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Focused Feasibility Study
Revision 3

Crab Orchard National Wildlife Refuge
PCB Operable Unit
Sites 32/33
Marion, Illinois

August 2004

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List of Acronyms and Abbreviations

[Note: All acronyms and abbreviations may not be used in this document.]

µg/L	micrograms per liter
AA	atomic absorption
ARARs	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
bgs	below ground surface
BNA	base-neutral-acid extractables
BOD	biochemical oxygen demand
CADD	computer-aided design and drafting
CCB	continuing calibration blank
CCC	calibration check compound
CCV	continuing calibration verification
CE	chloroethene (also known as vinyl chloride)
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
CFR	Code of Federal Regulations
CLP	Contract Laboratory Program
cm/s	centimeter per second
COC	Chain of Custody
CONWR	Crab Orchard National Wildlife Refuge
COPC	constituent of potential concern
CRDL	Contract Required Detection Limits
CRL	Central Regional Laboratory
CRQL	Contract Required Quantitation Limits
CVOC	chlorinated volatile organic compound
1,2-DCE	1,2-dichloroethene
DCF	document control format
DO	dissolved oxygen
DOD	United States Department of Defense

DOI	United States Department of the Interior
DQO	Data Quality Objective
ERH	Electrical resistive heating
FCR	field change request
FERA	Final Effective Risk Assessment
FFA	Federal Facility Agreement
FID	flame ionization detector
FIT	field investigation team
FS	Feasibility Study
FSP	Field Sampling Plan
F&WS	United States Fish and Wildlife Service
GC/MS	gas chromatograph/mass spectrophotometer
gpm	gallons per minute
HSC	Health and Safety Coordinator
HSP	Health and Safety Plan
HSR	Health and Safety Representative
IAC	Illinois Administrative Code
ICB	initial calibration blank
ICP	inductively coupled plasma
ICS	interface check samples
ID	internal diameter
IDW	investigation-derived waste
IEPA	Illinois Environmental Protection Agency
IQAT	Independent Quality Assurance Team
kg	kilogram
L	liter
LCS	laboratory control sample
LRA	linear range analysis
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MDL	Method Detection Limit
mg	milligram
mL	milliliter
MNA	monitored natural attenuation

MS	matrix spike
MS/MSD	matrix spike/matrix spike duplicate
MSD	matrix spike duplicate
M.S.L.	mean sea level
mV	millivolt
NAPL	nonaqueous-phase liquid
NCP	National Contingency Plan
ng	nanogram
NGVD	National Geodetic Vertical Datum, 1929
NIST	National Institute of Standards and Technology
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NTU	nephelometric turbidity units
O&M	operation and maintenance
ORP	oxidation-reduction potential
OSC	On-site Coordinator
OSHA	Occupational Safety and Health Administration
OVA	organic vapor analyzer
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCBOU	PCB Operable Unit
PCDD	polychlorinated dibenzo(p)dioxin
PCDF	polychlorinated dibenzofuran
pg	picogram
pH	negative logarithm (base 10) of hydrogen ion activity
PID	photoionization detector
PLFA	phospholipid fatty acid
PM	Project Manager
ppb	parts per billion
PPE	personal protective equipment
ppm-v	parts per million - volume basis
PRP	Potentially Responsible Party
PVC	polyvinyl chloride
QA/QC	Quality Assurance/Quality Control

QAM	Quality Assurance Manual
QAMP	Quality Assurance Management Plan
QAO	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QC	quality control
RA	remedial action
RAGS	Risk Assessment Guidance for Superfund
RAS	routine analytical services
RCRA	Resource Conservation and Recovery Act
RD	remedial design
the Refuge	Crab Orchard National Wildlife Refuge
RF	response factor
RI	Remedial Investigation
ROD	Record of Decision
ROI	radius of influence
RPD	relative percent difference
RPM	Remedial Project Manager
RSD	relative standard deviation
RT	retention time
SAP	Sampling and Analysis Plan
SARA	Superfund Amendments and Reauthorization Act
SAS	special analytical services
SC	specific conductance
SHERP	Safety, Health, and Emergency Response Plan
SI	Supplemental Investigation
SII	Schlumberger Industries, Inc.
SMC	Sample Management Coordinator
SOP	standard operating procedure
SOW	Statement of Work
SPCC	system performance check compound
SRM	standard reference materials
S.U.	standard units
SVOC	semivolatile organic compound
SW846	Test Methods for Evaluating Solid Waste, 1986

