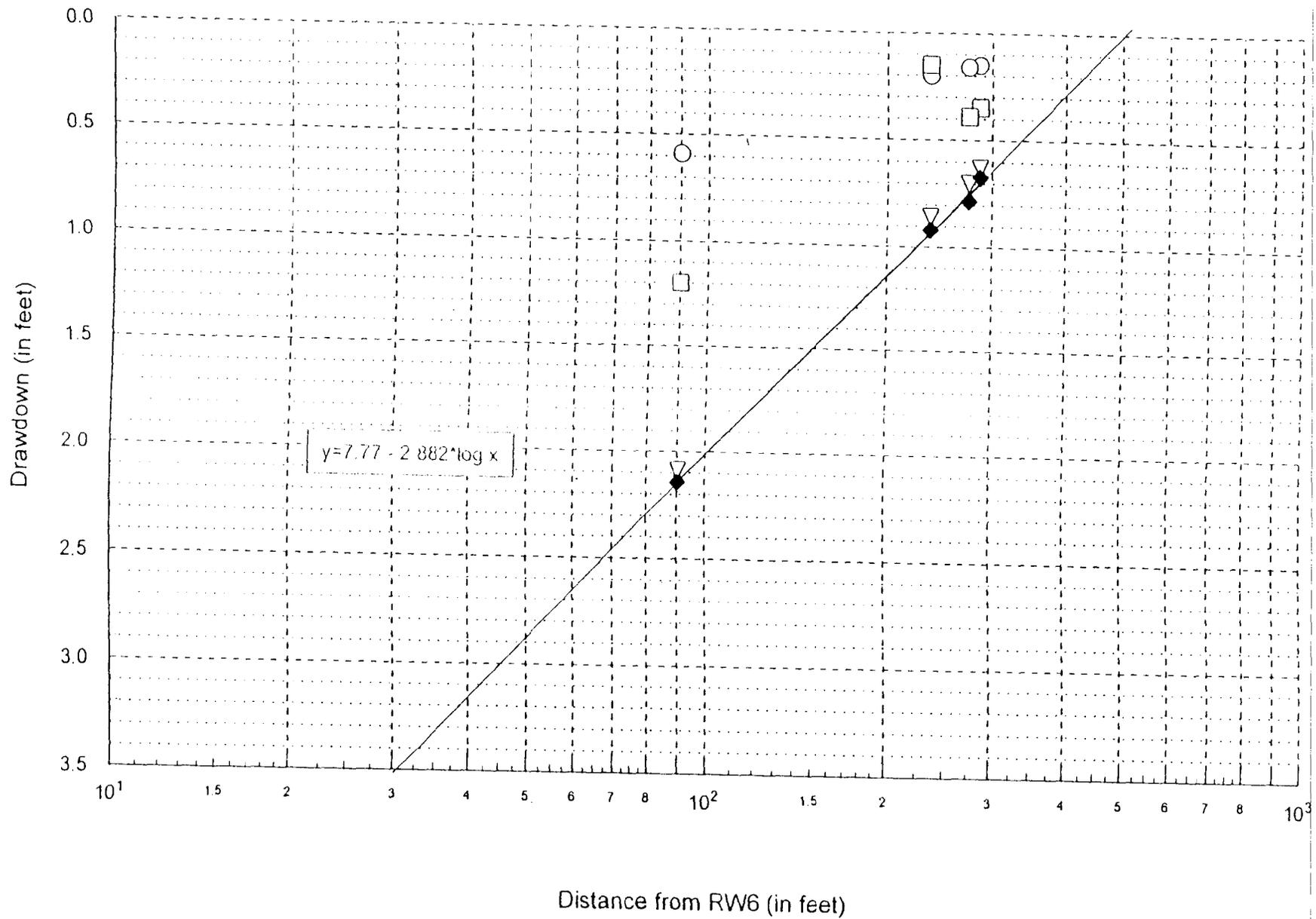
# NSB Kings Bay, Site 11: IM Phase II Upgrade Activities

## Hantush-Bierschenk Method of Analysis



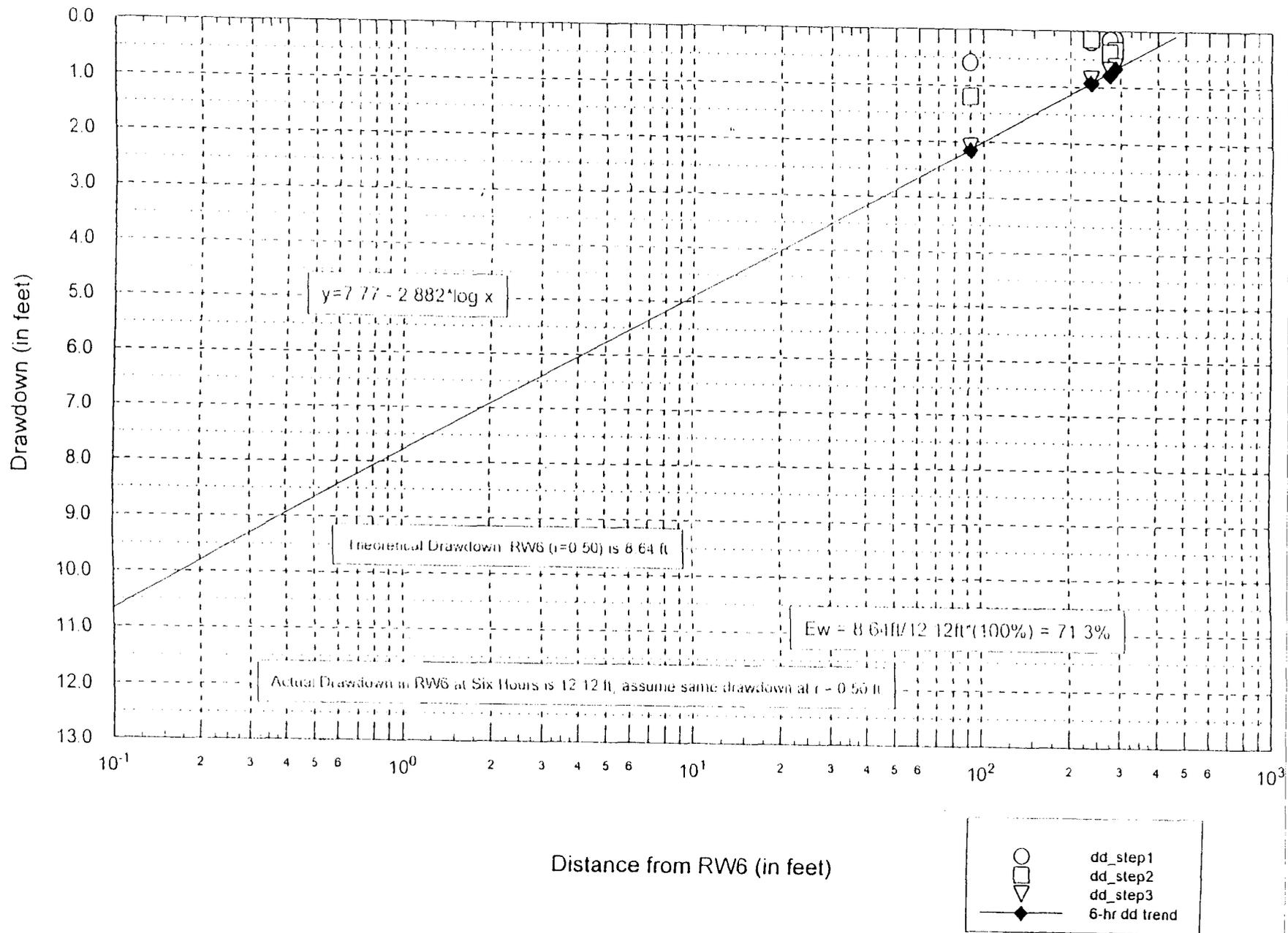
# NSB Kings Bay, Site 11:IM Phase II Upgrade Activities

## RW6 Step Drawdown Test: All Data



# NSB Kings Bay, Site 11:IM Phase II Upgrade Activities

## RW6 Step Drawdown Test: All Data





December 09, 1996

Southern Division  
Naval Facilities Engineering Command  
ATTN. Mr. Anthony Robinson  
2155 Eagle Drive  
North Charleston, SC 29418

Dear Anthony:

**SUBJECT:** Interim Measure (IM) System Phase II: Upgrades  
Existing Recovery Well Redevelopment  
Site 11, Old Camden County Landfill  
Naval Submarine Base  
Kings Bay, Georgia

### INTRODUCTION

ABB Environmental Services, Inc. (ABB-ES), is pleased to present this letter report regarding the redevelopment of four groundwater recovery wells (RW-1, RW-2, RW-3, and RW-4). These four recovery wells are part of the IM groundwater extraction and treatment system at Site 11, Old Camden County Landfill, at the Naval Submarine Base, Kings Bay, Georgia. The work performed and described herein is a part of the IM System Phase II activities. The work was performed under contract to the U.S. Department of the Navy, Southern Division, Naval Facilities Engineering Command within the Comprehensive Long-term Environmental Action, Navy (CLEAN) program, Contract No. N62467-89-D-0317, Contract Task Order No. 94.

The purpose of the redevelopment of the four existing groundwater recovery wells was to enhance the well efficiencies and increase their specific capacities. An increase in specific capacity would enhance overall system performance by decreasing cycling of the well pumps.

### FIELD ACTIVITIES SUMMARY

Field activities associated with redevelopment of the existing recovery wells were conducted from November 11, 1996, through November 22, 1996. The field activities comprised six separate tasks, (1) initial well performance tests, (2) removal and cleaning of pumps, (3) redevelopment of the wells, (4) disposal of groundwater and sediment, (5) reinstalling the pumps, and (6) well performance tests after redevelopment. These field activities were performed under the Supplemental RFI Health and Safety Plan (ABB-ES, 1994). The work was performed in Level D personal protective equipment.

### DATA AND OBSERVATIONS

Data and observations regarding well performance before and after redevelopment are presented in the following subsections.

#### Specific Capacity Tests

Specific capacity tests were performed on each well to establish a baseline for measuring improvement. The submersible pumps in the wells were shut off and the water levels in the wells were allowed to stabilize for a minimum of approximately 4 hours. Each well was then pumped for 60 minutes at

ABB Environmental Services Inc.

pumping rates between 8 and 9 gallons per minute. Water levels in the recovery wells were measured prior to and after 1 hour of pumping. The drawdowns in response to pumping were measured and used with the pumping rate to calculate the specific capacity of each well. The results of the initial specific capacity tests are presented in Table 1 in Attachment A.

After redevelopment specific capacity tests were performed again on each well to measure improvement in well performance. These tests were performed in the same manner as the initial tests. All wells show measurable improvement in specific capacity after redevelopment. The relative improvements range from 16 percent for RW-1 to 47 percent for RW-3. The results are presented in Table 2 in Attachment A.

#### Distance-Drawdown Data and Estimated Well Efficiencies.

The specific capacity tests performed after redevelopment were extended to provide distance-drawdown data and 6-hour specific capacities. Aquifer drawdown produced by pumping the recovery wells individually was measured in selected observation wells. The distance-drawdown data for these 6-hour tests is presented in Table 3 in Attachment A. The distance-drawdown data were used to construct plots of drawdown versus log distance on semi-log paper for each recovery well. The plots were used to estimate present well efficiencies. Estimated well efficiencies from the 6-hour tests range from 11 percent for RW-4 to 28 percent for RW-2. The distance-drawdown plots are presented in Attachment B.

Additionally, distance-drawdown data for RW-1 and RW-2 were compiled from 1993 and 1994 Phase I system performance tests. Phase I distance-drawdown data for RW-1 and RW-2 are presented in Table 4 in Attachment A. The Phase I distance-drawdown data were used to construct plots of drawdown versus log distance on semi-log paper for RW-1 and RW-2. The distance-drawdown plots were used to estimate well efficiencies for these two wells as they were in 1993 and 1994. These two additional plots are presented in Attachment B. Phase I well efficiency estimates are compared with efficiency estimates after redevelopment in Table 5 presented in Attachment A. Both RW-1 and RW-2 show measurable improvement in estimated efficiencies and specific capacities since redevelopment. Estimated well efficiency for RW-1 improved from 12 to 13 percent. Estimated well efficiency for RW-2 improved from 21 to 28 percent. No analogous single-well pumping data is available for RW-3 or RW-4 from Phase I IM system evaluation.

### REDEVELOPMENT

The following subsections describe procedures used and observations made during redevelopment.

#### Treatment with Unacid™ Products.

Following pump removal the wells were treated with Unacid™ liquid catalyst and Unacid™ granular acid according to the manufacturer's suggested application rates. Treatment with Unacid™ granular acid was performed to dissolve any mineral scale buildup in the well screens. Treatment with Unacid™ liquid catalyst was performed to attack biological growth suspected to be present in the wells and aid in the removal of any residual bentonite drilling mud from the aquifer material and filter pack. The Unacid™ treatment products were added gradually to the wells and mixed from top to bottom as the swab and surge rods were tripped into the wells. All down-hole tools were steam-cleaned between wells at the Site 11 decontamination facility.

Prior to treatment, the pH of groundwater from the upper portion of the wells was measured with pH paper. The initial pH ranged from 5 to 7. These measurements agreed with historical total IM system influent pH measurements of approximately 5.5. After treatment, the pH of groundwater in each well was again measured and found to be 1 or less. The pH of 1 persisted in each well for the specified minimum of at least 24 hours; after 48 hours, the pH was 3. The treatment of the wells is summarized in Table 6 in Attachment A.

### Surging.

Following treatment the wells were developed by surging to suspend fines and move the Unacid™ treatment products into the filter pack and adjacent aquifer material. Surging was performed with a 5-foot-long swab equipped to also surge with compressed air. The surge rods were 10-foot-long sections of threaded 2-inch steel pipe and the surge assembly was operated with the subcontractor's Smeal A58 workover rig. Each well was surged at approximately 3 feet per second in the well screen for approximately 3.5 hours. The workover rig and surge rod configuration allowed a 10- to 25-foot stroke of the swab. The well screens were also surged with compressed air through the surge rods and out of holes in the swab at approximately 55 pounds per square inch (psi).

### Pumping.

Following treatment and surging, the wells were then pumped to remove sediment from the sump and flush the filter pack. The wells were pumped with the subcontractor's Wüden M-15 air-driven dual-diaphragm pump operated at 100 psi. The pump was connected by rubber hose and cam-lock fittings to the open surge rods which also served as the pump intake. The wells were pumped from the bottom to minimize disturbance to the filter pack, avoid intake of the fine gray sand aquifer material through the filter pack, and remove sediment from the well sump. Although the pump's diaphragm chambers and ball-valve seats occasionally clogged with sand during early pumping, the pump was easily disassembled and rinsed out and quickly pressed back into service.

The pump proved very effective in removing sediment from the well sumps and flushing the filter packs. The sediment was fine gray sand (aquifer material) with trace medium tan sand (filter pack) and trace gray fines (silt, clay, and possibly bentonite). Final groundwater effluent after approximately 25 well volumes were removed was sand-free and contained no observable fines. The pH of groundwater pumped from the wells and retrieved from the wells with a bailer was monitored with pH paper. Final pH measurements were made with a calibrated meter. Total depths, pumping rates, and total gallons of water removed were measured during pumping. All down-hole tools were steam-cleaned between wells at the Site 11 decontamination facility. The surging and pumping of the wells is summarized in Table 7 in Attachment A.

### DISPOSAL OF GROUNDWATER AND SEDIMENT

Development water and sediment was pumped directly from each recovery well into two poly tanks (a 325-gallon tank and a 200-gallon tank) and transferred to a 5,000-gallon plastic-lined roll-off container with a trash pump. In the roll-off container, sediment was allowed to settle out and the pH of the development groundwater was buffered to pH 6 with Unacid™ pH Neutralize. The development water was then pumped into the IM system for treatment.

Approximately 34 gallons of sediment remaining in the roll-off was shoveled into a single Department of Transportation-approved 55-gallon steel drum provided by the base. The drum was removed from Site 11 by Base Operations Systems personnel. The contents will be added to drill cuttings from the installation of RW-6 and characterized for final disposal.

### SUBMERSIBLE PUMPS

After the initial well tests, and prior to treatment with Unacid™ products, the submersible pumps were removed from the wells and stored on plastic at the decontamination area. The pumps were later steam-cleaned, treated with Unacid™ liquid catalyst to enhance removal of slime and biological growth, steam-cleaned a second time, and wrapped in plastic until reinstallation. Visual inspection of the pumps, hoses, water level sensors, and sanitary well seals after cleaning revealed no obvious defects.

Following redevelopment, the cleaned pumps were reinstalled into the wells and all connections restored. The hose lengths below the sanitary well seals were measured to verify that the pumps were set at mid-sump. The low-pumping-level sensors, which stop the pumps, were positioned to 1.5 feet above the top of the well screens. This should prevent drawdowns in the wells below the top of the screens, which causes biological fouling from oxygenation.

### CONCLUSIONS

While redevelopment did not increase specific capacities as much as anticipated for this type of aquifer, all recovery wells showed measurable improvement in well performance afterward. Specific capacities (1-hour test data) improved from 0.58 to 0.67 for RW-1, 0.81 to 1.0 for RW-2, 0.66 to 0.97 for RW-3, and 0.46 to 0.64 for RW-4. Specific capacities and well efficiencies estimated from Phase II 6-hour distance-drawdown plots for RW-1 and RW-2 show measurable improvement over analogous 1993-1994 Phase I data for these wells. Specific capacities (6-hour test data) improved from 0.52 to 0.64 for RW-1 and 0.72 to 1.0 for RW-2. Estimated well efficiencies improved from 12 to 13 percent for RW-1 and from 21 to 28 percent for RW-2. No analogous single-well pumping data is available for RW-3 or RW-4 from Phase I operations. However, well efficiency data for RW-3 and RW-4 has been established for any future comparisons.

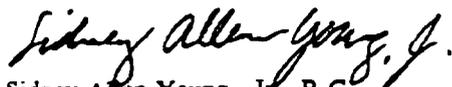
### RECOMMENDATIONS

Well performance data should be compiled monthly on each recovery well presently in operation as well as any recovery wells installed and brought on line in the future. It is recommended that these specific capacities be accepted as performance standards for these four recovery wells. Should specific capacities decline below 25 percent of their present values, the wells should be redeveloped. Future redevelopment activities should be focused on treating encrustation and biofouling in the well screens and filter pack. These redevelopment operations should follow the six tasks and general procedures outlined in this letter report.

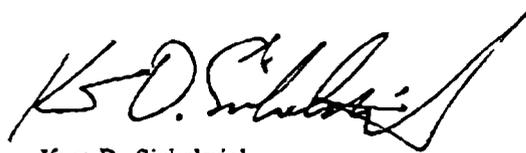
If you have any questions or comments regarding this information or should you require any additional information, please contact us.

Sincerely,

ABB Environmental Services, Inc.