TAL	Target Analyte List
TBD	to be determined
TCE	trichloroethene
TCL	Target Compound List
TCLP	Toxicity Characteristic Leaching Procedure
TEMP	temperature
TIC	Tentatively Identified Compound
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
TSCA	Toxic Substances Control Act
TTU	Thermal Treatment Unit
USDOT	United States Department of Transportation
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOA	volatile organic analysis
VOC	volatile organic compound

Section 1
Introduction

1.1 Background and Document Chronology

1.1.1 Actions Leading to ESD for Groundwater Remediation

The PCB Areas Operable Unit (PCBOU) consists of four of the original "study sites" defined in the remedial investigation for the Crab Orchard National Wildlife Refuge Superfund Site. Two of these sites, Site 32 (Area 9 Landfill) and Site 33 (Area 9 Building Complex), are addressed in this document. A site plan showing the key features of Sites 32/33 is included on Figure 1-1.

As required in the Record of Decision (ROD) for the PCBOU issued by the United States Environmental Protection Agency (USEPA) in 1990, remedial action of polychlorinated biphenyls (PCBs) was performed at Sites 32/33 from late 1995 to June 1997. This action included several excavations of PCB-impacted soil near Building I-1-23 and near Building I-1-2, and from surface water drainage swales at the sites. PCB-impacted soil beneath the landfill area was also excavated after the removal and disposal of waste materials from the Area 9 Landfill. PCB-impacted sediment was also removed from the Crab Orchard Lake embayment.

During the PCB remedial action, three of the excavated PCB source areas at Sites 32/33 (Area 9 Repository, Building I-1-23, Building I-1-2) were further characterized. During this additional sampling, volatile organic compounds (VOCs) were detected in groundwater. The VOC-contaminated groundwater was determined to warrant further characterization. An additional groundwater investigation was performed at the Sites in the 3rd quarter of 1997. The results from this work were presented in a report in March 1998, which indicated that at least three plumes of VOC-contaminated groundwater were present in the shallow aquifer. However, the nature and extent (horizontal and vertical) of the contamination and the site characteristics were not sufficiently defined at that time to allow selection of a remedial approach for groundwater. Therefore, a workplan proposing further groundwater investigation and on-site pilot tests of preselected cleanup technologies was issued in March 1998; a May 1998 revision of the workplan was approved by USEPA.

The work defined in the May 1998 workplan was performed during the summer of 1998. A sampling round that included confirmatory investigation sampling of monitoring wells and other sampling for Performance Standards Compliance Monitoring for the PCBOU under the Consent Decree was performed in December 1998.

A document titled Groundwater Investigation Report and Focused Feasibility Study was submitted to USEPA in July 1999 (Revision 0). That report contained a summary and analysis of the results of the summer 1998 groundwater investigation (GWI) for Sites 32/33 and the December 1998 sampling for all sites within the PCBOU, and a Focused Feasibility Study (FFS) that evaluated a number of alternatives for remediation of contaminated groundwater at Sites 32/33. The document was subsequently revised to address USEPA's comments on Revision 0, and was reissued in January 2000 (Revision 1) (RMT, 2000). Following discussions with USEPA to resolve certain review comments on Revision 0, the Revision 1 GWI/FFS report was approved by USEPA.

In June 2000, USEPA issued an Explanation of Significant Differences (ESD) for the PCBOU. The ESD specifies the remedy selected for additional source removal to address trichloroethene (TCE) contamination in the soil and to mitigate further degradation of the groundwater associated with Sites 32/33 at the PCBOU. The selected remedy is described as Alternative "E" in the Revision 1 GWI/FFS report. This alternative addresses the sources of VOCs through the use of multiphase extraction (MPE) wells to be installed at each VOC source area. The selected alternative also includes the use of phytoremediation (planting of hybrid poplar trees) for the groundwater plumes at their farthest downgradient extent, to reduce VOC concentrations in the groundwater before it discharges to Crab Orchard Lake or to drainage swales tributary to the lake. The use of monitored natural attenuation (MNA) is also included as a component of the remedy.

U.S. Fish and Wildlife Service (F&WS) did not concur with the remedial action specified in the ESD. Rather than the use of MPE technology, F&WS informed USEPA of their preference for use of phytoremediation alone (Alternative "C" in the FFS Report) for remediation at the VOC source areas (F&WS, 2000).

1.1.2 Predesign Investigation and Preliminary Design Report

Predesign investigation fieldwork and pilot testing were conducted from September to November 2000, following workplans approved by USEPA, to obtain data and other information needed for the final design of the remedial action specified in the ESD.

The predesign investigation fieldwork included an extensive soil sampling program focused on the VOC source areas identified from previous work, to better define the nature and extent of the source areas. A total of 377 soil samples were collected and analyzed for VOCs using an on-site mobile laboratory. Several monitoring wells were also installed during the predesign fieldwork, and groundwater samples were collected from the new wells and several previously existing wells across the site. Pilot testing was also performed to attempt to simulate the expected performance of MPE wells, and to provide data to support the final design of the remediation systems.

Prior to performing the pilot tests, it was recognized that interpretation of the test results would be difficult owing to the inability to simulate longer-term full-scale effectiveness of a MPE system in a very short-term test that did not allow for sufficient time to dewater the clay soil. Although these difficulties were indeed encountered, the pilot testing results and the data from the tests of physical properties of the Upper Clay soil were sufficient to show that the remediation effectiveness of MPE wells using a conventional design approach was likely to be more limited than the effectiveness expected at the time the ESD was prepared. In addition, information obtained from the predesign investigation indicated that the extent of the VOC source areas and the amount of VOC source mass remaining were significantly greater than estimated prior to the investigation.

The information from the predesign fieldwork was used to develop a preliminary design that applied MPE technology at each VOC source area as specified in the ESD, while addressing the expected performance challenges seen from the predesign testing. The preliminary design plans and the investigation data from the predesign fieldwork were combined in a Preliminary Design (PD) Report for the Groundwater Remedial Action - Revision 0, issued in May 2001.

1.1.3 Developments Subsequent to Preliminary Design Report

After the initial review of the data and design concepts in the PD Report, additional information was requested by F&WS to support their evaluation of the preliminary design concepts and details. This request led to the preparation of three addenda to the PD Report that were issued over the period June to September 2001, as summarized below.

Addendum No. 1

In response to review comments on the PD Report provided in correspondence and in a conference call, estimates of the total VOC mass present in each of the primary VOC source areas, and of the VOC mass removal expected to be achievable using MPE as presented in the PD Report, were prepared and issued in Addendum No. 1 on 26 June 2001.

Addendum No. 2

During discussions of Addendum No. 1, modifications of the source area treatment systems as configured in the PD Report were proposed by Schlumberger. The purpose of the modifications was to address the expected difficulties in recovering significant quantities of VOCs from the clay soil in certain source areas, owing to the relatively low permeability and high moisture retention capacity of the clay. Simulations of the effect over time of the proposed treatment system modifications on the VOC plumes downgradient of the source areas were also prepared, using the groundwater contaminant transport model developed for the FFS Report (RMT, 2000). The modeling simulations and updated estimates of VOC mass removal effectiveness with the proposed treatment system enhancements were issued in Addendum No. 2 on 28 August 2001.

Several alternative technologies for possible application at the Building I-1-2/I-1-3 areas were also considered, in response to a request by F&WS. The technologies considered include the following:

VOC Source Area Treatment

In Situ Chemical Treatment

- ISOTEC process
  In Situ Oxidative Technologies, Inc.
- Ferox process
  ARS Technologies, Inc.