Sidney Allen Young, Jr. R.G.  
Tennessee Geologist No. 3776



Kurt D. Sichelstiel  
Technical Controller

Attachment

cc: Rhonda Bath, Naval Weapons Station, Kings Bay, Georgia

05/12/97

11:49

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ABB ENV SERVICES →→→ RHONDA BATH

PW ☑ 006/020

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**ATTACHMENT A**

**TABLES**

**Table 1**  
**Existing Recovery Well Construction Data and Initial Short-Term Specific Capacities**

IM System Phase II: Upgrades  
 Existing Recovery Well Redevelopment  
 Site 11, Old Camden County Landfill  
 Naval Submarine Base  
 Kings Bay, Georgia

Recovery Well <sup>1</sup>	Total Depth <sup>2</sup> (Feet btoc)	Screen (Feet btoc)	Screen Length	Depth to Water <sup>3</sup> (Feet btop)	Q (gpm)	s (Feet)	Q/s
RW-1	65.4	20.0 to 80.0	40 feet	6.00	9.0	15.80	0.58
RW-2	75.4	20.0 to 70.0	50 feet	3.84	8.0	9.87	0.81
RW-3	75.4	20.0 to 70.0	50 feet	2.40	8.0	12.10	0.66
RW-4	70.4	25.0 to 85.0	40 feet	3.84	8.4	18.16	0.46

<sup>1</sup> All are 0.030-inch continuous slot, 6-inch inside diameter stainless steel, set in 12-inch borehole with filter pack.

<sup>2</sup> As constructed.

<sup>3</sup> Initial depth to water measured prior to pumping.

Notes:

btoc = below top of casing.

btop = below top of one-inch piezometer set in filter pack.

Q = Pumping rate during well test. RW-1 and RW-2 tested 11/11/96; RW-3 and RW-4 tested 11/12/96.

s = Drawdown in recovery well filter pack; measured in one-inch piezometer after 60 minutes of pumping.

Q/s = Specific capacity; measured after 60 minutes of pumping at constant rate (Q).

**Table 2**  
**Short-Term Specific Capacities Before and After Redevelopment**

IM System Phase II: Upgrades  
 Existing Recovery Well Redevelopment  
 Site 11, Old Camden County Landfill  
 Naval Submarine Base  
 Kings Bay, Georgia

Recovery Well <sup>1</sup>	Depth to Water <sup>2</sup> (Feet btop)	Q (gpm)	s (Feet)	Q/s After	Q/s Before	Percent Improvement
RW-1	5.69	8.1	12.01	0.67	0.58	16
RW-2	3.98	9.1	8.80	1.0	0.81	23
RW-3	2.49	9.4	9.74	0.97	0.66	47
RW-4	3.68	8.2	12.90	0.64	0.46	39

<sup>1</sup> All are 0.030-inch continuous slot, 6-inch inside diameter stainless steel, set in 12-inch borehole with filter pack.

<sup>2</sup> Initial depth to water measured prior to pumping.

Notes:

btop = below top of casing.

btop = below top of one-inch piezometer set in filter pack.

Q = Pumping rate during well test. RW-1 retested 11/20/96. RW-2 and RW-4 retested 11/21/96. RW-3 retested 11/22/96.

s = Drawdown in recovery well filter pack; measured in one-inch piezometer after 60 minutes of pumping.

Q/s = Specific capacity; measured after 60 minutes of pumping at constant rate (Q).

**Table 3**  
**Distance-drawdown Raw Data After Redevelopment**

IM System Phase II: Upgrades  
Existing Recovery Well Redevelopment  
Site 11, Old Camden County Landfill  
Naval Submarine Base  
Kings Bay, Georgia

		TOC Elevation (feet mlw)	Screen Interval (feet mlw)	r (feet)	s (feet)	Q (gpm)	t (min.)	Estimated Efficiency <sup>1</sup>	Q/s
Pumped Well	RW-1	32.47	12.47 to -27.53	—	12.67	8.1	375	13%	0.64
Observation	PS-1	33.02	3.02 to -1.98	14	0.92	—	—	—	—
Wells	PS-2	33.59	-0.06 to -5.08	83	0.48	—	—	—	—
	PS-3	34.49	3.04 to -1.97	64	0.51	—	—	—	—
	KBA-11-13A	34.20	1.70 to -8.30	399	0.11	—	—	—	—
Pumped Well	RW-2	30.49	10.49 to -39.51	—	8.91	9.1	364	28%	1.0
Observation	PS-5	33.37	4.15 to -0.85	62	0.72	—	—	—	—
Wells	KBA-11-13A	34.20	1.70 to -8.30	130	0.46	—	—	—	—
	KBA-11-3B	33.49	-4.61 to -14.61	278	0.15	—	—	—	—
Pumped Well	RW-3	27.70	7.70 to -42.40	—	10.51	9.4	315	26%	0.89
Observation	PS-9	28.72	1.27 to -3.73	31	1.06	—	—	—	—
Wells	PD-8	28.53	-17.97 to -22.97	44	0.96	—	—	—	—
	PS-7	28.20	6.20 to 1.20	98	0.57	—	—	—	—
	PS-10	30.54	4.54 to -0.46	226	0.25	—	—	—	—
	RW-4	28.89	3.89 to -36.11	287	0.16	—	—	—	—
Pumped Well	RW-4	28.89	3.89 to -36.11	—	13.72	8.2	352	11%	0.60
Observation	PS-10	30.54	4.54 to -0.46	62	0.46	—	—	—	—
Wells	PS-2	33.59	-0.06 to -5.08	181	0.20	—	—	—	—
	PS-9	28.72	1.27 to -3.73	318	0.13	—	—	—	—
	PD-8	28.53	-17.97 to -22.97	331	0.11	—	—	—	—
	PS-7	28.20	6.20 to 1.20	385	0.07	—	—	—	—

<sup>1</sup> Estimated from distance-drawdown plot.

Notes:

TOC = top of casing

mlw = mean low water

r = distance from center of pumped well.

s = drawdown

Q = Pumping rate during test. RW-1 tested 11/20/96. RW-2 and RW-4 tested 11/21/96. RW-3 tested 11/22/96.

t = total elapsed time of test.

Q/s = Specific capacity; measured after t minutes of pumping at rate Q.

**Table 4**  
**Distance-drawdown Raw Data for RW-1 and RW-2: IM System Phase I 1993-1994**

IM System Phase II: Upgrades  
 Existing Recovery Well Redevelopment  
 Site 11, Old Camden County Landfill  
 Naval Submarine Base  
 Kings Bay, Georgia

		TOC Elevation (feet mlw)	Screen Interval (feet mlw)	r (feet)	s (feet)	Q (gpm)	t (min.)	Estimated Efficiency <sup>1</sup>	Q/s
Pumped Well	RW-1	32.47	12.47 to -27.53	---	12.48	6.5	1501	12%	0.52
Observation	PS-1	33.02	3.02 to -1.98	14	0.80	---	---	---	---
Wells	PS-2	33.59	-0.06 to -5.08	63	0.51	---	---	---	---
	PS-3	34.49	3.04 to -1.97	64	0.49	---	---	---	---
Pumped Well	RW-2	30.49	10.49 to -39.51	---	14.12	10.2	360	21%	0.72
Observation	PS-5	33.37	4.15 to -0.85	62	0.84	---	---	---	---
Wells	KBA-11-3B	33.49	-4.61 to -14.61	278	0.19	---	---	---	---

<sup>1</sup> Estimated from distance-drawdown plot.

Notes:

- TOC = top of casing
- mlw = mean low water
- r = distance from center of pumped well.
- s = drawdown.
- Q = Pumping rate during well test. RW-1 tested 10/25-26/93. RW-2 tested 03/23/94.
- t = total elapsed time of aquifer test.
- Q/s = Specific capacity; measured after t minutes of pumping at rate Q.

**Table 5**  
**Phase I and Phase II Specific Capacities and Well Efficiencies: RW-1 and RW-2**

IM System Phase II: Upgrades  
 Existing Recovery Well Redevelopment  
 Site 11, Old Camden County Landfill  
 Naval Submarine Base  
 Kings Bay, Georgia

Recovery Well <sup>1</sup>	Phase I <sup>2</sup>		Phase II <sup>3</sup>	
	Q/s	Estimated Well Efficiency <sup>4</sup>	Q/s	Estimated Well Efficiency <sup>4</sup>
RW-1	0.52	12%	0.64	13%
RW-2	0.72	21%	1.0	28%

<sup>1</sup> All are 0.030-inch continuous slot, 6-inch inside diameter stainless steel, set in 12-inch borehole with filter pack.

<sup>2</sup> RW-1 was pumped at 6.5 gallons per minute (Q) for 25 hours on 10/25-26/93 with 12.48 feet of observed drawdown (s) at the end of the test. RW-2 was pumped for seven days from 03/23/94 through 03/29/94 at 10.2 gallons per minute (Q) with 14.12 feet of observed drawdown (s) after 360 minutes.

<sup>3</sup> RW-1 was pumped at 8.1 gallons per minute (Q) for 375 minutes on 11/20/96 with 12.67 feet of observed drawdown (s) at the end of the test. RW-2 was pumped for 364 minutes on 11/21/96 at 9.1 gallons per minute (Q) with 8.91 feet of observed drawdown (s) at the end of the test.

<sup>4</sup> Well efficiencies estimated from distance-drawdown plots.

**Table 5**  
**I and Phase II Specific Capacities and Well Efficiencies: RW-1 and RW-2**

IM System Phase II: Upgrades  
 Existing Recovery Well Redevelopment  
 Site 11, Old Camden County Landfill  
 Naval Submarine Base  
 Kings Bay, Georgia

	Phase I <sup>2</sup>		Phase II <sup>3</sup>	
	Q/s	Estimated Well Efficiency <sup>4</sup>	Q/s	Estimated Well Efficiency <sup>4</sup>
	0.52	12%	0.64	13%
	0.72	21%	1.0	28%

4-inch continuous slot, 6-inch inside diameter stainless steel, set in 12-inch borehole with filter

pumped at 6.5 gallons per minute (Q) for 25 hours on 10/25-26/93 with 12.48 feet of observed drawdown (s) at the end of the test. RW-2 was pumped for seven days from 03/23/94 through 03/29/94 at 14.12 gallons per minute (Q) with 14.12 feet of observed drawdown (s) after 360 minutes.

RW-1 was pumped at 8.1 gallons per minute (Q) for 375 minutes on 11/20/96 with 12.67 feet of observed drawdown (s) at the end of the test. RW-2 was pumped for 364 minutes on 11/21/96 at 9.1 gallons per minute (Q) with 9.91 feet of observed drawdown (s) at the end of the test.

Well efficiencies estimated from distance-drawdown plots.

**Table 6**  
**Unicid™ Products Treatment Summary**

IM System Phase II: Upgrades  
Existing Recovery Well Redevelopment  
Site 11, Old Camden County Landfill  
Naval Submarine Base  
Kings Bay, Georgia

Recovery Well <sup>1</sup>	Total Depth <sup>2</sup> (Feet btoc)	Screen Length	Water Column <sup>3</sup>	Unicid™ Granular Acid Applied <sup>4</sup>	Unicid™ Acid Catalyst Applied <sup>5</sup>	Initial pH	pH After Treatment
RW-1	63.0	40 feet	57.0 feet	42 pounds	7 gallons	6	1
RW-2	73.5	50 feet	70.0 feet	50 pounds	5 gallons	7	1
RW-3	74.2	50 feet	71.7 feet	50 pounds	5 gallons	5	1
RW-4	68.5	40 feet	64.7 feet	50 pounds	5 gallons	5	1

<sup>1</sup> All are 0.030-inch continuous slot, 6-inch inside diameter stainless steel, set in 12-inch borehole with filter pack.

<sup>2</sup> As measured after submersible pumps were removed.

<sup>3</sup> Amount of water standing in well.

<sup>4</sup> Manufacturer's suggested application rate is 0.70 to 1.50 pounds per foot of screen length in a 6-inch well.

<sup>5</sup> Manufacturer's suggested application rate is 0.05 to 0.08 gallons per foot of water column in a 6-inch well.

Note: btoc = below top of casing.

**Table 7  
Redevelopment Summary**

IM System Phase II: Upgrades  
Existing Recovery Well Redevelopment  
Site 11, Old Camden County Landfill  
Naval Submarine Base  
Kings Bay, Georgia

Recovery Well <sup>1</sup>	Total Depth <sup>2</sup> (Feet btoc)	Total Depth <sup>3</sup> (Feet btoc)	Surging Time	Total Depth <sup>4</sup> (Feet btoc)	Pumping Time (min.)	Water / Sediment <sup>5</sup> Removed (gal.)	Average Pumping Rate (gal./min.)	Total Depth <sup>6</sup> (Feet btoc)	Final pH From Pump <sup>7</sup>	Final pH From Bailer <sup>8</sup>
RW-1	65.4	63.0	205 minutes	69.5	151	2030 / 8 to 9	13.4	65.4	4.18	5.98
RW-2	75.4	73.5	190 minutes	70.5	168	2565 / 7 to 8	15.3	75.4	5.20	6.07
RW-3	75.4	74.2	205 minutes	69.8	159	2865 / 8 to 9	18.0	75.2	3.08	4.94
RW-4	70.4	68.5	205 minutes	68.5	150	2495 / 2 to 3	16.6	70.0	3.80	4.91

<sup>1</sup> All are 0.030-inch continuous slot, 6-inch inside diameter stainless steel, set in 12-inch borehole with filter pack.  
<sup>2</sup> As constructed.  
<sup>3</sup> Measured prior to surging.  
<sup>4</sup> Measured after surging.  
<sup>5</sup> Sediment comprised of fine grey sand (aquifer material) with trace medium tan sand (filter pack) and (-) trace gray fines (silt, clay, bentonite).  
<sup>6</sup> Measured after pumping.  
<sup>7</sup> Measured with calibrated meter. Pump effluent is from bottom of the well.  
<sup>8</sup> Measured with calibrated meter. Bailer sample retrieved from top of water column.

Note: btoc = below top of casing.

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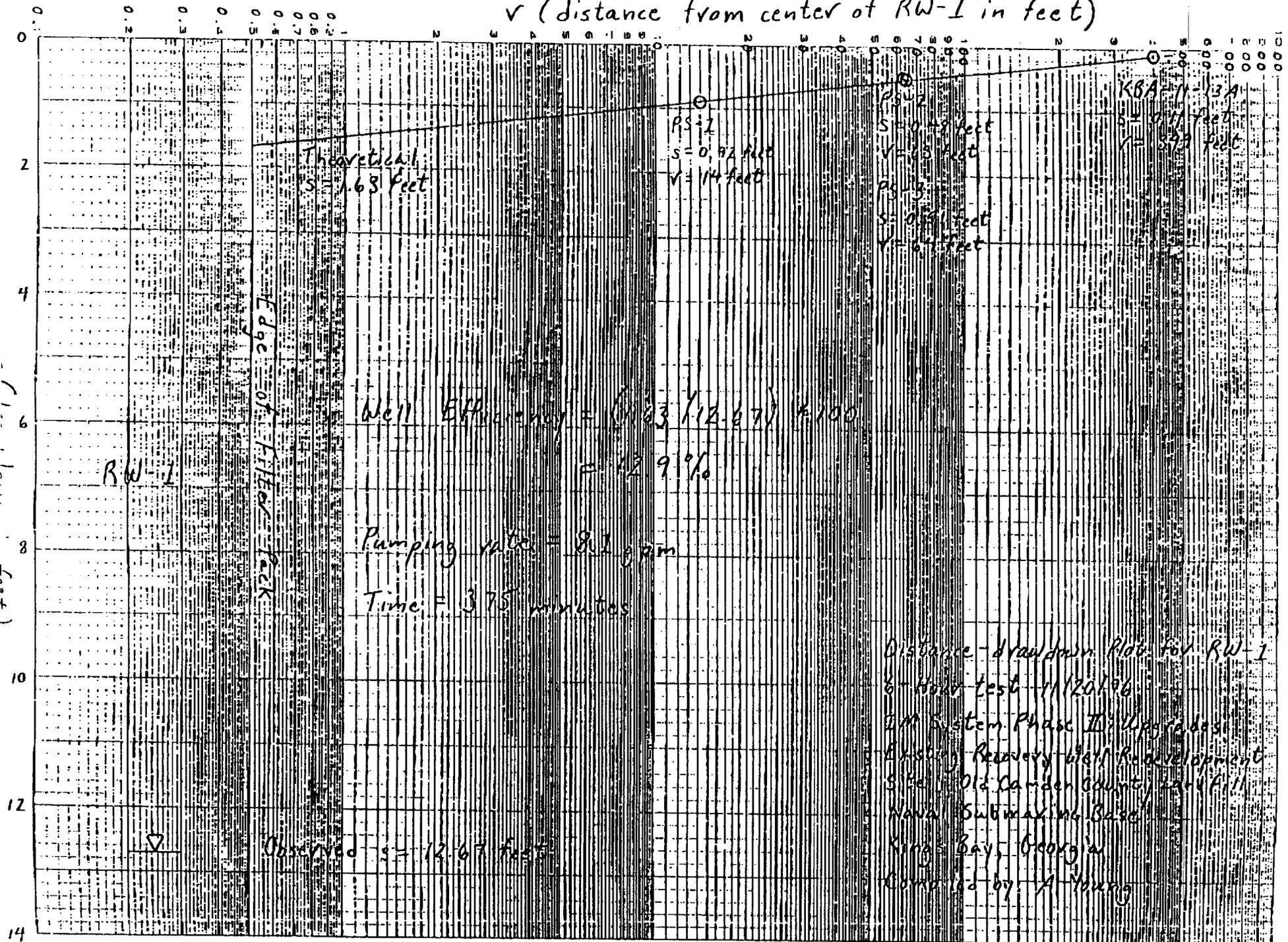
ABB ENV SERVICES --- RHONDA BATH

PW ☐ 014/020

**ATTACHMENT B**

**PLOTS**

$r$  (distance from center of RW-1 in feet)



Theoretical:  
 $s = 1.68$  feet

PS-1  
 $s = 0.92$  feet  
 $v = 114$  feet

PS-2  
 $s = 0.49$  feet  
 $v = 67$  feet  
 $s = 0.21$  feet  
 $v = 37.9$  feet

KBA-11-13A  
 $s = 0.21$  feet  
 $v = 37.9$  feet

Well Efficiency =  $(12.67 / 12.67) * 100$   
 = 129%

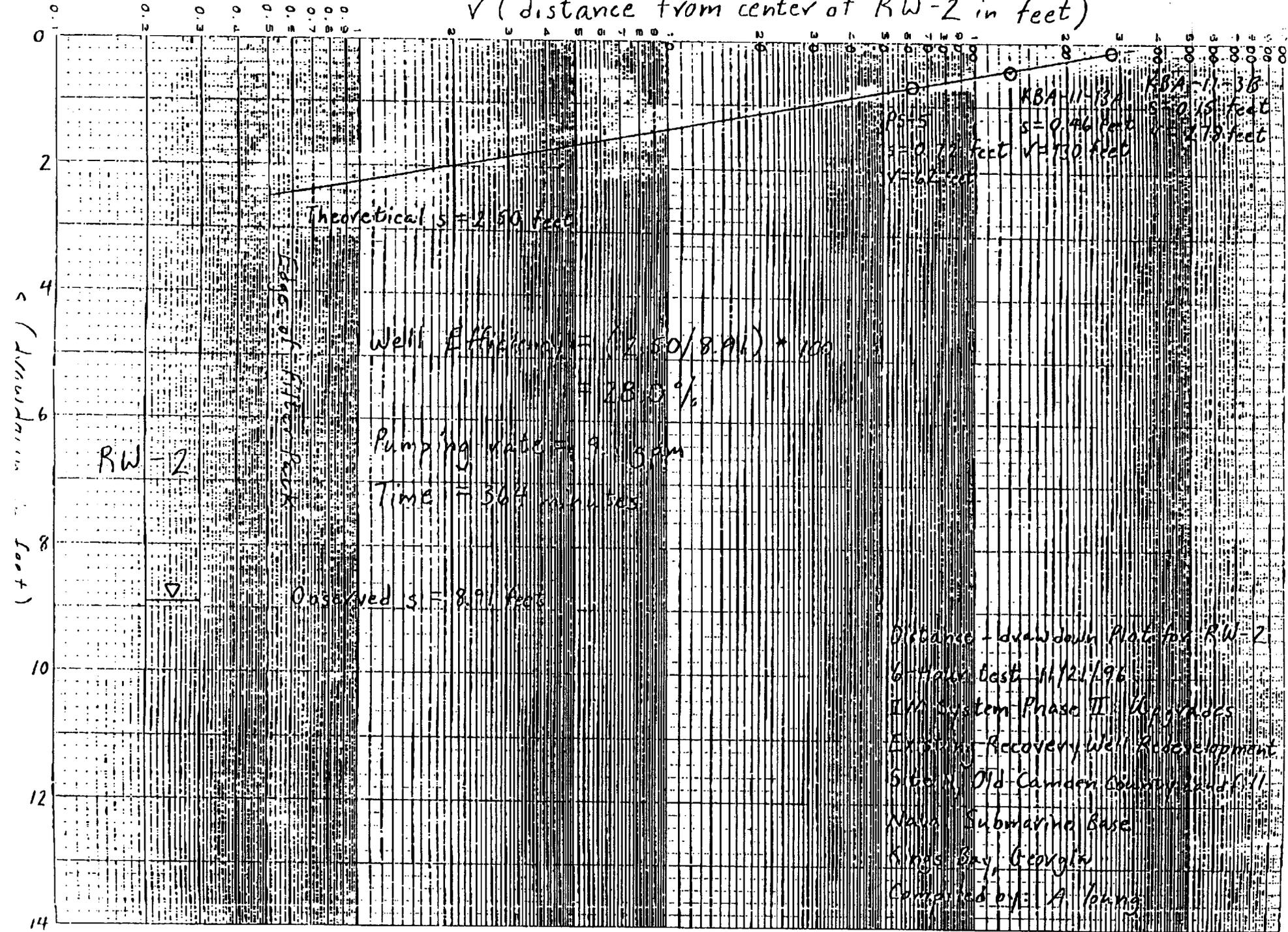
Pumping rate = 8.1 gpm

Time = 375 minutes

Observed  $s = 12.67$  feet

Distance - drawdown plot for RW-1  
 6-hour test 11/20/96  
 IIR System Phase II: Upgrades  
 Existing Recovery Well Rehabilitation  
 Site: Old Camden County Jail #11  
 Naval Submarine Base  
 Kings Bay, Georgia  
 Compiled by: A Young

$r$  (distance from center of RW-2 in feet)



Theoretical  $s = 2.50$  feet

Well Efficiency =  $(2.50 / 8.91) * 100$   
 = 28.0%

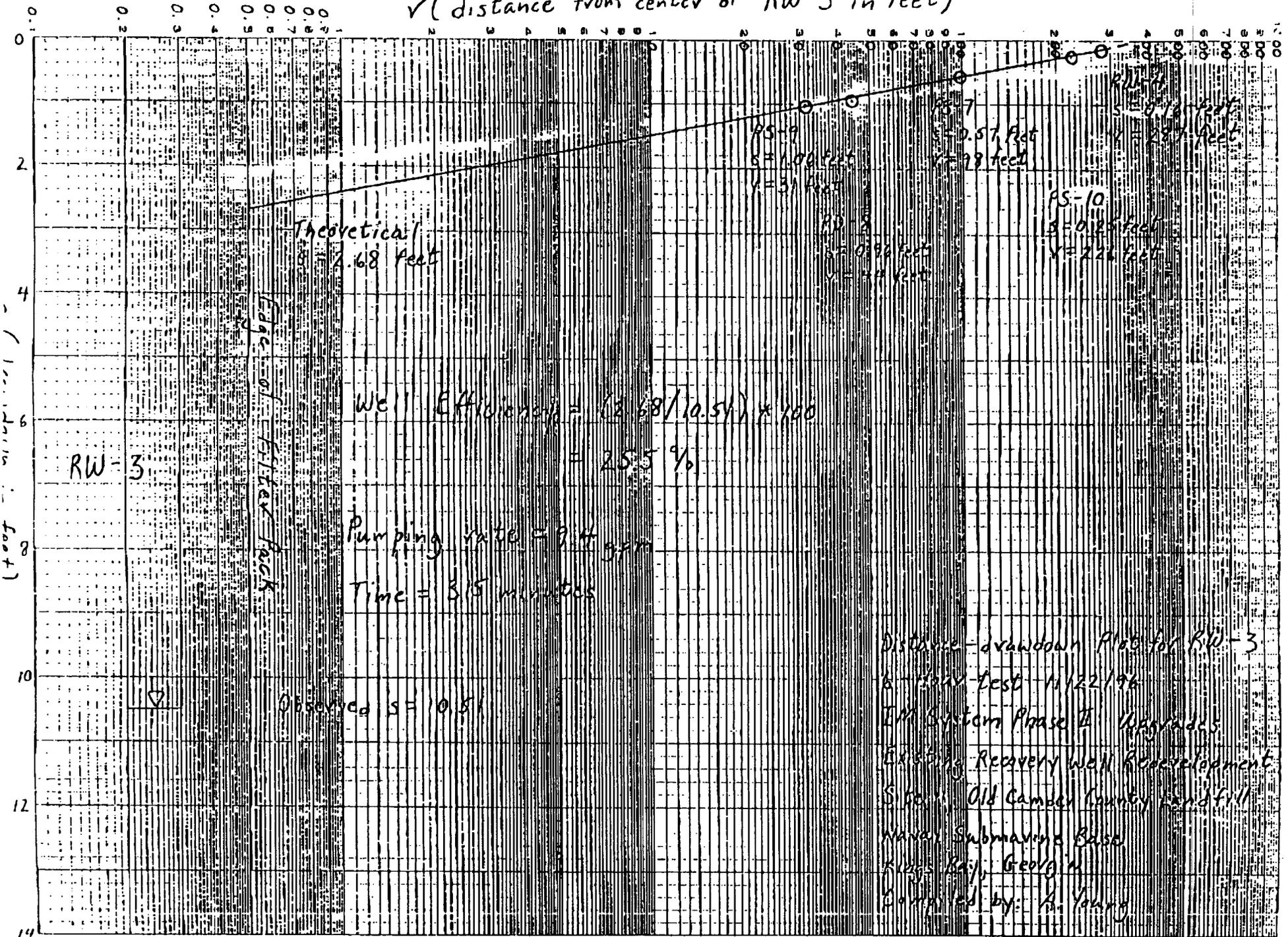
Pumping rate = 9.5 gpm  
 Time = 365 minutes

Observed  $s = 8.91$  feet

WBA-11-13A  $s = 0.46$  feet  $r = 130$  feet  
 WBA-11-38  $s = 0.15$  feet  $r = 275$  feet  
 WBA-11-38  $s = 0.72$  feet  $r = 165$  feet

Distance + drawdown Plot for RW-2  
 6-Month Test 11/21/96  
 IIR System Phase II Upgrade  
 Existing Recovery Well Redevelopment  
 Site of Old Cannon Company Fuel Oil  
 Naval Submarine Base  
 Kings Bay, Georgia  
 Compiled by: A. Young

$\sqrt{}$  (distance from center of RW-3 in feet)



Theoretical  
s = 2.68 feet

Edge of Filter Pack

Well Efficiency =  $(2.68 / 10.51) \times 100$   
= 25.5%

Pumping rate = 2 ft gpm

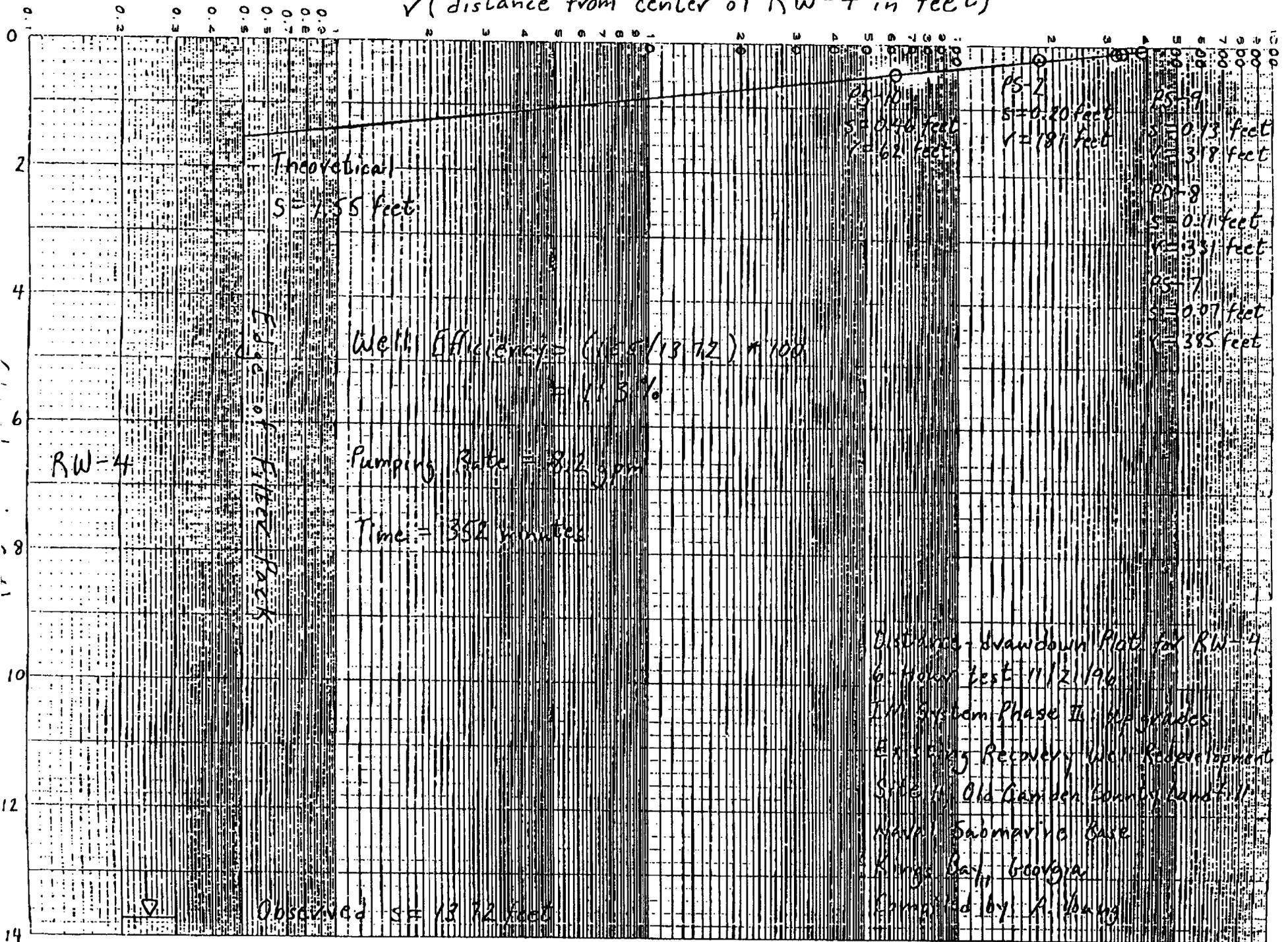
Time = 3.5 minutes

Observed s = 10.51

RW-3

Distance-drawdown Plot for RW-3  
6-Year Test 11/22/96  
IIM System Phase II Upgrade  
Existing Recovery Well Redevelopment  
Site in Old Camden County Landfill  
Naval Submarine Base  
Kings Bay, Georgia  
Compiled by: A. Young

$\sqrt{}$  (distance from center of RW-4 in feet)



Well ID	s (feet)	r (feet)
PS-10	0.46	162
PS-2	0.20	181
PS-9	0.13	318
PS-8	0.11	331
PS-17	0.07	385

Well Efficiency =  $(13.72 / 18.72) * 100$   
= 73%

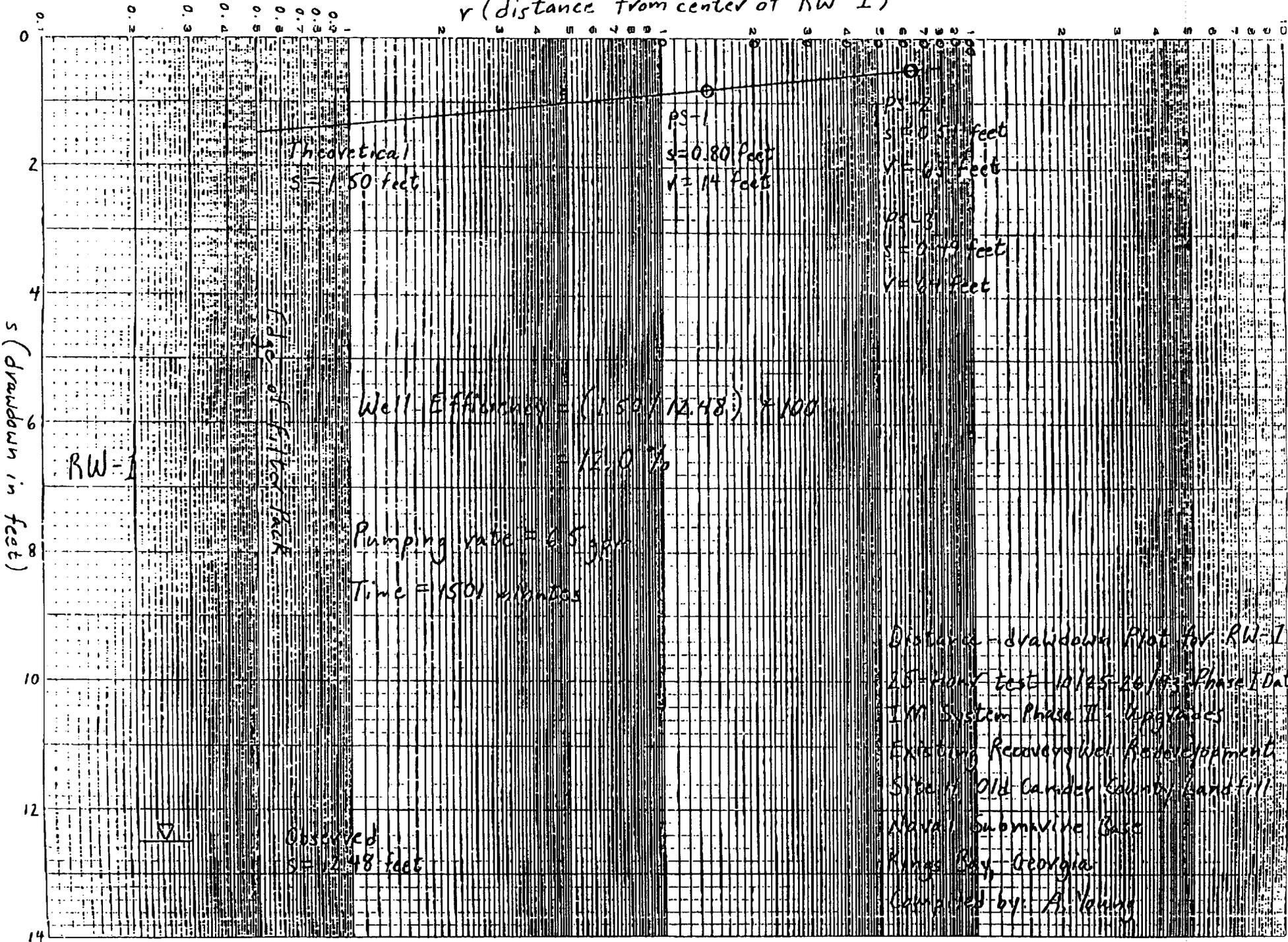
Pumping Rate = 8.2 gpm

Time = 352 minutes

Observed s = 13.72 feet

Distance - drawdown Plot for RW-4  
6-hour test 11/21/96  
IM System Phase II: 600 gphs  
Emergency Recovery Well Redevelopment  
Site in Old Garden County Landfill  
Naval Submarine Base  
Kings Bay, Georgia  
Compiled by: A. Young

$r$  (distance from center of RW-1)



Theoretical  
 $s = 1.50$  feet

PS-1  
 $s = 0.80$  feet  
 $r = 14$  feet

PS-2  
 $s = 0.57$  feet  
 $r = 65$  feet

or  
 $s = 0.49$  feet  
 $r = 67$  feet

Well Efficiency =  $(1.50 / 12.48) \times 100 = 12.0\%$

Pumping rate = 0.5 gpm

Time = 1501 minutes

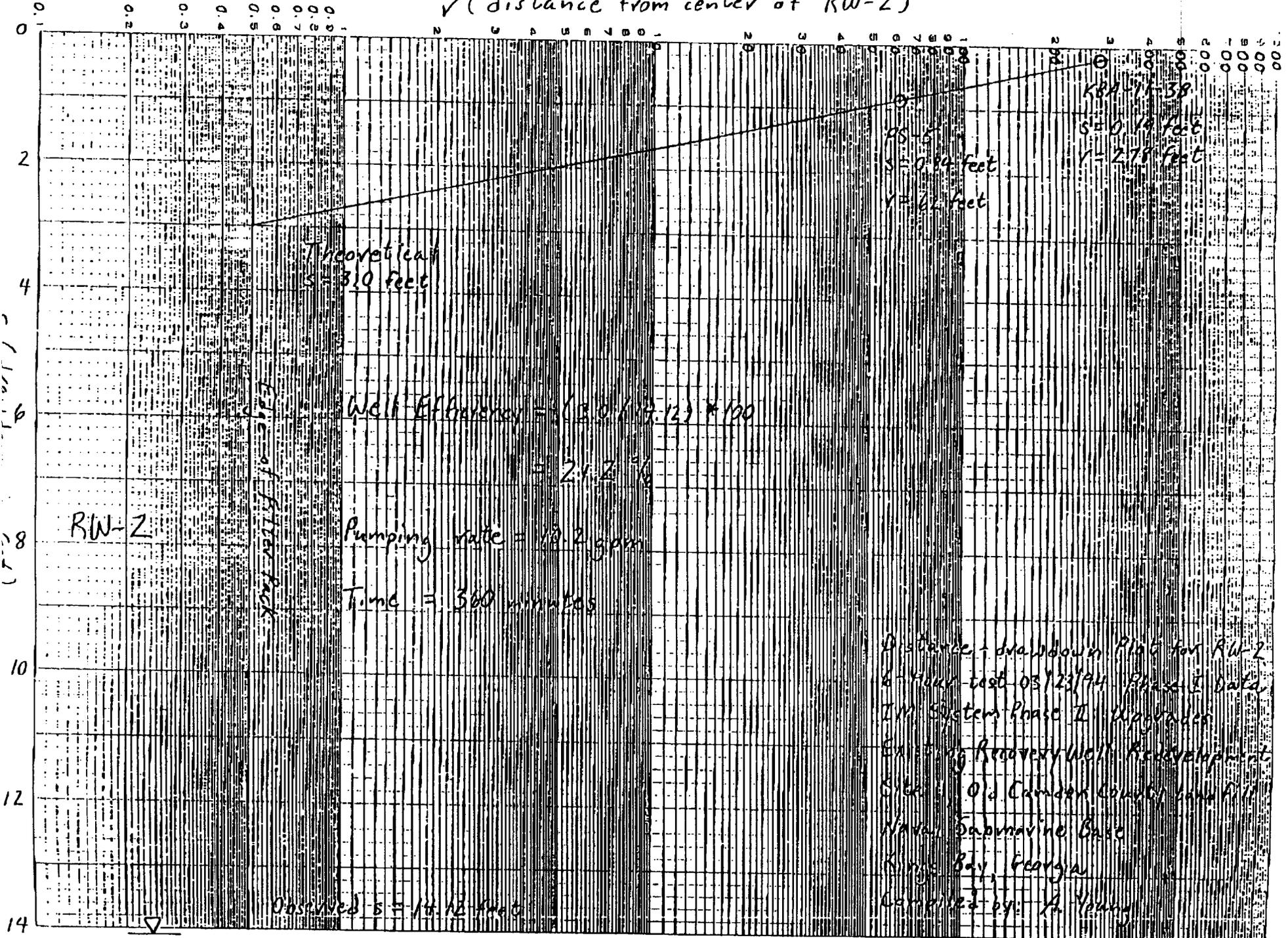
RW-1

Edge of Filter Pack

Observed  
 $s = 12.48$  feet

Distance-drawdown Plot for RW-1  
25-foot test 10/25-26/83 Phase I Data  
IM System Phase II Upgrade  
Existing Recovery Well Redevelopment  
Site of Old Camden County Landfill  
Naval Submarine Base  
Kings Bay, Georgia  
Compiled by: A. Young