In Situ Bio-enhancement

- HRC process
  Regenesis

VOC Plume Cutoff and *In Situ* Treatment

Chemical Treatment

- Permeable reactive barrier (PRB) with zero-valent iron (trenching method)
  EnviroMetal Technologies, Inc.

- PRB with zero-valent iron (pneumatic injection method)
  ARS Technologies, Inc.
- ISOTEC process
  In Situ Oxidative Technologies, Inc.

In Situ Bio-enhancement

- HRC process
  Regenesis

Based on the updated estimate of VOC mass removal that could be accomplished, the alternative technology evaluations, and the groundwater modeling simulations, the following remedial actions for each of the VOC source areas were recommended in Addendum No. 2:

VOC SOURCE AREA	RECOMMENDED ACTION IN ADDENDUM NO. 2
Buildings I-1-2/I-1-3	PRB with monitored natural attenuation
Building I-1-23	Groundwater extraction and treatment system with phytoremediation and monitored natural attenuation
Area 9 Repository	Phytoremediation with monitored natural attenuation

Addendum No. 3 and Technical Supplement Report

During discussions of Addendum No. 2, the following additional information was requested:

- Modeling simulations of expected groundwater quality improvements over time for several additional remediation approaches.
- A listing of key advantages and disadvantages for use of a PRB or hydraulic control (groundwater pump-and-treat system) for the VOC source area at Building I-1-23.
- Estimates of the capital and present value costs for use of a PRB or a groundwater pump-and-treat system at the Building I-1-23 source area.
- A comparison of the use of a PRB or a groundwater pump-and-treat system for the Building I-1-23 source area with the standard Superfund selection-of-remedy criteria.

- Estimated volume of soil, VOC mass removal, and costs associated with potential excavation and off-site disposal of VOC-impacted soil at the Building I-1-23 source area.

The additional information listed above was provided in Addendum No. 3, issued on 25 September 2001.

During discussions of Addendum No. 3 to the PD Report, it was acknowledged that the physical differences among the separate VOC source areas, and the expected difficulties in achieving the desired level of remediation effectiveness using conventional MPE technology, were sufficiently significant to warrant re-evaluation of remedial alternatives for the separate primary VOC source areas.

It was also acknowledged by all parties involved with the PCBOU that the re-evaluation of alternatives should be documented in a revision of the FFS Report, and that a new Decision Document issued by USEPA following selection of a modified remedial action for groundwater would likely be required. A final report titled Technical Supplement for Groundwater Remedial Alternatives (RMT, 2002) was subsequently prepared and issued on 22 February 2002, containing the following information:

- A description of and details for specific remedial alternatives for each of the primary VOC source areas
- Cost estimates for the remedial alternatives
- Screening and comparative analysis of the alternatives

Comments on a draft of the Technical Supplement report (issued on 30 November 2001) were sent to Schlumberger by F&WS in a letter dated 22 February 2002. F&WS indicated their intention to prepare new human health and ecological risk assessments to support their evaluation of the remedial alternatives presented in the draft Technical Supplement report. F&WS noted that they believed that an evaluation of remedial alternatives in addition to those described in the Technical Supplement report was necessary. F&WS indicated their intention to prepare a submittal to USEPA that would present their preferred remedial action for groundwater at Sites 32/33.

In June 2002, F&WS issued a Draft Human Health Risk Assessment and a Draft Ecological Risk Assessment for Sites 32/33 to USEPA. On 8 August 2002, F&WS transmitted their Proposed Remedy Modifications for Sites 32/33 to USEPA. The remedial action proposed by F&WS was included among several alternatives for each VOC source area and plume in a draft Summary of Final Revised Remedial Alternatives for Groundwater, submitted to USEPA by Schlumberger on 30 August 2002. An updated draft of the summary of alternatives was issued to USEPA by Schlumberger on 29 January 2003, addressing comments received from USEPA and F&WS on the initial draft summary issued in August 2002. Comments on the 29 January 2003 revised summary of alternatives were sent by USEPA to Schlumberger in a letter dated 3 March 2003.