$\sqrt{r}$  (distance from center of RW-2)



Theoretical  
 $s = 3.0$  feet

Well Efficiency =  $\left( \frac{3.0}{14.12} \right) \times 100$   
= 21.2 %

Pumping rate = 10.2 gpm

Time = 360 minutes

Observed  $s = 14.12$  feet

KBAL-58  
 $s = 0.14$  feet  
 $r = 2.75$  feet  
 $s = 0.64$  feet  
 $r = 61$  feet

Distance - drawdown Plot for RW-2  
6-hour test 03/23/94 Phase I Data  
IM System Phase II Upgrade  
Existing Recovery Well Re-development  
Site of Old Camden County Landfill  
Naval Submarine Base  
Kings Bay, Georgia  
Compiled by: A. Young

NSB KINGSBAY  
SITE 11 GROUNDWATER  
DETECTED VOLATILE ORGANIC COMPOUNDS

ENCLOSURE (4)

CONSTITUENT (Units in ug/l)	SITE	KBA-11-13A	KBA-11-16	PS-10	PS-2	PS-4	PS-7
	SAMPLE ID	13A030701	16030801	PS10030901	PS2030801	PS4031101	PS7030801
	DATE / TIME	03/07/97 / 14:27	03/08/97 / 16:22	03/09/97 / 08:46	03/08/97 / 14:17	03/11/97 / 15:21	03/08/97 / 16:50
	RESULT TYPE	Primary	Primary	Primary	Primary	Primary	Primary
Vinyl chloride		<20 U	<2 U	<2 U	8.8	<2 U	42
Methylene chloride		<10 U	<1 U	5.7	<1 U	<1 U	92
1,1-Dichloroethane		<10 U	<1 U	40	10	<1 U	1.8
cis-1,2-Dichloroethene		280	<1 U	13	110	<1 U	110
Trichloroethene		890	<1 U	<1 U	2.8	<1 U	3.1
Benzene		<10 U	<1 U	1.2	5.9	<1 U	2.6
Tetrachloroethene		100	<1 U				

Values represent total concentrations unless noted < = Not detected at indicated reporting limit --- = Not analyzed

U = not detected, J = estimated value For RCL DPVOA

NSB KINGSBAY  
SITE 11 GROUNDWATER  
DETECTED VOLATILE ORGANIC COMPOUDS

CONSTITUENT (Units in ug/l)	SITE SAMPLE ID	RW-1 GW010303	RW-2 GW020303	RW-3 GW030303	RW-3 RW3031301	RW-4 GW040303	V202 V20230
	DATE / TIME	03/03/97 / 12:21	03/03/97 / 12:26	03/03/97 / 12:30	03/13/97 / 17:44	03/03/97 / 12:31	03/06/97 / 12:14
	RESULT TYPE	Primary	Primary	Primary	Primary	Primary	Primary
Vinyl chloride		9.1	20	38	< 2 U	16	9
Methylene chloride		< 1 U	1.1	< 1 U	1.1	15	< 1 U
1,1-Dichloroethane		40	1.2	4.5	< 1 U	19	1.5
cis-1,2-Dichloroethene		41	64	240	29	46	29
Trichloroethene		5.7	1.8	38	9.6	5.3	1.4
Benzene		1.4	3.2	2.4	1	1.3	< 1 U
Tetrachloroethene		< 1 U	< 1 U	37	13	< 1 U	< 1 U

Values represent total concentrations unless noted < = Not detected at indicated reporting limit --- = Not analyzed

U = not detected, J = estimated value For RCL DPVOA

NSB KINGSBAY  
 SITE 11 GROUNDWATER  
 DETECTED VOLATILE ORGANIC COMPOUDS

CONSTITUENT (Units in ug/l)	SITE SAMPLE ID DATE / TIME RESULT TYPE	V202 V20240 03/06/97 / 12:39 Primary	V202 V20250 03/06/97 / 13:05 Primary	V204 V20430 03/06/97 / 09:03 Primary	V204 V20440 03/06/97 / 09:25 Primary	V204 V20450 03/06/97 / 09:51 Primary	V204 V20470 03/06/97 / 10:22 Primary
Vinyl chloride		62	2.8	<2 U	7.3	3.8	<2 U
Methylene chloride		<1 U	4	<1 U	<1 U	1.2	<1 U
1,1-Dichloroethane		34	2.5	2.9	5.7	3.4	<1 U
cis-1,2-Dichloroethene		46	9.8	3.8	4.3	3.6	1.4
Trichloroethene		<1 U					
Benzene		<1 U	<1 U	<1 U	<1 U	1.3	<1 U
Tetrachloroethene		<1 U					

Values represent total concentrations unless noted < = Not detected at indicated reporting limit --- = Not analyzed

U = not detected, J = estimated value For RCL DPVOA

NSB KINGSBAY  
SITE 11 GROUNDWATER  
DETECTED VOLATILE ORGANIC COMPOUNDS

CONSTITUENT (Units in ug/l)	SITE	V205	V205	V205	V206	V206	V206
	SAMPLE ID	V20530	V20540	V20550	V20630	V20640	V20650
	DATE / TIME	03/05/97 / 15:22	03/05/97 / 15:50	03/05/97 / 16:12	03/05/97 / 10:07	03/05/97 / 10:58	03/05/97 / 11:41
	RESULT TYPE	Primary	Primary	Primary	Primary	Primary	Primary
Vinyl chloride		<2 U					
Methylene chloride		<1 U	3.1				
1,1-Dichloroethane		1.1	5.5	2.7	<1 U	<1 U	2.1
cis-1,2-Dichloroethene		2.7	1.9	13	<1 U	<1 U	9.5
Trichloroethene		<1 U					
Benzene		1.2	<1 U	1.8	<1 U	<1 U	2.6
Tetrachloroethene		<1 U					

Values represent total concentrations unless noted < = Not detected at indicated reporting limit --- = Not analyzed

U = not detected, J = estimated value For RCL DPVOA

NSB KINGSBAY  
SITE 11 GROUNDWATER  
DETECTED VOLATILE ORGANIC COMPOUNDS

CONSTITUENT (Units in ug/l)	SITE	V207	V207	V207	V207	V208	V208
	SAMPLE ID	V20735	V20737	V20740	V20748	V20825	V20835
	DATE / TIME	03/07/97 / 09:29	03/07/97 / 09:42	03/07/97 / 09:58	03/07/97 / 10:13	03/11/97 / 15:21	03/11/97 / 15:41
	RESULT TYPE	Primary	Primary	Primary	Primary	Primary	Primary
Vinyl chloride		<2 U	<2 U	2.2	<2 U	2.7 J	<2 U
Methylene chloride		<1 U	<1 U	<1 U	1.2	<1 U	<1 U
1,1-Dichloroethane		<1 U					
cis-1,2-Dichloroethene		140	390	190	19	170 J	2.6 J
Trichloroethene		1600	600	310	36	<1 U	<1 U
Benzene		1.8	<1 U	<1 U	1.4	<1 U	<1 U
Tetrachloroethene		8.7	16	11	<1 U	3 J	2.3 J

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U = not detected, J = estimated value For RCL DPVOA

NSB KINGSBAY  
SITE 11 GROUNDWATER  
DETECTED VOLATILE ORGANIC COMPOUNDS

CONSTITUENT (Units in ug/l)	SITE	V209	V209	V209	V210	V210	V210
	SAMPLE ID	V20930	V20940	V20950	V21030	V21035	V21040
	DATE / TIME	03/06/97 / 18:12	03/06/97 / 18:39	03/06/97 / 19:02	03/06/97 / 15:36	03/06/97 / 16:08	03/06/97 / 16:32
	RESULT TYPE	Primary	Primary	Primary	Primary	Primary	Primary
Vinyl chloride		75	2.8	< 2 U	2.8	2.4	< 2 U
Methylene chloride		< 1 U	< 1 U	4.4	< 1 U	< 1 U	< 1 U
1,1-Dichloroethane		< 1 U	2.1	< 1 U	< 1 U	< 1 U	< 1 U
cis-1,2-Dichloroethene		77	6.2	9.9	1.3	110	14
Trichloroethene		9.8	3.8	1.6	< 1 U	730	160
Benzene		< 1 U	< 1 U	3.5	< 1 U	2.1	< 1 U
Tetrachloroethene		< 1 U	< 1 U	< 1 U	< 1 U	64	13

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NSB KINGSBAY  
SITE 11 GROUNDWATER  
DETECTED VOLATILE ORGANIC COMPOUNDS

CONSTITUENT (Units in ug/l)	SITE	V210	V210	V211	V211	V212	V212
	SAMPLE ID	V21050	V21050D	V21135	V21140	V21225	V21235
	DATE / TIME	03/06/97 / 16:56	03/06/97 / 16:56	03/07/97 / 14:20	03/07/97 / 14:41	03/07/97 / 12:21	03/07/97 / 12:47
	RESULT TYPE	Primary	Duplicate	Primary	Primary	Primary	Primary
Vinyl chloride		< 2 U	< 2 U	< 2 U	< 2 U	< 2 U	< 2 U
Methylene chloride		3.5	2.3	39	1.2	< 1 U	< 1 U
1,1-Dichloroethane		1	< 1 U	1	1.8	< 1 U	< 1 U
cis-1,2-Dichloroethene		7.3	4.6	4.2	1.4	< 1 U	3
Trichloroethene		28	18	5.6	3.1	6	1200
Benzene		2.4	1.5	4.2	6.1	< 1 U	< 1 U
Tetrachloroethene		4.9	2.2	72	41	< 1 U	3500

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NSB KINGSBAY  
 SITE 11 GROUNDWATER  
 DETECTED VOLATILE ORGANIC COMPOUNDS

CONSTITUENT (Units in ug/l)	SITE	V212	V213	V214	V215	V216	V216
	SAMPLE ID	V21240	V21335	V21435	V21535	V21635	V21640
	DATE / TIME	03/07/97 / 13:05	03/07/97 / 15:50	03/07/97 / 16:49	03/07/97 / 18:22	03/08/97 / 09:36	03/08/97 / 09:58
	RESULT TYPE	Primary	Primary	Primary	Primary	Primary	Primary
Vinyl chloride		<2 U	<2 U	<2 U	<2 U	<40 U	<2 U
Methylene chloride		<1 U	<1 U	<1 U	<1 U	<20 U	<1 U
1,1-Dichloroethane		<1 U	<1 U	<1 U	<1 U	<20 U	<1 U
cis-1,2-Dichloroethene		<1 U	<1 U	<1 U	<1 U	180	39
Trichloroethene		54	7.9	2	2.3	370	48
Benzene		<1 U	2.7	<1 U	<1 U	<20 U	<1 U
Tetrachloroathene		460	55	22	23	490	93

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NSB KINGSBAY  
 SITE 11 GROUNDWATER  
 DETECTED VOLATILE ORGANIC COMPOUDS

CONSTITUENT (Units in ug/l)	SITE	V217	V217	V218	V218	V218	V219
	SAMPLE ID	V21735	V21740	V21835	V21835D	V21840	V21935
	DATE / TIME	03/08/97 / 11:58	03/08/97 / 12:14	03/08/97 / 14:51	03/08/97 / 14:51	03/08/97 / 15:10	03/08/97 / 16:22
	RESULT TYPE	Primary	Primary	Primary	Duplicate	Primary	Primary
Vinyl chloride		220	5.6	<2 U	<2	<2 U	2.4
Methylene chloride		<50 U	<1 U	<1 U	<1	<1 U	<1 U
1,1-Dichloroethane		<50 U	2.4	1.9	1.5	<1 U	4.5
cis-1,2-Dichloroethene		3100	160	4.8	5.8	1.6	8.6
Trichloroethene		<50 U	<1 U	<1 U	<1	<1 U	1.8
Benzene		<50 U	2.7	2.6	2.3	1	1.6
Tetrachloroethene		<50 U	10	6.5	7.8	4.4	8.8

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NSB KINGSBAY  
 SITE 11 GROUNDWATER  
 DETECTED VOLATILE ORGANIC COMPOUDS

CONSTITUENT (Units in ug/l)	SITE	V219	V220	V220	V221	V221	V222
	SAMPLE ID	V21940	V22035	V22040	V22135	V22140	V22235
	DATE / TIME	03/08/97 / 16:40	03/09/97 / 08:16	03/09/97 / 08:35	03/09/97 / 09:48	03/09/97 / 10:05	03/09/97 / 11:26
	RESULT TYPE	Primary	Primary	Primary	Primary	Primary	Primary
Vinyl chloride		2.1	< 2 U	10	< 2 U	37	(1.5)
Methylene chloride		< 1 U	< 1 U	29	< 1 U	34	< 1 U
1,1-Dichloroethane		2.7	3.6	23	10	17	3.4
cis-1,2-Dichloroethene		7	4.8	9.8	23	31	9.3
Trichloroethene		< 1 U	< 1 U	2	1.1	1.2	< 1 U
Benzene		1.6	< 1 U	1.4	1	1.4	4
Tetrachloroethene		5.1	10	6.3	6.2	2.9	5.1

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 () = Less than Reporting Limit  
 U = not detected, J = estimated value For RCL DPVOA

NSB KINGSBAY  
 SITE 11 GROUNDWATER  
 DETECTED VOLATILE ORGANIC COMPOUNDS

CONSTITUENT (Units in ug/l)	SITE	V222	V222	V224	V224	V224	V225
	SAMPLE ID	V22240	V22250	V22435	V22440	V22445	V22540
	DATE / TIME	03/09/97 / 11:46	03/09/97 / 12:10	03/09/97 / 15:18	03/09/97 / 15:45	03/09/97 / 16:08	03/09/97 / 17:40
	RESULT TYPE	Primary	Primary	Primary	Primary	Primary	Primary
Vinyl chloride		4.6	<2 U				
Methylene chloride		8.7	140	<1 U	<1 U	<1 U	<1 U
1,1-Dichloroethane		<1 U	5.4	<1 U	<1 U	<1 U	<1 U
cis-1,2-Dichloroethene		4.4	3.4	<1 U	1	7.6	<1 U
Trichloroethene		<1 U	1.5	<1 U	<1 U	<1 U	<1 U
Benzene		1.5	<1 U	<1 U	<1 U	1.7	<1 U
Tetrachloroethene		3.1	1.7	4.1	3.5	2.3	<1 U

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U = not detected, J = estimated value For RCL DPVOA

NSB KINGSBAY  
SITE 11 GROUNDWATER  
DETECTED VOLATILE ORGANIC COMPOUDS

CONSTITUENT (Units in ug/l)	SITE	V225	V226	V226	V226	V227	V227
	SAMPLE ID	V22545	V22635	V22640	V22645	V22735	V22740
	DATE / TIME	03/09/97 / 18:12	03/10/97 / 08:45	03/10/97 / 09:04	03/10/97 / 09:25	03/10/97 / 11:00	03/10/97 / 11:21
	RESULT TYPE	Primary	Primary	Primary	Primary	Primary	Primary
Vinyl chloride		<2 U	150	<2 U	2.3	<2 U	<2 U
Methylene chloride		<1 U	<1 U	<1 U	3.9	<1 U	<1 U
1,1-Dichloroethane		<1 U	<1 U	1	2.2	<1 U	3.9
cis-1,2-Dichloroethene		9.6	1100	16	19	6.2	1.3
Trichloroethene		<1 U	6.6	<1 U	<1 U	<1 U	<1 U
Benzene		1.8	1.9	<1 U	4.6	1.1	<1 U
Tetrachloroethene		<1 U	6.4	2.3	2.3	1.6	1.4

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NSB KINGSBAY  
 SITE 11 GROUNDWATER  
 DETECTED VOLATILE ORGANIC COMPOUDS

CONSTITUENT (Units in ug/l)	SITE	V228	V228	V228	V229	V229	V229
	SAMPLE ID	V22835	V22835D	V22840	V22935	V22940	V22950
	DATE / TIME	03/10/97 / 14:15	03/10/97 / 14:15	03/10/97 / 14:43	03/10/97 / 16:02	03/10/97 / 16:23	03/10/97 / 16:51
	RESULT TYPE	Primary	Duplicate	Primary	Primary	Primary	Primary
Vinyl chloride		<2 U	<2 U	<2 U	<2 U	(1.4)	<2 U
Methylene chloride		<1 U					
1,1-Dichloroethane		4	1.6	<1 U	5.5	9.8	13
cis-1,2-Dichloroethene		7	3.5	<1 U	14	9.9	3.6
Trichloroethene		<1 U					
Benzene		1.1	<1 U	<1 U	<1 U	1.6	<1 U
Tetrachloroethene		2.1	1.4	1.1	2.5	1	<1 U

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 () = Less than Reporting Limit  
 U = not detected, J = estimated value For RCL DPVOA

NSB KINGSBAY  
SITE 11 GROUNDWATER  
DETECTED VOLATILE ORGANIC COMPOUNDS

CONSTITUENT (Units in ug/l)	SITE	V230	V230	V230	V232	V232	V232
	SAMPLE ID	V23040	V23045	V23050	V23220	V23230	V23235
	DATE / TIME	03/11/97 / 08:43	03/11/97 / 09:08	03/11/97 / 09:31	03/12/97 / 08:35	03/12/97 / 08:57	03/12/97 / 09:16
	RESULT TYPE	Primary	Primary	Primary	Primary	Primary	Primary
Vinyl chloride		2.9 J	<2 U	<2 U	300	19	11
Methylene chloride		<1 U	9.8	5.9	1	<1 U	<1 U
1,1-Dichloroethane		15 J	3.6 J	5.2 J	1.4	<1 U	<1 U
cis-1,2-Dichloroethene		49 J	11 J	33 J	120	280	79
Trichloroethene		20 J	3.8 J	6.1 J	<1 U	100	29
Benzene		<1 U	<1 U	<1 U	1.2	1	1.2
Tetrachloroethene		5 J	<1 U	1.5 J	2.9	1.7	1.2

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U = not detected, J = estimated value For RCL DPVOA

NSB KINGSBAY  
 SITE 11 GROUNDWATER  
 DETECTED VOLATILE ORGANIC COMPOUNDS

CONSTITUENT (Units in ug/l)	SITE	V235	V235
	SAMPLE ID	V23520	V23530
	DATE / TIME	03/12/97 / 13:45	03/12/97 / 14:02
	RESULT TYPE	Primary	Primary
Vinyl chloride		< 2 U	< 2 U
Methylene chloride		< 1 U	< 1 U
1,1-Dichloroethane		< 1 U	< 1 U
cis-1,2-Dichloroathene		< 1 U	< 1 U
Trichloroethene		< 1 U	< 1 U
Benzene		< 1 U	< 1 U
Tetrachloroethene		< 1 U	< 1 U

Values represent total concentrations unless noted < = Not detected at indicated reporting limit --- = Not analyzed

U = not detected, J = estimated value For RCL DPVOA



March 21, 1997

Southern Division  
Naval Facilities Engineering Command  
ATTN. Mr. Anthony Robinson  
2155 Eagle Drive  
North Charleston, SC 29418

SUBJECT: Letter Report, Interim Measure (IM) System Phase II Upgrades, Treatment System Evaluation, Site 11, Old Camden County Landfill, Naval Submarine Base, Kings Bay, Georgia, Contract No. N62467-89-D-0317/094

Dear Mr. Robinson:

In accordance with the statement of work for the modification to CTO-094, dated May 30, 1996, the following letter report is submitted which presents an evaluation of the groundwater extraction and treatment system (GETS) located at Site 11 of the Naval Submarine Base (NSB), Kings Bay, Georgia.

### BACKGROUND

The GETS, in operation since March 1994, was designed to hydraulically control movement of the VOC contaminants within the surficial aquifer. The initial GETS, which included RW-1, RW-2, RW-3, RW-4, and RW-5, was installed as part of Phase I Interim Measure activities. RW-5 was subsequently abandoned in December 1996.

Phase II Upgrades consisting of an additional recovery well (RW-6) were completed in December 1996. RW-6 was installed using a cable tool drill rig, which resulted in a higher well efficiency and sustainable yield as compared to previously installed recovery wells. The well location is near the most contaminated portion of the groundwater plume. The connection of RW-6 to the GETS has resulted in a significantly higher flow rate entering the existing treatment system and may eventually yield higher contaminant levels in the treatment system influent.

### PURPOSE AND SCOPE

This letter report presents (1) a process performance evaluation of the IM treatment system and (2) an operational evaluation of the equipment and appurtenances of the overall IM system. The process performance evaluation (PPE) focuses on the capability of the existing treatment system to maintain compliance with the groundwater effluent and air discharge requirements. The operational evaluation (OPE) focuses on options to improve the functional aspects of various components of the overall IM system. The evaluations are based on the current configuration of the treatment system with the assumption that telemetry monitoring components will be installed in the near future.

### PROCESS PERFORMANCE EVALUATION

The purpose of the PPE is to determine if the existing treatment system, consisting of a diffused aeration tank (DAT) and vapor-phase carbon drums, will continue to meet Georgia Environmental Protection Division (GEPD) discharge requirements for effluent water and air, respectively. The PPE uses historical

ABB Environmental Services Inc.

operating data, collected from March 1994 through January 1997. The evaluation is based on hydraulic and contaminant loading conditions in the treatment system water influent. Future performance and compliance of the system, based on an increase in hydraulic and contaminant loading on the system, will be predicted in this evaluation.

The treatment system is periodically tested for chemical concentrations (1) in the water influent to the DAT, (2) the water effluent from the DAT, (3) the air influent to the granular activated carbon (GAC), (4) and the air effluent from the GAC to verify that the system is meeting the compliance requirements imposed by the GEPD. By testing both the influent and the effluent of both air and water streams, treatment system efficiencies can be determined. This information can then be used to predict future performance under varying contaminant influent concentrations and flows.

### Historical Data Summary

Water. In order to focus this evaluation, historical analytical data for the system's water influent was evaluated for exceedences of maximum contaminant levels (MCLs). MCLs are the compliance standard for the treated water effluent from the DAT. Contaminants in the system's water influent, that have historically exceeded the MCLs at least once, were targeted as contaminants of concern (COCs). This is considered a conservative approach to identify COCs because, if a contaminant does not exceed the MCL in the water influent then it does not require any treatment for discharge. Table 1 depicts the COCs for the water stream, which include methylene chloride, vinyl chloride, cis-1,2-dichloroethene, trichloroethene, and tetrachloroethene.

<p style="text-align: center;"><b>Table 1</b> <b>Water Stream Contaminants of Concern</b></p> <p style="text-align: center;">Site 11, IM Phase II Upgrade Activities Treatment System Evaluation Naval Submarine Base Kings Bay, Georgia</p>					
Parameter	MCL	Units	Average Influent	Maximum Influent	Frequency of Detection
cis-1,2-Dichloroethene	70	ug/l	157.95	330.00	22/23
Tetrachloroethene	5	ug/l	21.71	69.00	21/23
Trichloroethene	5	ug/l	31.27	78.00	22/23
Vinyl chloride	2	ug/l	12.86	24.00	21/23
Methylene chloride	5	ug/l	10.12	33.00	17/23

Note: Nondetected values are not used in averages or maximums.

Air. The GEPD established the compliance standard for the treated air effluent based solely on a restriction of the amount of vinyl chloride that can be discharged from the system into the air. The compliance standard is 0.37 mg/m<sup>3</sup> of vinyl chloride in the effluent air stream. This standard was based on ambient air emission limitations approved by GEPD for protection of human health and the environment. Vinyl chloride was chosen as the indicator compound for compliance due to its extreme toxicity. Consistent with this standard, vinyl chloride is the only contaminant identified as a contaminant of concern for the treatment system's air stream. Table 2 summarizes the historical analytical data for vinyl chloride in the air streams.

Table 2 Air Stream Contaminant of Concern					
Site 11, IM Phase II Upgrade Activities Treatment System Evaluation Naval Submarine Base Kings Bay, Georgia					
Parameter	Units	Average Influent	Average Effluent	Maximum Influent	Maximum Effluent
Vinyl chloride	mg/m <sup>3</sup>	0.08	0.05	0.15	0.10
Note: Nondetected values are not used in averages or maximums.					

### Current Operating Conditions

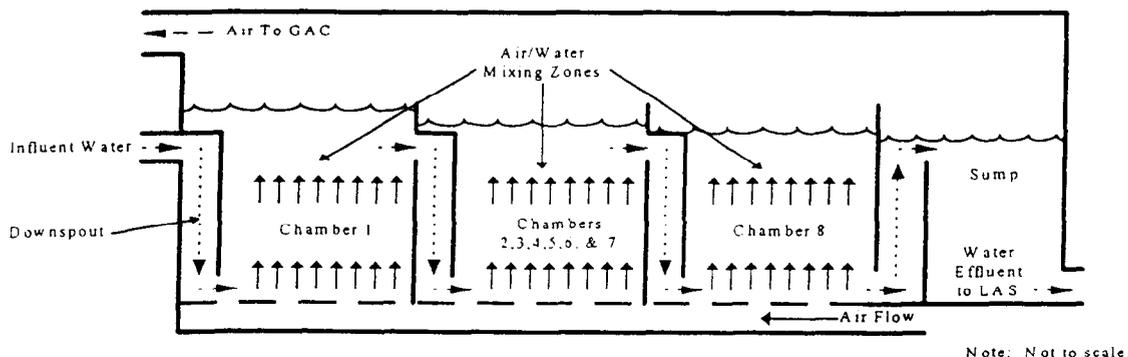
Table 3 summarizes the current operating parameters for the water and air streams in the treatment system. These parameters were developed from startup sampling data taken after RW-6 was installed as part of the Phase II Upgrades. As stated above, only contaminants of concern are presented in this summary. This recent data represents a good indication of how the system is performing under current conditions. Furthermore, using both the current and historical operating data, the system's future performance under varying operating conditions can be predicted.

Table 3 Current System Operating Conditions						
Site 11, IM Phase II Upgrade Activities Treatment System Evaluation Naval Submarine Base Kings Bay, Georgia						
Parameter	MCL	Units	Average Influent	Maximum Influent	Average Effluent	Maximum Effluent
<b><u>DAT Water Streams</u></b>						
cis-1,2-Dichloroethene	70	ug/l	73.70	84.00	2.0 U	2.0 U
Tetrachloroethene	5	ug/l	28.00	36.00	2.0 U	2.0 U
Trichloroethene	5	ug/l	26.50	31.00	2.0 U	2.0 U
Vinyl chloride	2	ug/l	10.33	12.00	2.0 U	2.0 U
Methylene chloride	5	ug/l	6.00	7.00	2.0 U	2.0 U
<b><u>GAC Air Streams</u></b>						
Vinyl chloride		mg/m <sup>3</sup>	0.09	0.11	0.0051 U	0.0051 U
Note: Nondetected values are not used in averages or maximums. Table represents a summary of data taken during startup sampling in December 1996 and January 1997.						
IM = interim measure.						
MCL = maximum contaminant levels.						
DAT = diffused aeration tank.						
ug/l = micrograms per liter.						
U = represents nondetection.						
GAC = granular activated carbon.						
mg/m <sup>3</sup> = milligrams per cubic meter.						

DAT Performance. Figure 1 contains a typical illustration of the DAT. The DAT transfers contaminants from the influent groundwater stream to the air stream by bubbling the air through the water, creating a high surface area for mass transfer. A critical design parameter for the DAT is the air to water volume

ratio, which determines the amount of mass transfer. Higher air to water ratios will allow more mass transfer, but also will result in increased energy and space requirements. A minimum air to water ratio will result in the smallest energy and space requirements possible for the system while meeting water discharge requirements. The original design assumed the amount of air entering the DAT is essentially constant at 800 cubic feet per minute (cfm) and the maximum design water flow rate is 60 gallons per minute (gpm), yielding a minimum air to water ratio for this system of approximately 100:1. Thus, if the air to water ratio falls below 100:1, poor mass transfer will result, and effluent concentrations could exceed MCLs.

**Figure 1 DAT Cross Section Illustration (Typical)**



Appendix A contains graphs of the historical and current water influent and effluent data for each of the COCs. According to these figures the DAT is achieving good to excellent removal efficiencies of COC. All of the effluent concentrations have been reduced to below the respective MCLs with the exception of two points (trichloroethene, 7/30/96 and tetrachloroethene, 7/30/96). These excursions are limited to one instance in time, which was short in duration and occurred just after system startup after a several month period of nonoperation. Because these increases occurred just after system startup, it is believed the excursions are the result of poor mass transfer due to low air to water ratios in the DAT.

While the system is operating adequately for present flow rates and contaminant concentrations, additional capacity will be limited by contaminant and/or flow conditions. Generally speaking, the removal efficiency is inversely proportional to the flow rate. Thus, as water flow rates increase, the system removal efficiency decreases. For this evaluation, the original design removal efficiencies and the MCLs were used to calculate maximum allowable influent concentrations for the COCs based on a 60 gpm and a 800 cfm water and air flow rate. These calculated maximum influent concentrations can be used to indicate when the system would be approaching noncompliance. Table 4 lists (1) the original design's influent concentrations, (2) the historical maximum influent concentrations, (3) the original design removal efficiencies, and (4) the calculated maximum influent concentrations that could result in noncompliance.

It should be noted that the original design influent concentrations were greatly overestimated for vinyl chloride and cis-1,2-dichloroethene while the design influent concentrations for trichloroethene and tetrachloroethene were underestimated. The net effect is that while cis-1,2-dichloroethene was the contaminant defining DAT performance in the original design assumptions, it is now likely that trichloroethene and tetrachloroethene are the critical contaminants in determining DAT performance requirements.

**Table 4**  
**Calculated Maximum Influent Concentrations**

Site 11, IM Phase II Upgrade Activities  
Treatment System Evaluation  
Naval Submarine Base  
Kings Bay, Georgia

Contaminant	MCL (ug/l)	Original Design Influent Concentration (ug/l)	Historical Maximum Influent Concentration (ug/l)	Original Design Removal Efficiency (%)	Calculated Maximum Influent Concentration (ug/l)
cis-1,2-Dichloroethene	70	3600	330	98.24	3977
Tetrachloroethene	5	3	69	99.00	500
Trichloroethene	5	45	78	98.51	336
Vinyl chloride	2	310	24	99.87	1538
Methylene chloride*	5	--	33	97.90	238

System Influent Water Flow Rate = 60 gpm  
System Influent Air Flow Rate = 800 cfm

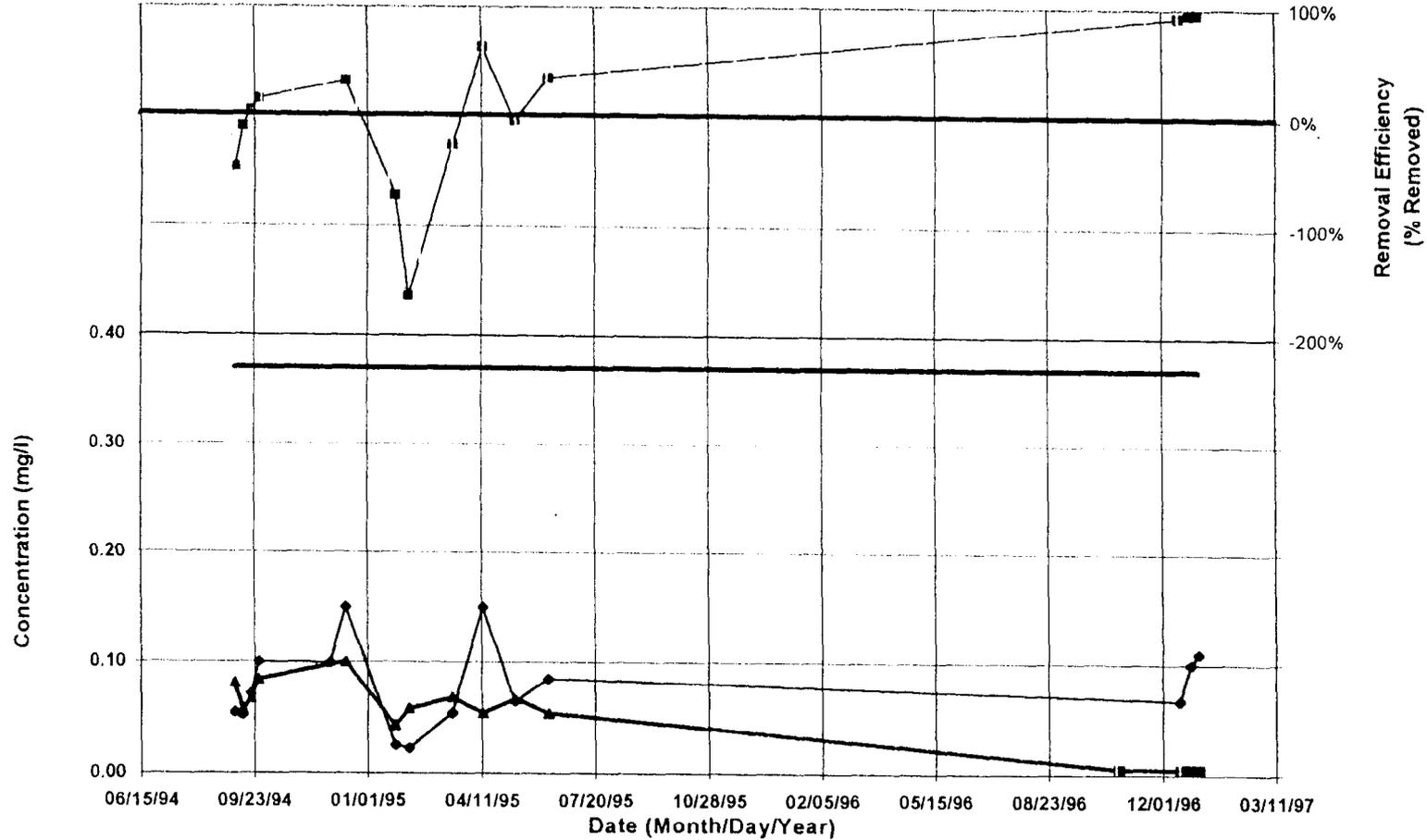
\* Methylene chloride was not included in the original design calculations. Design removal efficiency has been logarithmically extrapolated based on Henry's Law constants.

Notes: IM = interim measure.  
MCL = maximum contaminant level.  
ug/l = micrograms per liter.  
% = percent.  
gpm = gallons per minute.  
cfm = cubic feet per minute.

Activated Carbon Performance. According to historical and current system air data (see Table 2 and Figure 2), the activated carbon is achieving limited (if any) removal of vinyl chloride. The cause of this is most likely the result of the fact that activated carbon is not particularly suited for humid multicomponent waste streams. Generally speaking, activated carbon has an affinity for larger, heavier molecular weight compounds. Thus, as the adsorption sites available on the activated carbon become occupied, referred to as saturation, there is a tendency for smaller molecular weight compounds like vinyl chloride to be displaced by larger molecules. The result of this phenomena is a occasional negative removal efficiency, i.e., vinyl chloride concentrations may increase rather than decrease as the air moves through the carbon drums. This phenomena, which has been observed in the historical analytical data, is illustrated in Figure 3. If the activated carbon is not replaced, it will soon return to saturation as all of the vinyl chloride is displaced.

Water vapor in the air stream will also cause problems since water has a tendency to clog the pores of the activated carbon. As the pores become clogged, contaminants can not migrate to the adsorption sites within the activated carbon and a decrease in removal efficiency is the result. Furthermore, excessive amounts of water vapor may cause condensation within the carbon drums, resulting in an increase in pressure loss. This will cause increased power consumption by the blowers and will reduce the amount of air passing through the system.