Focused Feasibility Study – Revision 2

Revision 2 of the FFS Report was submitted to USEPA by Schlumberger in October 2003 (RMT, 2003). The revised remedial alternatives that were evaluated in Revision 2 of the FFS included the alternatives as described in the 29 January 2003 summary prepared by Schlumberger, with modifications to address the comments provided by USEPA on 3 March 2003, and additional alternatives that were subsequently developed jointly by Schlumberger and F&WS.

USEPA provided written comments on the FFS – Revision 2 in a letter to Schlumberger dated 27 February 2004. Responses to USEPA's comments were sent to USEPA on 12 April 2004 by RMT, on behalf of Schlumberger. Subsequent discussions of various topics pertaining to the FFS – Revision 2 occurred among the involved parties in conference calls and at the Technical Working Group meeting held on 10 June 2004. USEPA provided clarifications for their comments on the FFS – Revision 2 in a letter to Schlumberger dated 22 June 2004.

This Revision 3 of the FFS addresses USEPA's written comments on the Revision 2 FFS and their clarifications of those comments received in correspondence as well as in conference call and meeting discussions.

1.2 Purpose and Scope

The purpose of this Revision 3 of the FFS Report is to evaluate revised and additional alternatives for the remediation of groundwater at Sites 32/33 of the PCBOU that have been developed to address VOC contamination identified at the sites.

The scope of the FFS includes the following:

- A statement of the Cleanup Standards and definition of the Remedial Action Objectives for groundwater at Sites 32/33

- A description of the approach and key assumptions used for updating the estimates of the mass of trichloroethene (TCE) remaining in the primary VOC source areas identified at the sites
- An updated review and screening of available remedial technologies
- The development and screening-level evaluation of site-specific remedial alternatives, including computer modeling simulations to estimate the effectiveness of the alternatives in meeting the remedial objectives for the sites
- The presentation of estimated costs to construct, operate, and maintain facilities, and to monitor performance, for each alternative
- A comparative analysis of the remedial alternatives developed for each VOC source area, with a discussion of the alternatives relative to one another, and with respect to each of the nine evaluation criteria identified in the National Contingency Plan (NCP) (33 FR 8664, 8 March 1990, and 40 CFR 300.430[e])

The response action objectives for groundwater are well defined in the existing Decision Documents for the PCBOU. For this reason, and to expedite the decision-making process for groundwater, as agreed by USEPA, this feasibility study proceeds directly from an initial screening of the alternatives to a more "focused" comparative analysis of the alternatives using the nine criteria specified in the NCP.

Section 2
Cleanup Standards

The Consent Decree executed by USEPA and Schlumberger Industries, Inc. (SII) (effective date August 27, 1992), for environmental remediation at the Crab Orchard National Wildlife Refuge (CONWR) near Marion, Illinois, includes a Scope of Work for Remedial Design/Remedial Action of the PCB Areas Operable Unit (PCBOU). The Scope of Work specifies Cleanup Standards for soil and sediment, groundwater, and surface water at the study sites comprising the PCBOU. The standards are based on the risk assessment as documented in the Remedial Investigation Report (O'Brien & Gere, 1988), which evaluated potential risk to human health and the environment.

The Cleanup Standards for groundwater, excerpted directly from the Consent Decree Scope of Work, are as follows:

> "Before soil remediation begins, the groundwater at the study sites comprising the PCB Areas Operable Unit will be monitored to establish current concentrations of site-related contaminants. Groundwater at the remediated study sites, and groundwater and leachate at the containment unit will then be monitored during and after remediation of the sites. The monitoring results will be evaluated to see if any of the following levels of contaminants above naturally occurring background levels has [have] been exceeded in groundwater:
>
> 1. any MCL or non-zero MCLG for carcinogens
> 2. a cumulative, excess life-time cancer risk greater than 1.0×10^{-6}; or
> 3. any MCL, non-zero MCLG, or a hazard index of 1.0, for noncarcinogens.
>
> If, at any time following completion of the remedy, groundwater at a remediated study site exceeds any of the stated cleanup standards, the need for additional remedial work, as contemplated by Section VII of the Decree shall be evaluated. The risk assessment shall follow procedures established in the "Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual" (RAGS) (EPA/540/1-89/02) or any amendments thereof. All of the assumptions used in the risk assessment calculations shall be subject to the review and approval by U.S. EPA prior to their use."

The federal Primary Drinking Water Standards Maximum Contaminant Levels (MCLs) and non-zero Maximum Contaminant Level Goals (MCLGs) for volatile organic compounds detected in groundwater at Sites 32/33 are listed in Table 2-1.

Section 3
Remedial Action Objectives

As defined in USEPA's RI/FS guidance (USEPA, 1988), remedial action objectives developed for a site are to consist of medium-specific or operable unit-specific goals for protecting human health and the environment. The objectives should be as specific as possible, but not so specific that the range of remedial alternatives that can be developed is unduly limited.

The Record of Decision (ROD) issued for remediation of the PCBOU included Groundwater Remediation Goals and Groundwater Cleanup Standards, intended to accomplish the objective of restoring groundwater at Sites 32/33 to an acceptable level of protectiveness for human health and the environment. Therefore, the objective for further remediation of groundwater at Sites 32/33 will address the remaining groundwater quality requirements defined for the sites, specifically, the attainment of the chemical-specific Cleanup Standards for groundwater contained in the Consent Decree Scope of Work, as summarized in Section 2 of this FFS.

The Remedial Action Objectives (RAOs) for groundwater at Sites 32/33 of the PCBOU are as follows:

- To restore groundwater quality over time to achieve, to the extent practicable, the Cleanup Standards for groundwater contained in the Consent Decree Scope of Work.
- To reduce or control, to the extent practicable, the impact of subsurface sources of volatile organic compounds on groundwater quality.

Section 4
Estimation of VOC Mass Present in Source Areas

4.1 Background

Estimates of the mass of total VOCs present in the soil within the VOC source areas were provided in previous documents (RMT, 2001a, 2001b, 2001c, 2002). Those estimates were made using computer software known as Environmental Visualization System (EVS) Pro, sold by C Tech Development Corporation, Huntington Beach, California. EVS software was used to provide 3-D interpolation and geostatistical analysis of the VOC mass in each source area using a process called kriging. USEPA has recognized kriging as a method for interpolation and extrapolation of environmental data such as contaminant concentrations in groundwater and soil. USEPA has also published an evaluation of the EVS software (Environmental Technology Verification Report - Environmental Visualization System Pro [EVS-Pro], EPA/600/R-00/047, March 2000).

The key input data used with the EVS software were the laboratory results for VOC concentrations in the 377 soil samples collected in fall 2000 at the VOC source areas. The samples were collected from saturated as well as unsaturated soil. Other input data included physical characteristics of the various soil units found at each source area (Upper Clay - UC, Upper Sand - US, Lower Clay - LC), physical properties of the VOCs, and the elevations of the interface between the geologic units and the groundwater table. With these input data, the EVS software was able to provide the estimated mass of total VOCs within each geologic unit at the VOC source areas. The estimates of total VOC mass presented in the previous documents were based on the assumption that the total mass was represented by soil with total VOC concentrations ≥ 1 mg VOCs/kg soil (wet weight or "as-is" basis).

As noted in previously issued documents, several variables associated with this estimation method result in uncertainty with regard to the total VOC mass present in the subsurface. These variables are as follows:

- **Discrete sample collection** - Soil samples that were collected and analyzed during the predesign fieldwork program in 2000, each of which were smaller than the size of a thumb, represent only discrete data points. Due mostly to soil heterogeneity, and the resulting spatial variability of VOC concentrations, it is difficult to develop accurate VOC mass estimates for the overall source areas.