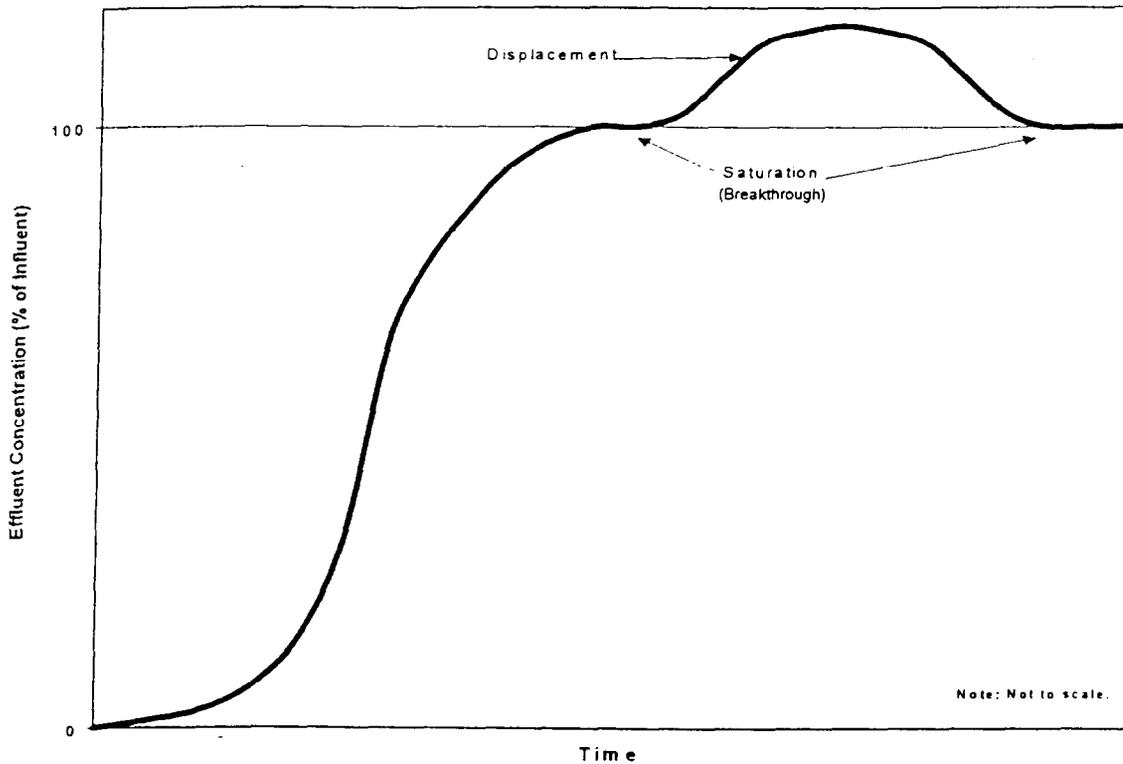
Figure 2 Vinyl Chloride Concentrations and Activated Carbon Removal Efficiency vs. Time  
 Vinyl Chloride Concentrations in Air From the DAT



Note: Non-detected results are reported at the sample quantitation limit (SQL).



Figure 3 Effluent Concentrations of Vinyl Chloride vs Time.



When all of the adsorption sites on the activated carbon are filled (Saturation), vinyl chloride molecules will be displaced by larger, heavier molecular weight compounds resulting in higher effluent concentrations than corresponding influent concentrations. If the carbon is allowed to remain on line, it will reach a second state of saturation as all of the vinyl chloride is displaced.

Based on the above deficiencies, activated carbon is not an effective means to control vinyl chloride emissions in the DAT offgas. Furthermore, it should be noted that vinyl chloride concentrations entering the GAC drums have never exceeded the GEPD discharge criteria. The continued use of GAC does not appear to be warranted and will be discussed further in the operational evaluation.

While the system is currently operating within the compliance standard for vinyl chloride in the air stream, future compliance will be a function of the vinyl chloride levels in the water influent. If the vinyl chloride levels in the water influent increase, more vinyl chloride will be stripped off by the DAT, thus entering the air stream.

The following equations are a conservative approach to determine the concentration of vinyl chloride in the system groundwater influent that will result in the offgas reaching the GEPD discharge level. The equations assume 100 percent of the vinyl chloride in the water stream is stripped off the DAT. The total mass of vinyl chloride entering the system in the water is divided by the air flow rate. The equations are as follows:

$$\text{and, } C_{w \text{ in}} \times Q_w = M_{w \text{ in}} \quad (1)$$

$$M_{w \text{ in}} \div Q_a = C_{a \text{ out}} \quad (2)$$

Where

- $C_{w\ in}$  = Concentration of vinyl chloride in the system groundwater influent stream (mg/l)  
 $Q_w$  = Flow rate of groundwater into the system (liters/minute)  
 $M_{w\ in}$  = Mass flow rate of vinyl chloride into the system (mg/minute)  
 $Q_a$  = Flow rate of air into the system (meters<sup>3</sup>/minute)  
 $C_{a\ out}$  = Concentration of vinyl chloride in the system offgas (mg/m<sup>3</sup>).

Assuming a system air flow rate of 800 cfm and a system water flow rate of 60 gpm, a water concentration of 36.9 µg/l could result in the offgas exceeding the GEPD discharge requirement. This maximum concentration should be used as the governing indicator in predicting overall system compliance, since it is more likely to be exceeded than the calculated maximum concentrations for water presented in Table 4.

Compliance

Comparing the most recent discharge compliance sampling data, which was gathered during Phase II Upgrades system startup, the system is currently operating within compliance (See Table 5). In fact, the system has the capacity to treat higher flow rates and more contaminated groundwater than is currently being treated, as can be seen by the remaining capacities in Table 5. Currently the system is operating at approximately 45 gpm with relatively low levels of contaminants in the influent water stream. Provided that system water influent concentrations do not reach the maximum influent concentrations for the contaminants of concern, and the water flow rate does not exceed 60 gpm, the system will continue to operate within compliance.

Table 5 Comparison of Current System Concentrations to Discharge Compliance Standards and Remaining Additional Capacity					
Site 11, IM Phase II Upgrade Activities Treatment System Evaluation Naval Submarine Base Kings Bay, Georgia					
<u>Water</u>					
Contaminant	Current Average Effluent Concentration (ug/l)	MCL (ug/l)	Current Average Influent Concentration (ug/l)	Calculated Maximum Influent Concentration (ug/l)	Remaining Capacity (%)
cis-1,2-Dichloroethene	2.0 U	70	73.7	3977	98
Tetrachloroethene	2.0 U	5	28.0	500	94
Trichloroethene	2.0 U	5	26.5	336	92
Vinyl chloride	2.0 U	2	10.33	34.6	70
Methylene chloride	2.0 U	5	6	238	97
<u>Offgas</u>					
Contaminant	Current Average Effluent Concentration (mg/m <sup>3</sup> )	Compliance Standard (mg/ m <sup>3</sup> )	Current Average Influent Concentration (mg/m <sup>3</sup> )	Remaining Capacity (%)	
Vinyl chloride	0.0051 U	0.370	0.09	NA	
Maximum System Influent Water Flow Rate = 60 gallons per minute.					
System Influent Air Flow Rate = 800 cubic feet per minute.					

Notes: IM = interim measure.	MCL = maximum contaminant level.	NA = not applicable.
ug/l = micrograms per liter.	U = represents nondetection.	
% = percent.	mg/m <sup>3</sup> = milligrams per cubic meter.	

### Recommendations

Since the system is operating within compliance for treated water discharge, no process changes are recommended for the DAT under current conditions. In order to maximize contaminant removal efficiencies in the DAT, the treatment system should be monitored and maintained regularly, and operated according to established procedures. System parameters (flow rates, pressures, etc.) should be collected on a weekly basis and sampling of the DAT water influent and water effluent should be continued on a semiannual basis to verify system performance.

If future water influent flow is increased above the 60 gpm rated capacity of the DAT, the system should be expanded to accommodate the additional flow. If water influent concentrations of COCs reach or exceed the maximum concentration levels presented in Table 4 or the water discharge is not meeting the MCLs due to poor mass transfer rates, the system should be redesigned and/or expanded to increase mass transfer rates.

For the air discharge stream, vinyl chloride concentrations have never been above the GEPD discharge standard. Since the carbon is not needed to keep the system in compliance, as currently operating, it is recommended that the GAC drums be taken offline and the DAT offgas be vented directly to the atmosphere. If the GAC drums are taken offline, the heat pump prior to the GAC drums should be switched off to reduce power consumption, and the heat transfer coils should be removed to avoid corrosion.

If vinyl chloride concentrations in the DAT offgas reach the GEPD discharge standard or the groundwater influent vinyl chloride concentration reaches 36.9 µg/l (indicating the potential for an exceedence in the offgas) the GAC drums may be placed back on line as a short-term measure and/or a new offgas treatment system capable of effectively removing vinyl chloride from the offgas should be installed. Any decision to remove or substitute another technology for the GAC drums should be made in consultation with GEPD.

### OPERATIONAL EVALUATION

The operational evaluation will discuss the performance of the existing GETS. For evaluation purposes, the system will be subdivided into eight major topics or components and discussed individually.

1. Recovery well vaults
2. System piping, instrumentation, and controls
3. Equalization tank
4. Diffused aeration tank
5. Heat pump
6. Carbon units
7. System effluent
8. Treatment pad layout

Recovery wells will not be evaluated in this letter report since they were previously evaluated in the letter reports "Interim Measure (IM) System Phase II Upgrades: Existing Recovery Well Redevelopment Site

11, Old Camden County Landfill," dated December 9, 1996, and "Interim Measure (IM) System Phase II Upgrades, New Recovery Well Installation and Performance Test," dated March 7, 1997. In performing this evaluation, it is assumed that telemetry components will be installed to monitor the operation of the system and to collect performance data. Recommendations for replacements or modifications will also be included in the individual sections.

### Recovery Well Vaults

The first major component of the GETS is the recovery well vaults that house the recovery well wellheads, extraction pumps, piping, instruments and controls. Four of the five vaults have been in operation since 1994 and the fifth vault has been operating since December 1996. The fifth vault represents an upgraded version of the others. The components of the groundwater transfer piping within the vaults include check valves, wye strainers, ball valves and pressure gauges. The four older well vaults should be upgraded to provide more manageable work space, added component life, and easier maintenance. The following are the recommended modifications and changes with the reason identified in parenthesis:

- Retrofit the piping with schedule 80 PVC and relocate it along the vault walls (increase work space);
- Anchor the piping to the vault walls (stabilize piping);
- Replace the brass ball valves with PVC (better withstand corrosion from groundwater);
- Install the pressure gauges into a reducing tee instead of tapping into the side of the piping (eliminate possibility of line blowout), and provide a bleed off valve to protect the gauge when not being read (increase gauge life);
- Install flap type check valves (easier to maintain and more reliable);
- Remove rust and repaint the vault interior walls and lids (protect metal vault material from further rust);
- Install a vault lid support arm to hold up the lid (safety protection); and
- Install a well casing extension in RW-3 and RW-4 (eliminate surface water from entering well).

The groundwater extraction pumps currently installed in RW-1 through RW-4 are Grundfos® model no. 10SO5-9, 1/2 horsepower and the extraction pump in RW-6 is model no. 10SO3-6, 1/3 horsepower. Each of the pumps have a capacity of 5 to 14 gpm. Proper pump selection is based on total system head and flow needed. Total system head for each individual well has been calculated based on the maximum flow, expected under current operating conditions, from the wells. These head values and corresponding flow rates are provided in Table 6.

Table 6 Recovery Well Flow Rates and Headlosses		
Site 11, IM Phase II Upgrade Activities Treatment System Evaluation Naval Submarine Base Kings Bay, Georgia		
Recovery Well	Flow (gpm)	Head (feet)
RW-1	6	35
RW-2	9	44
RW-3	8.5	47
RW-4	8.5	48
RW-6	12.5	45
Notes: IM = interim measure. gpm = gallons per minute.		

The most efficient extraction pumps, based on the system head and flow rate, selected for the GETS is 1/3 horsepower. However, in an effort to provide spare extraction well pumps, 1/2 horsepower pumps were purchased and installed in May 1996 due to unavailability of 1/3 horsepower pumps within the purchase schedule. Although these pumps are adequate for the task, they are less efficient and more costly to operate than the 1/3 horsepower pumps. It is recommended that the spare, 1/3 horsepower pumps be reinstalled in recovery wells RW-1 through RW-4 and the 1/2 horsepower pumps be used as backup only.

#### System Piping, Instrumentation, and Controls

Groundwater is transferred from the five recovery wells to the treatment system pad through 1-1/2 inch schedule 40 PVC for RW-1 through RW-4 and SDR-11 high density polyethylene (HDPE) for RW-6. RW-5 has been abandoned and no longer in use. As the piping from each recovery well enters onto the treatment pad they manifold into a 2 inch diameter pipe and then immediately into a 3 inch diameter pipe before entering into the equalization (EQ) tank. The groundwater is then gravity fed from the EQ tank to the DAT by a 4 inch diameter pipe. After treatment, the groundwater is transferred from the DAT through a 3 inch ball valve that reduces down to 2 inch diameter pipe to pass through the transfer pump. After the transfer pump, the piping is expanded to 3 inch diameter and then reduces to 2 inch diameter to pass through the effluent water meter. After passing through the water meter, the piping expands to 3 inch diameter and discharges to the base sanitary sewer system. The vapors from the DAT are collected within an 8 inch diameter pipe that is routed through a heat pump and activated carbon before being released to the atmosphere.

System Piping. This section discusses the piping and connected components, which include valves and strainers. All system piping located on the treatment pad is Schedule 40 PVC and ranges in size from 1 inch to 4 inch diameter. Although Schedule 40 is adequate for the present application, it is recommended that Schedule 40 piping be replaced with Schedule 80 during any upgrade activities. Schedule 80 PVC pipe is more rigid and provides added protection from everyday wear at a low cost difference.

There are many expansions and reductions in pipe size throughout the GETS, as discussed above, that create turbulent flow throughout the system. These size changes affect the accuracy of measuring devices, and create head loss throughout the system thus affecting flow. Piping should be sized according to the application being used and based on flow and head loss. Although calculations are not provided in this report, they have been completed in order to recommend the following pipe changes:

- Piping at the manifold should remain 2 inch diameter to the equalization tank to provide added headloss to the extraction well pumps, which will help the pumps operate more efficiently.
- System effluent piping should remain as currently constructed. However, retrofits to piping before and after the system effluent flow meter should be completed, which will help minimize turbulent flow through the effluent meter.

Several different types of valves are being utilized throughout the system that include ball, globe, gate, diaphragm, butterfly, ball check, and flap check valves. Ball valves are located at the pipe manifold and are being used for flow adjustment of each well. They are also being used on the system effluent line for on/off service. Ball valves are best utilized for on/off service and typically do not function well for flow adjustment. This is evident with RW-1 through RW-4. The desired flow in these wells is difficult to achieve and the ball valves create turbulent flow through the piping. For better throttling control of well flow, globe valves are recommended. RW-6 is currently outfitted with a globe valve and has demonstrated greater accuracy in flow adjustment than a ball valve.

Gate valves are located immediately before and after the equalization tank for isolation during maintenance events. These valves work well in this application in that they provide on/off service, however, if replacement is needed, ball valves are sufficient in this situation at a substantial cost savings.

There is one diaphragm valve that is used to throttle flow into the DAT. This valve is an excellent control mechanism in the present situation. Diaphragm valves are designed to minimize blockage due to sludge or sediments that may enter a line, and in the case of the existing system, will help eliminate blockage due to biogrowth that has been observed.

Butterfly valves are being utilized on the vapor phase system before and after the activated carbon drums. Although these valves are excellent for throttling flow, they are being utilized for on/off service only. However, this is the most cost effective application.

Several types of check valves are being utilized on the individual well piping runs as well as on the system effluent line. Ball check valves are being used on the system effluent line and modified flap type valves on the individual lines for RW-1 through RW-4. Although these check valves have been sufficient for the application, they are susceptible to fouling and difficult to clean. Flap type check valves are recommended for replacement. This type valve is less likely to foul because it opens to the full diameter of the pipe and is easier to clean because it can be left in line.

Instrumentation. Process data is collected from the GETS to monitor and evaluate its performance. This data includes: (1) flow from each well; (2) pipe pressure from each well; (3) flow of system effluent; (4) temperature of air stream before and after the heat pump; and (5) differential pressure across the carbon drums. All of the current instruments require manual data collection, however, the instruments will be replaced or coupled with automated instruments that will enable the system to be monitored via telemetry.

There are two different types of flow meters being used which include nutating disc and turbine. The nutating disc meters are installed on two of the five well influent lines. These type meters require several moving interior parts to register flow and have been inaccurate. Upon breakdown of these meters, several of the internal parts were observed to be broken due to sediment and biogrowth buildup. The turbine meters, installed on the remaining three wells and the system effluent, have only one moving part, minimizing fouling due to biogrowth and sediment. Turbine meters should be installed with the telemetry

system. Also, all meters except for RW-6 meter are installed incorrectly, causing a loss in accuracy. These meters have piping restrictions immediately before and after the meter. Flow meters installed within a piping system should have straight pipe runs before and after without any restrictions within a minimum distance of ten times the pipe diameter upstream and five times the pipe diameter downstream to provide the greatest accuracy.

There have always been discrepancies between the total flow from all recovery wells compared to total flow of the system. The system total flow has consistently been larger than the total well flows. Much of this discrepancy can be accounted for in meter inaccuracy and also water introduced to the system from the decontamination pad sump, treatment pad sump, and purge water that has not been accounted for. To account for this additional flow, it is recommended that flow meters be installed on the decon sump and treatment pad sump transfer lines. Also, records of groundwater added from purging activities should be maintained.

The pressure gauges used for the well pipe pressure are liquid filled, which should always be used for replacement. Bleed off valves should be installed on each of these pressure gauges to relieve pressure when not in use. This will help prolong the life of the gauges.

The differential pressure gauges should be observed for accuracy each time the system is shutdown. If the gauges do not return to zero during shutdown periods, they should be corrected or replaced. The stems of the temperature gauges should be checked for excessive wear or deterioration. If a gauge appears faulty, it should be replaced.

Controls. The GETS is controlled with a programmable logic controller (PLC) that controls all pumps manually or automatically, and activates alarm conditions. This section does not discuss the PLC, but addresses the float controls in the equalization tank and DAT that activate alarms. The float control system is setup identical in both applications with a low level sensor, a high level sensor, and a high/high level sensor. These type float controls have a small enclosed magnet that floats up and down a shaft and either opens or closes a circuit. These floats have been susceptible to fouling causing the float to work incorrectly and repeated alarms to be activated. It is recommended that the current float controls be replaced with cable suspended floats. These type floats consist of either a mercury switch or micro-switches that are hermetically enclosed in the float. The exterior of the float is usually conical in shape. As the water level rises, the float tilts activating the interior switch which controls the pumps or alarm conditions. The cable suspended floats are easily cleaned and provide highly reliable service and eliminate problems due to fouling since the switches are isolated from the process water. Cable suspended floats are currently found in the decon pad sump and treatment pad sump.

#### Equalization Tank

The existing equalization tank is constructed of carbon steel that is coated with epoxy paint. The tank has a maximum capacity of 1,500 gallons and is six feet in diameter and seven feet tall. The tank is corroding in several places internally. The exterior of the tank is also rusting in several areas on the top. Because the tank is steel and there is no site glass installed, the water level cannot be monitored during normal operations. The tank is also difficult to clean because entry is limited through the top of the tank.