- **Limited samples to define lateral limits of source areas** - The edges of the VOC source areas were either defined by a relatively "clean" boring, or they were estimated by extrapolation from the nearest boring where VOCs were present. Although it is commonly used, this technique could result in estimates of VOC mass that differ from the actual amount in the subsurface.
- **Soil physical parameters** – Soil samples that were collected and analyzed for physical parameters are representative of the soil matrix at a specific localized point, not necessarily the surrounding bulk formation. Variability in parameters such as permeability/hydraulic conductivity can be expected, due mostly to soil heterogeneity.
- **Presence of nonaqueous-phase liquids (NAPL)** – Determining the quantity, and even detecting the presence, of residual NAPL using field investigation methods and laboratory analysis of soil samples is very difficult to accomplish, as has been well documented in the technical literature (Pankow and Cherry, 1996; Cohen and Mercer, 1993; ITRC, 2000; and ITRC, 2002). The presence of even a relatively small amount of residual NAPL can significantly affect the total VOC mass. The presence of dissolved TCE concentrations substantially in excess of 1% of the solubility of TCE in water (approximately 1,400 mg/L) (Pankow and Cherry, 1996) detected in the groundwater associated with all of the identified VOC source areas at Sites 32/33 indicates the likely presence of NAPL at all of the source areas (Pankow and Cherry, 1996). The EVS software provides estimates of total VOC mass using valid statistical methods, but the accuracy of the estimates is dependent on how well the input data represent the actual distribution of VOC mass in the overall source area. As noted above, the input data for the EVS software included total VOC concentrations from laboratory analyses of soil samples collected in the VOC source areas. Although NAPL is likely to be present in the source areas, the soil sampling results did not conclusively indicate a uniform presence of NAPL throughout the source area, or even at a specific sample location. Therefore, it is likely that the VOC mass estimates provided from the EVS software did not account for NAPL present in the soil, thus potentially underestimating the total VOC mass by a substantial amount.

The mass of total VOCs present in the soil within the separate VOC source areas, and the locations and distribution of the VOC mass within the soil, are important factors in assessing the likely effectiveness of available remedial technologies, the remediation time frame required, and the degree to which any remedial action approach can achieve the specified Remedial Action Objectives for these sites. The importance of these factors warrants further estimates of the mass of VOCs remaining in the source areas, and the spatial distribution of the mass within those areas, despite the substantial difficulties and uncertainties inherent in making such estimates. The remainder of this section presents a description of the approach and key assumptions used for preparing updated estimates of the VOC mass that may be remaining in each of the identified source areas at Sites 32/33.

The contaminant transport model uses the primary or "indicator" VOC in groundwater and soil at the site, TCE, as the compound upon which the model setup and calibration are based. The discussion below and throughout this section will distinguish between estimates, assumptions, etc., based on TCE, as distinct from total VOCs. The actual mass of all VOCs present in the source area is greater than the estimated mass of TCE alone. The proportion of TCE mass with respect to the total VOC mass varies at the separate source areas. However, estimates based on the primary indicator VOC at this site, TCE, are expected to provide the necessary and appropriate information to support the evaluation and selection of appropriate remedial alternatives.

4.2 Building I-1-23 Source Area

4.2.1 TCE Mass Flux

To provide a general basis for gauging the reasonableness of any estimate of source mass currently remaining in the Building I-1-23 source area, it is helpful to use certain information available from the calibrated groundwater flow model for the site. That information is the mass flow or flux of dissolved TCE migrating from the source zone in the groundwater flow, which is required to create and sustain the observed TCE plume associated with the source area.

The calibrated model simulates the observed groundwater flow system and TCE plumes over the entire site relatively accurately. To sustain the observed TCE plume associated with the Building I-1-23 source area over time, the model shows that a uniform dissolved TCE concentration of approximately 20,000 μg/L must be continuously present over the full water-saturated "source zone volume." The three-dimensional boundaries of the source zone (and thus the source zone volume) were estimated using the VOC iso-concentration plots of the source area soil concentrations obtained from the predesign fieldwork in 2000. The calibrated groundwater model also provides an estimate of the volumetric groundwater flow that must be present in the Upper Clay and Upper Sand units at Building I-1-23 to create the observed flow gradients. Using these and other data such as measured soil physical properties, the model yields estimates of dissolved TCE mass flux from the Building I-1-23 source area of 6.06 g/day from the Upper Clay, and 165 g/day from the Upper Sand, or a total mass flow of 171.1 g/day (equivalent to 0.377 lb TCE/day total flux).