It is recommended that the steel tank be replaced with a polyethylene tank. Polyethylene is resistant to the contaminants of concern and does not rust. A tank constructed of clear polyethylene would allow observation of the water level during normal operations. The tank should also be equipped with a ladder and should be fitted with a large diameter bung near the bottom so that sediments could be easily cleaned

out of the tank from ground level. Currently, groundwater is fed into the tank and dropped from the top through a three inch opening. This action causes aeration that promotes biogrowth within the tank. The feed pipe should be extended to feed beneath the normal water level, which should help eliminate some biogrowth.

### Diffused Aeration Tank

The DAT is designed to aerate the contaminated groundwater and remove the volatile contaminants. The aeration process is accomplished by air forced into the DAT chambers through diffuser pipes. Previously, the water flow into the DAT was limited by stoppage of air flow through diffuser pipes due to hydraulic head pressure above the pipes in the first four chambers. One diffuser pipe was removed from the seventh and eighth chamber in an attempt to force additional air to the front chambers. This did allow some increased flow into the DAT. Later, the diffuser pipes were moved upward by approximately one inch to compensate for the hydraulic head pressure above the diffuser pipes. This allowed an increase in flow into the DAT and the system is currently running at maximum capacity based on the yield of the recovery wells. It is recommended that the diffuser pipes removed for the seventh and eighth chamber be reinstalled to add additional aeration to the process.

### Heat Pump

The heat pump is used to lower the relative humidity of the vapor stream from the DAT and condense out as much moisture as possible before the vapor stream enters the carbon drums. This decrease in moisture content provides more efficient use of the carbon. The heat pump contains copper coils that are corroded by hydrogen sulfide gas that is produced from the aeration process in the DAT. The copper coils breakdown and corrode when brought in contact with hydrogen sulfide gas. The entire heat pump unit has been replaced once and the copper coils have been replaced three times. The coils on the pump at this time have been coated with a protective heresite compound that resists corrosion from the hydrogen sulfide gas. If the heat pump is kept on line it is recommended that the copper coils be replaced with stainless steel coils, which will not be affected by hydrogen sulfide gas and the unit should be serviced by a certified HVAC technician on a quarterly basis.

Other options to removing moisture from the vapor stream, including duct heater and regenerative dryers, have been researched. However, these options do not provide a maintenance cost savings. The carbon drums are also a limiting factor to the type of technology used to dry the air due to the heat restrictions associated with using carbon. A recommendation to take the heat pump offline will be justified in the next section.

### Carbon Units

There are four carbon drums, installed in parallel, used to remove contaminants from the air stream before discharge to the atmosphere. The only COC for regulatory compliance of offgas discharge is vinyl chloride. Activated carbon is not a viable treatment technology for a mixed contaminant stream that contains vinyl chloride. This is due to different compound molecular weights. It has been observed that vinyl chloride concentrations have actually increased from the carbon influent to the effluent because the lighter compound (vinyl chloride) will remain in the carbon until heavier compounds enter and displace the lighter compounds resulting in higher effluent concentrations due to a collected mass.

The air effluent is currently regulated by a vinyl chloride concentration of  $0.37 \text{ mg/m}^3$ , which has not been exceeded in either the carbon influent or effluent since the system has been in operation. Vinyl chloride

was chosen as the indicator due to its more carcinogenic characteristics compared to all contaminants existing at the site. In the event the vinyl chloride level of  $0.37 \text{ mg/m}^3$  is exceeded, corrective action must be implemented.

The carbon continues to filter out the contaminants in the vapor stream until it becomes saturated with the contaminants and breakthrough is observed indicating that the carbon needs replacement. To enhance the life of carbon it is important to eliminate moisture from the vapor stream so that water molecules do not use the adsorption sites needed for the contaminants. This was the rationale behind installing the heat pump to increase the carbon life by removing the moisture present in the vapor stream.

Carbon influent and effluent samples have shown levels below the compliance standard for vinyl chloride during the entire operation period of the system. Since it is apparent that no offgas controls are currently needed for compliance, it is recommended that the heat pump be shut down and the carbon drums removed. Should trends ever indicate the necessity for offgas controls, more effective options for controlling vinyl chloride emissions in a mixed waste stream should be evaluated. Any decision to remove or substitute another technology for the GAC drums should be made in consultation with GEPCD.

### System Effluent

The current effluent line configuration promotes a siphoning action that evacuates water from the system transfer pump causing it to lose prime. When this occurs, the pump cavitates due to air being introduced to the line, which in turn prevents the pump from working properly. This causes the DAT to become hydraulically overloaded and activates a high/high alarm in the DAT sump. As soon as the high/high alarm is activated the recovery well pumps shutdown until the water level in the sump recedes below the high level sensor.

The system effluent discharges to a manhole located approximately 400 feet southeast of the treatment pad that feeds into the base sanitary sewer system. For this discussion, the system effluent represents the piping and appurtenances from the DAT sump to the manhole. As discussed earlier, the effluent piping has several enlargements and reductions prior to the buried portion of the line. The discharge line setup creates a siphoning action that pulls water out of the DAT discharge pump causing it to lose its prime. This results in stoppage of the pump and causes hydraulic backup of the system. There is currently a vacuum relief valve installed on the effluent line to break the siphoning action, but is unreliable. To ensure that the siphoning is eliminated, which in turn will increase the efficiency of the system, it is recommended that an actuator ball valve be installed immediately after the transfer pump. The actuator ball valve functions from the transfer pumps operation. When the transfer pump turns on the valve simultaneously opens and vice versa. This will eliminate any siphoning action and also ensure that the transfer pump is always primed. This retrofit will also eliminate alarm conditions which will allow the system to operate with less frequent alarm downtime and more efficiently.

### Treatment Pad Layout

The current treatment pad layout was designed to allow space for a lamella unit and a pilot-scale rotating biological contactor; however, it currently does not efficiently use the available workspace. All major system components are located on the north half of the pad while available space on the south half is not being utilized. All system groundwater and vapor piping and electrical conduits are anchored to the pad which creates many trip hazards. The vapor stream discharge pipe is partially elevated and crosses over several monitoring components making it difficult to maneuver during maintenance activities. Figure 4 provides a layout option. The biggest differences between this layout and the current layout is to move the

EQ tank immediately south of the DAT and also move the DAT further south. These two steps would open up the entire treatment pad and allow easy access to the major components. This would also eliminate one trip hazard from piping between the EQ tank and DAT. Other changes include elevating all piping and conduit in walk spaces to eliminate potential trip hazards and also protect monitoring components, retrofit effluent line plumbing to allow required pipe runs before and after the effluent water meter, and construct a separate containment pad for the carbon drums (if retained). Pipe runs on the upstream and downstream sides of flow meters should be 10 times and 5 times the pipe diameter, respectively. These straight pipe runs will minimize turbulent flow through the meters caused by abrupt bends or size changes. Turbulent flow does not produce a steady stream through the meter which causes inaccuracies. The pad for the carbon units would contain any spill that might occur from the drums, keep the drums level, and allow room for the vapor stream blower unit. The vapor effluent stack should also be plumbed and supported to discharge vertically immediately after the blower unit. This will eliminate the current crossover of the line.

The fencing should also be retrofitted with a large opening gate along the north side of the pad. This will allow easy access for carbon drum removal and also for removal of larger components such as blowers and heat pump. The carbon drums currently have to be lifted over the fence with a crane. With the large gate, the drums could be easily handled with a backhoe. Although these changes seem extensive, they are effective ways to increase operational efficiency, safety, and productivity at the site.

### CONCLUSIONS AND RECOMMENDATIONS

The GETS is currently operating within GEPD compliance standards. Evaluation of the original design specifications and 2 years of operating data indicate the GETS has limited capacity to accept additional contaminated water flow. If additional flow above the maximum design flow rate of 60 gpm is necessary for future operations, the system should be expanded and/or redesigned.

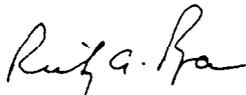
Air influent samples to the GAC drums have shown levels well below the compliance standard for vinyl chloride during the entire 2-year operating period of the system. As it is apparent no offgas treatment is necessary, it is recommended that the GAC drums be taken offline. Further, the heat pump, which supports the GAC drums, should be shut down or taken offline, which will significantly reduce operating and maintenance costs. Any decision to remove the GAC drums should be made in consultation with GEPD.

Several components of the GETS should be considered for replacement. The recommendations for component replacement made in the OPE are effective ways to increase operational efficiency, safety, and productivity at the site.

Should you have any questions, please feel free to contact me at (423) 531-1922.

Sincerely,

**ABB ENVIRONMENTAL SERVICES, INC.**

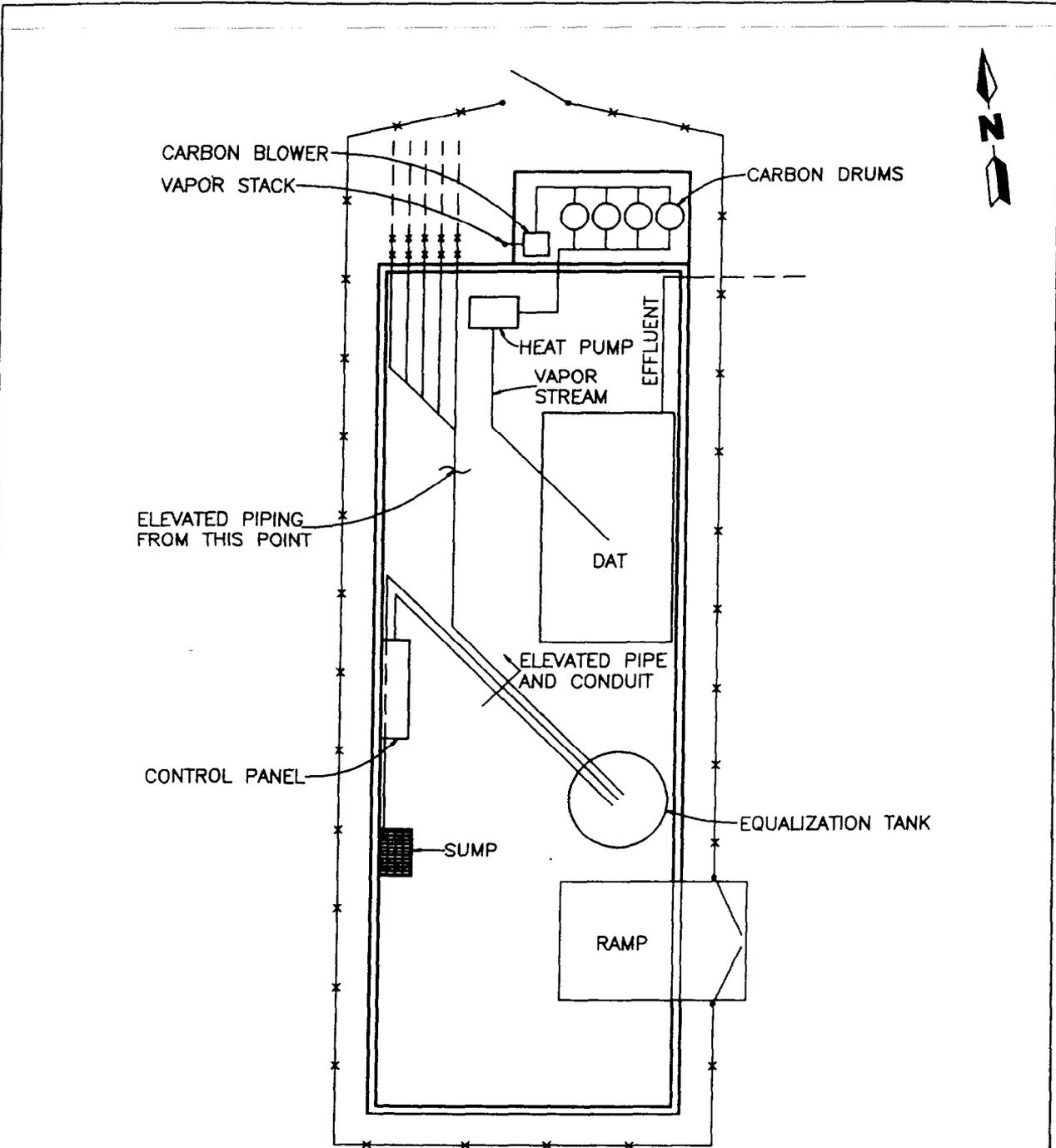


Ricky A. Ryan, P.E.  
Project Engineer

Attachments

c: Rhonda Bath, NSB Kings Bay  
Richard Tringale, ABB-ES

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NOT TO SCALE

FIGURE 4  
CONCEPTUAL TREATMENT SYSTEM LAYOUT



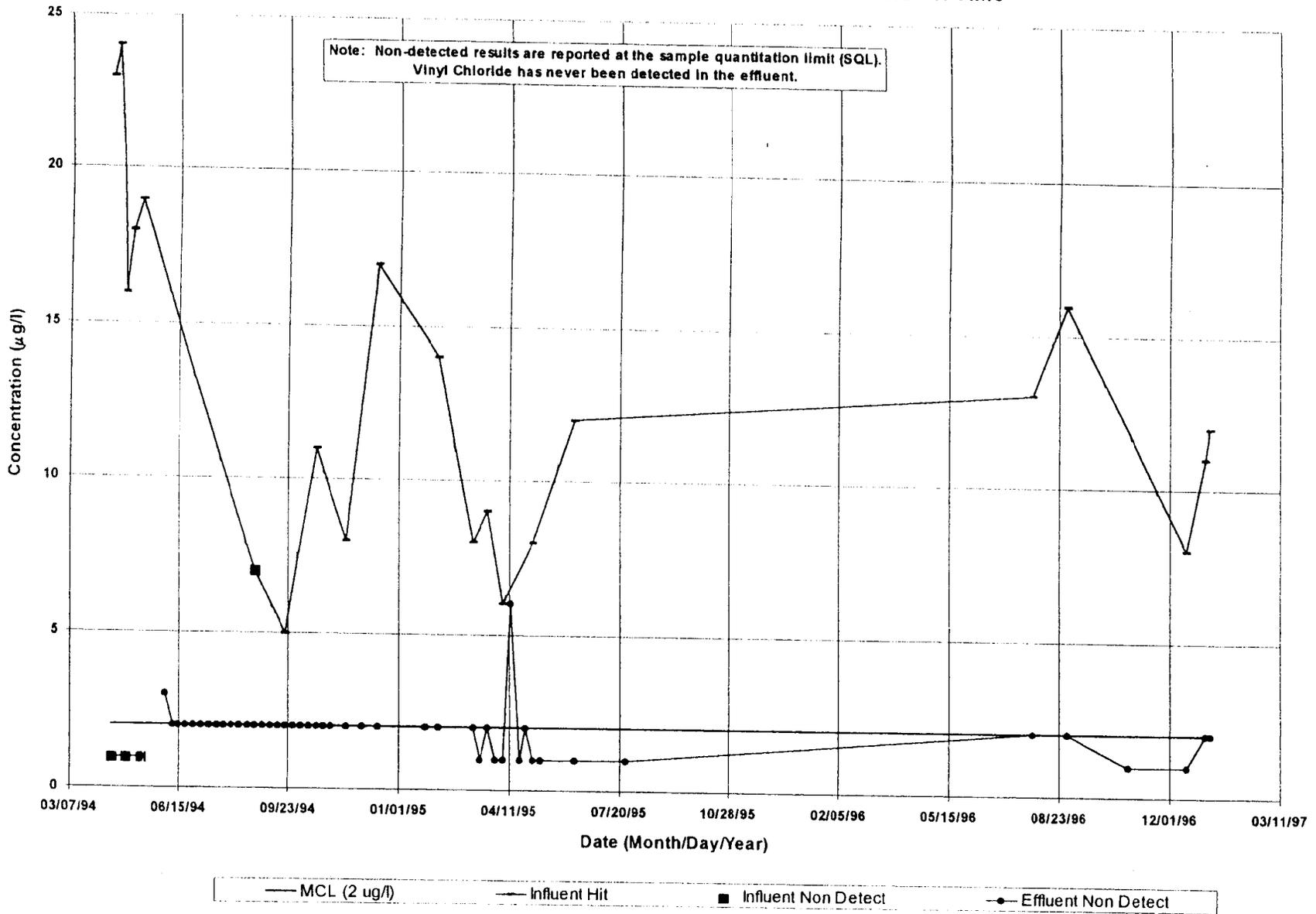
TREATMENT SYSTEM  
EVALUATION  
SITE 11, OLD CAMDEN  
COUNTY LANDFILL  
NAVAL SUBMARINE BASE  
KINGS BAY, GEORGIA

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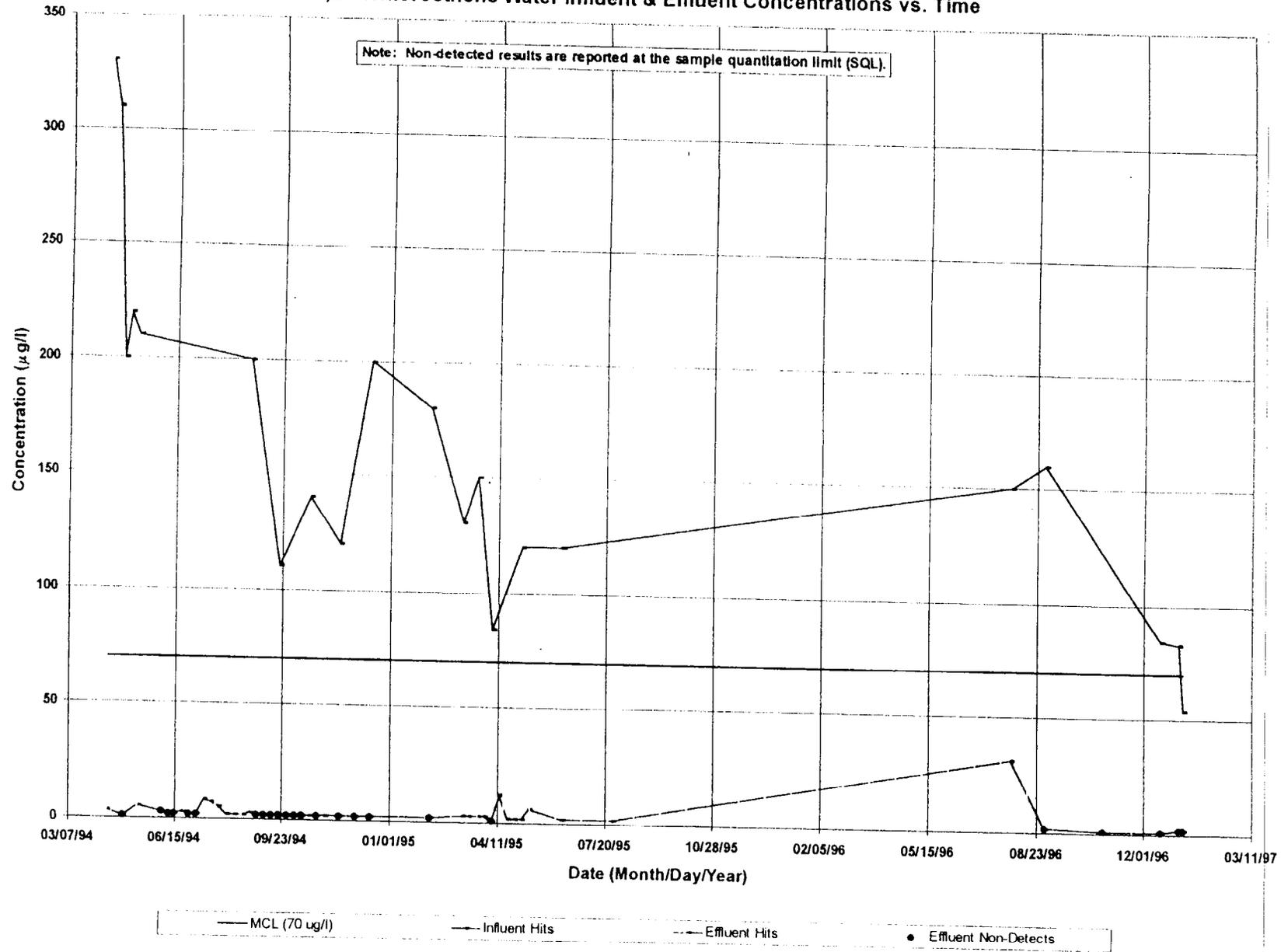
## Appendix A

### Graphs

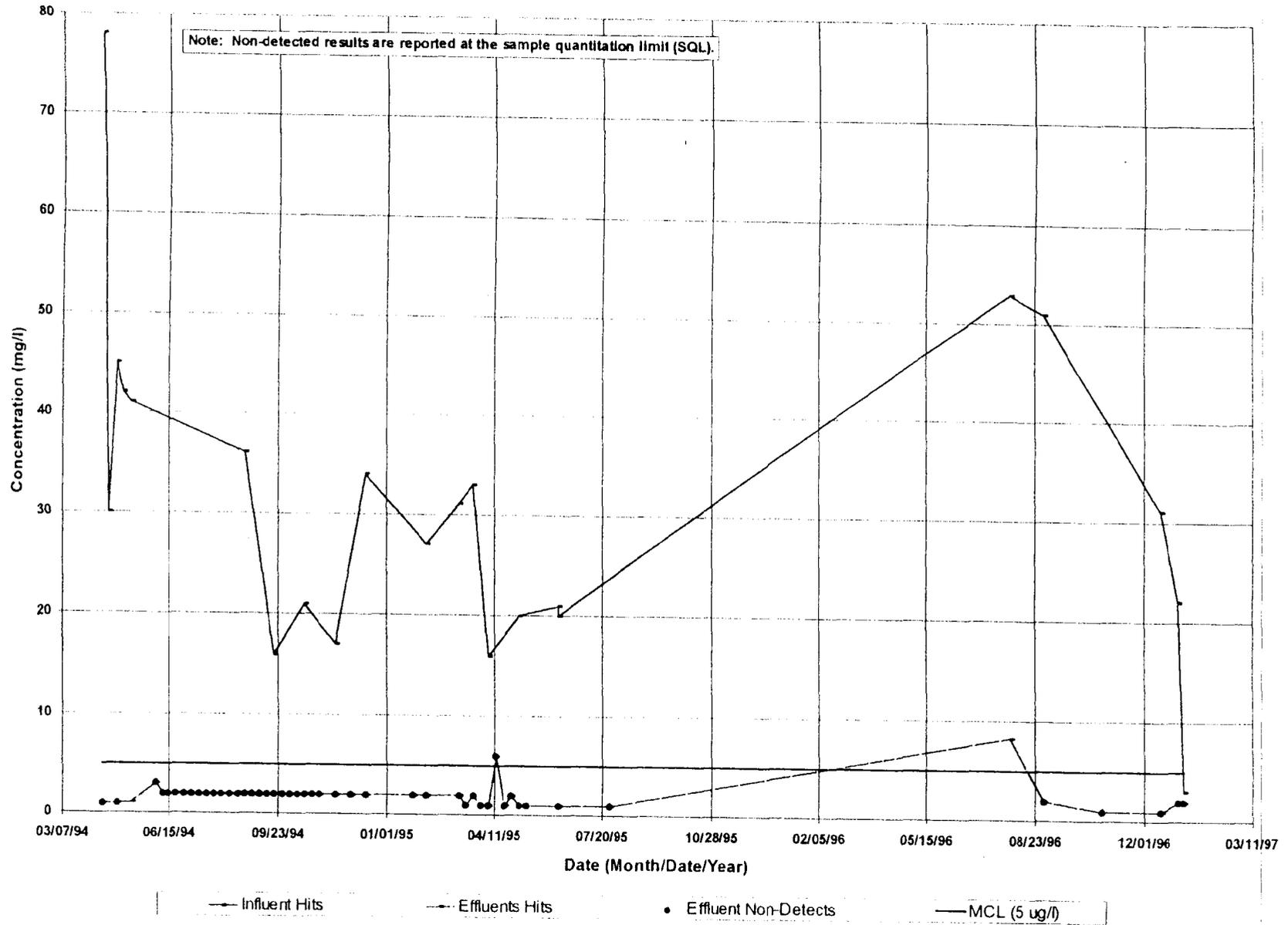
### Vinyl Chloride Water Influent & Effluent Concentrations vs. Time



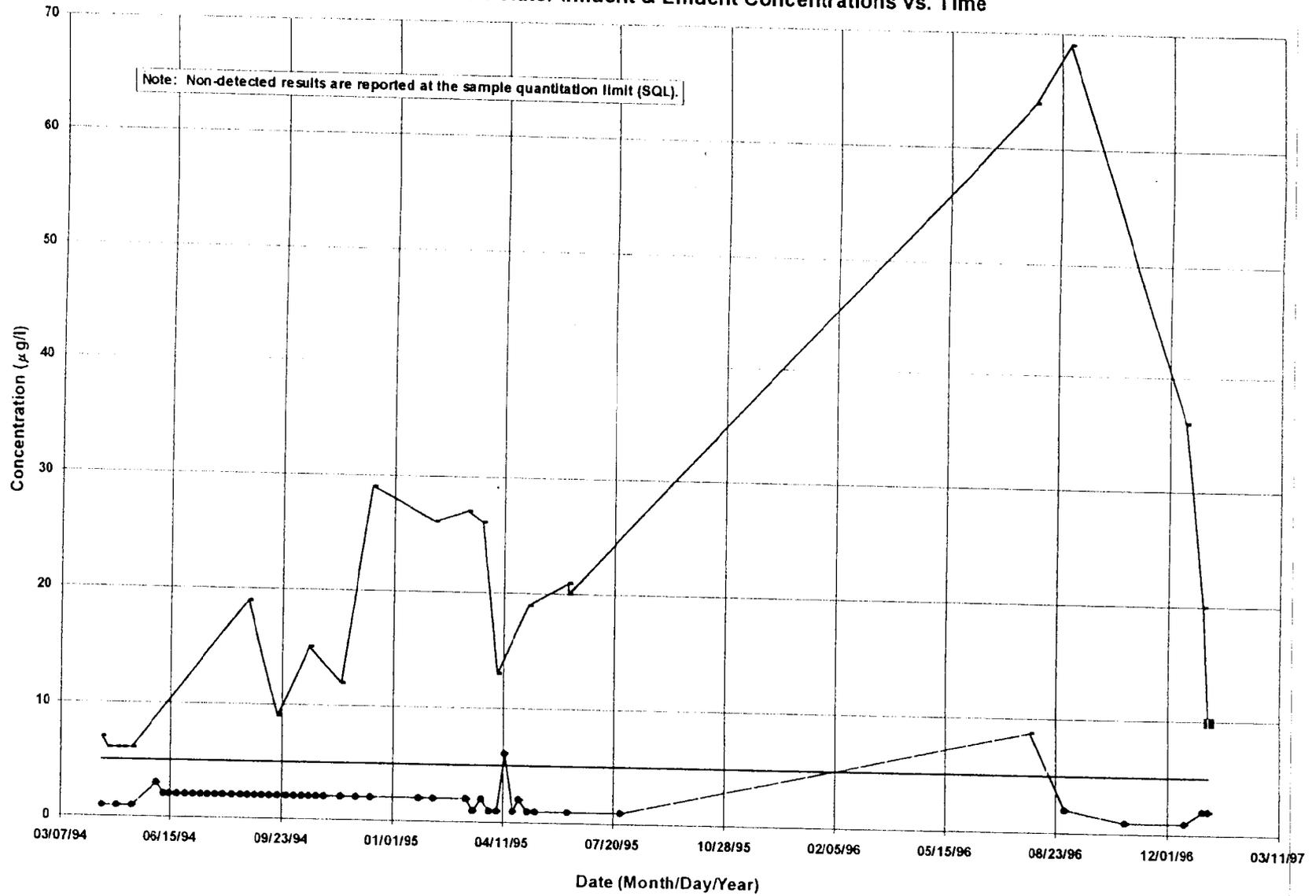
cis-1,2-Dichloroethene Water Influent & Effluent Concentrations vs. Time



Trichloroethene Water Influent & Effluent Concentrations vs. Time

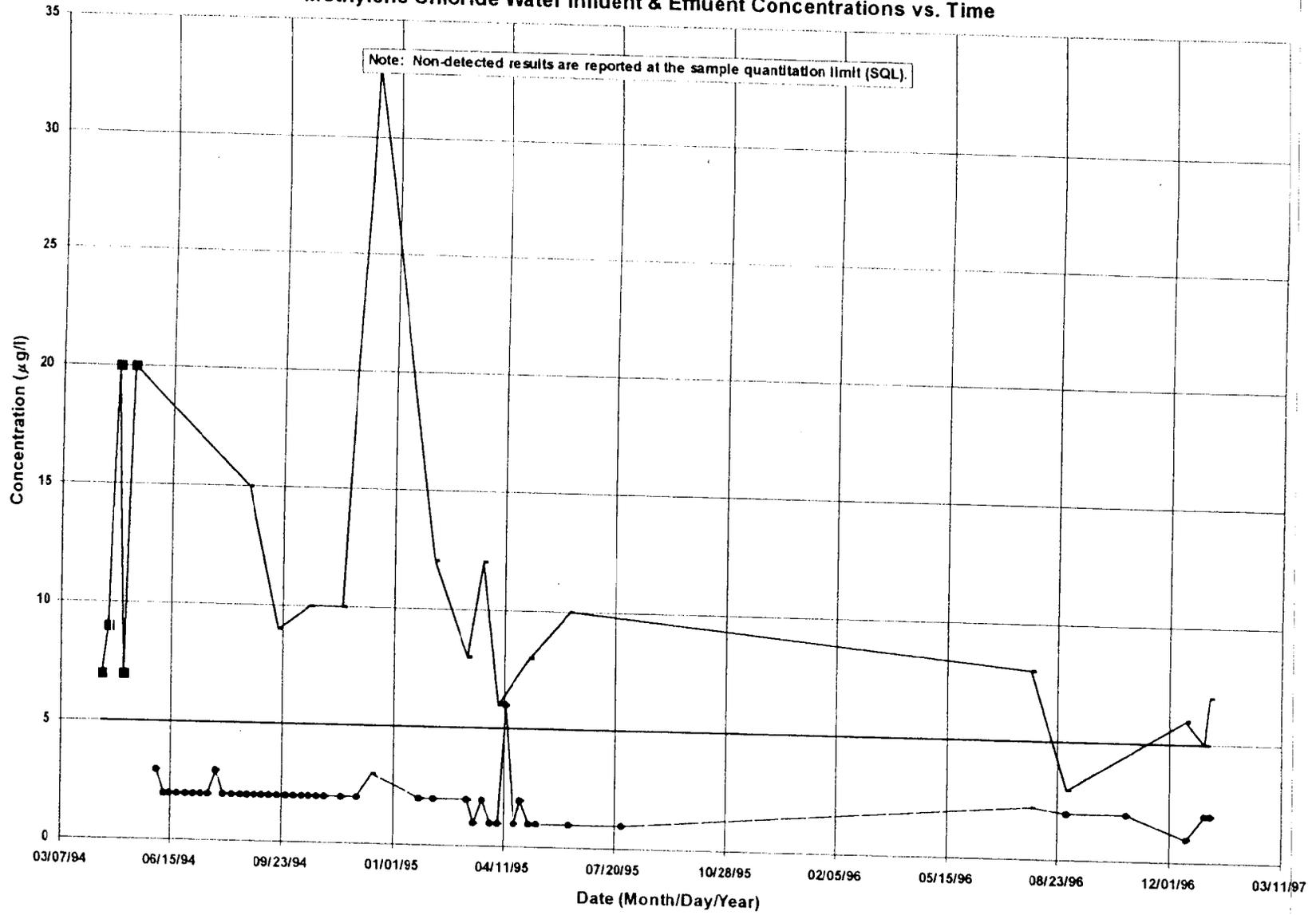


### Tetrachloroethene Water Influent & Effluent Concentrations vs. Time



— MCL (5 ug/l)    — Influent Hits    ■ Influent Non-Detects    - - - Effluent Hits    ● Effluent Non-Detects

# Methylene Chloride Water Influent & Effluent Concentrations vs. Time



— MCL (5 ug/l)    — Influent Hits    ■ Influent Non-Detects    - - - Effluent Hits    ● Effluent Non-Detects

Risk Assessment Meeting Minutes for Kings Bay Site 11 - Old Camden County Landfill  
April 3, 1997

Attendees:

Rhonda Bath (KingsBay)  
Julie Cozzie (ABB-ES, Inc.)  
Anthony Robinson (SOUTHDIV)  
Charles Shore (ABB-ES, Inc.)  
Richard Tringale (ABB-ES, Inc.)

The meeting opened at approximately 9:45 am with a discussion of the proposed agenda and the desired outcome and expectations of each participant. Rich Tringale of ABB Environmental Services, Inc. then gave a review of relevant Kings Bay site history including investigative activities, delays and changes to original RI/FS schedule, and a discussion of the groundwater interim measure.

Julie Cozzie summarized the evaluations that had been performed as part of a Screening Risk Evaluation in 1993. The conversation progressed to a discussion of the proposed evaluation pathways and scenarios for the current risk assessment at Old Camden County Landfill. Anthony Robinson expressed a concern about conflicting views of the complexity of risk assessment. Mr. Robinson had been informed that the process was cookbook. Ms. Cozzie explained that although many aspects of a human health risk assessment are well defined as to default scenarios and exposure parameters; it is most often in the client's best interest to provide site-specific, more detailed analyses. Furthermore, these more site-specific types of assessment are more readily received if all parties are involved in the decision making process rather than learning of the details of the assessment at the review stage. This led to a discussion of the usefulness and regulatory requirement for a work plan. Although the new Georgia Environmental Protection Division (GEPD) guidance for risk assessment at RCRA sites clearly requires a work plan be submitted and approved prior to conducting a risk evaluation, there has been discrepant views of the need for this work plan from GEPD. The attendees decided that this question should be again presented to the regulators.

Julie Cozzie and Charlie Shore discussed the Georgia guidance and requirements. Julie indicated that available USEPA, Region IV, and Georgia guidance provides a complete overview of the human health risk assessment process but that the specifics need to be agreed to prior to the conducting of the risk assessment. Charlie summarized the ecological guidelines and said that the guidance generally defaulted to Region IV protocol.

Julie led a discussion of available groundwater, surface water, surface soil, sediment, and air data for the risk assessment. A consensus was reached that it was appropriate to recommend to the State that the validated and comprehensive surface water, sediment, soil, and groundwater data collected in September of 1994 be used as the data set for the risk assessment. In accordance with the recent guidelines, Julie proposed using the lesser of the maximum detected value or the 95% upper confidence limit for media with greater than 10 samples, the maximum for media with less than 10 samples, and the average analyte concentration within the groundwater plume. ABB-ES proposed that air concentrations be modeled since the air sampling does not reflect seasonal variations, and is not extensive.

Enclosure (6)

Julie led a discussion of how the human health exposure assessment should be conducted, with respect to the interim measure (IM). Julie proposed the use of both residential and industrial future exposure scenarios, even though further development of the site is highly unlikely in the near future. An assessment of the risks to soils under a trespasser or recreational user (jogger) would be addressed. Surface water and sediment in the off-site pond under a recreational user scenario would be addressed. The groundwater assessment would include an assessment of risk from current potential exposures via volatilization and dermal contact with groundwater via an irrigation or sprinkler system. It was decided that input from the GEPD risk assessor should be sought to determine if an assessment of the risks from groundwater exposure in backyard swimming pools and wading pools is necessary (these assessments were evaluated in the screening risk evaluation in 1993). GEPD input is also required to determine the requirement to assess groundwater as a future potable water source. A consensus was reached on two groundwater exposure scenarios: 1) exposure outside of the capture zone, and 2) a hypothetical scenario evaluating the risks associated with exposure to the groundwater both inside and outside the capture zone. Additional input is requested from GEPD concerning a preferred volatilization model for the residential groundwater irrigation scenario.

Charlie Shore then summarized the proposed approach for the ecological risk assessment. Charlie proposed that a terrestrial risk assessment for ecological receptors is unnecessary. In a preliminary screening-level assessment, Charlie demonstrated that metals and pesticide concentrations are typically only slightly above or consistent with the background criterion, below or within the reporting limit range, and/or well below ecological levels of concern for terrestrial vertebrate, invertebrate, or plant receptors. Furthermore, many of these contaminants were only sporadically detected, and are not clearly site-related. Charlie suggested that the moderate Polynuclear Aromatic Hydrocarbon (PAH) concentrations at one sample location in soil could be addressed qualitatively in the text of the report without a formal risk assessment.

Charlie summarized several ecological issues that should be discussed with GEPD:

- \* the restriction of the assessment to Porcupine Lake and the surrounding littoral region,
- \* the choice of semi-aquatic species for study,
- \* the use of subsurface soils for sediment background screens,
- \* the exclusion of essential nutrients from the analysis, and
- \* the use of post-1994 groundwater data to estimate surface water concentrations. Charlie proposed that contaminants detected in Porcupine Lake surface waters, but not in the groundwater plume, would be excluded from further analysis.

A consensus was reached that a meeting with regulators is essential to discuss the elements of the human health and ecological risk assessment. This meeting would allow the ABB-ES, Inc. risk assessors and the GEPD risk assessors to reach an agreeable approach that will address all reasonable future pathways that are of concern to the community and the State. A tentative date for this meeting of April 23 was proposed. This tentative date has been postponed until an undetermined future date.

## Proposed KingsBay Risk Assessment Meeting Agenda

Site History Review

Discussion of Preliminary Risk Evaluation

Discussion of GA Guidance and Requirements

Current Proposed Approach and Issues with the Human Health Risk Assessment

Proposed data for evaluation

- September 1994 surface water, sediment, soil, and groundwater data - last comprehensive and validated data set
- Screen surface water against groundwater to determine site related contamination
- Screen sediment against subsurface soil background - manmade pond therefore sediments are consistent with subsurface soil geology

Exposure scenarios

- Only outside the interim measure area
- Assumption that interim measure both inside and outside the capture zone
- Future residential scenario - potable water, showering model
- Inhalation via volatilization into houses and via sprinkling system
- Dermal contact assessment - swimming pools and wading pools

Volatilization model(s)

- PRE model
- RBCA model

Ecological Risk Issues

- Screen sediment data against subsurface soil
- Terrestrial risk assessment
- Discussion of macroinvertebrate study
- Selection of semi-aquatic species for evaluation