4.2.2 TCE Mass Transported Over Time

Further perspective from which to gauge estimates of remaining source mass can be gained by estimating the dissolved TCE mass that has potentially migrated from the Building I-1-23 source area since the inception of the TCE releases at that location. The question that must be addressed to make this estimate is, How long have the source area conditions been as they are now? or How long has TCE been migrating from the source area at 0.377 lb/day?

The lack of complete historical information on past manufacturing and waste disposal practices at the site makes this difficult to estimate. Sangamo Electric reportedly had operations at the Site 33 buildings from 1946 to 1962, and Olin Corporation subsequently used the site until 1986. Several other companies representing a variety of manufacturing industries and product types that would have been likely to use solvents were also reported to have operated at the site. If it is assumed that the release of waste solvents at Building I-1-23 began shortly after the start of commercial/industrial operations (1946), then it is possible dissolved TCE mass flux could have been present in the groundwater since approximately that time. If this is the case, then TCE may have been migrating from the source area in the groundwater plume for over 50 years, possibly at a rate comparable to the currently observed mass flux (0.377 lb/day).

Several assumptions and rough estimates have been made in the discussion above, to provide only a general projection of the TCE mass that may have migrated from the Building I-1-23 source area since the TCE releases began. It is not important or necessary to accurately refine this estimate. The objective of this exercise is to provide only a rough estimate of the TCE mass that may have already migrated from the area, to be used as a point of comparison to gauge the reasonableness of further estimates of the TCE mass that is likely to remain in the source area. The dissolved TCE mass that has already migrated with the groundwater flow is only a "subset" of the TCE mass that is likely to remain in the Building I-1-23 source area.

4.2.3 Dissolved and Sorbed TCE Mass in Source Area

VOCs can be present in water-saturated soil in dissolved form in the groundwater; sorbed to the surface of soil particles; or as residual saturation in the soil pores in the form of NAPL. In unsaturated soil, VOCs may also be sorbed to soil solids, dissolved in water film on the solid surfaces, volatilized in the air-filled porosity, or present as residual NAPL.

TCE Mass in Unsaturated Soil

The amount of TCE mass expected to be present in the unsaturated clay at the Building I-1-23 source area is relatively small, with respect to the mass remaining in the saturated soil. A substantial percentage of the unsaturated soil in the overall source area was excavated during the soil-PCB remediation in 1996. Clean backfill from an off-site borrow area was used to fill the excavations. For this reason, the estimates of TCE mass remaining in the overall source area will focus on the saturated portion of the soil. When attempting to estimate the total TCE mass present in the source area, it is helpful to first consider the mass present in the dissolved and sorbed phases.

Dissolved-Phase Mass

The water-saturated soil volume within the overall "source zone" at Building I-1-23 used in the groundwater model was estimated from the approximate dimensions of the soil zone within the 1 mg/kg total VOC concentration contour shown on drawings from the Preliminary Design Report (RMT, 2001d). With this source zone volume, the measured porosity of the soil, and the uniform dissolved TCE concentration of 20,000 μg/L over the source zone as determined from the calibrated model (see Subsection 4.2.1), the calculated mass of dissolved TCE within the source zone is 32.0 lb in the Upper Clay, and 26.4 lb in the Upper Sand, for a total dissolved mass of 58.4 lb TCE.

Sorbed-Phase Mass

The mass of TCE sorbed to the surface of soil particles in equilibrium with dissolved TCE at a concentration of 20,000 μg/L that is expected to be present in the water-saturated soil at the Building I-1-23 source area was calculated following a procedure developed by Feenstra et al. (1991). These estimates yielded 72.9 lb in the Upper Clay, and 60.1 lb in the Upper Sand, for a total sorbed mass of 133.0 lb TCE. Parameters that are pertinent to these calculations include the measured parameters of dry bulk density, organic carbon content, and water-filled porosity of the soil, and the empirical organic carbon : water partition coefficient for TCE obtained from technical references. These TCE partitioning calculations provide a representative estimate of the TCE concentration sorbed on the soil solids that is in equilibrium with the dissolved concentration in the soil pore water, in the absence of NAPL residuals. In the localized soil zones where NAPL is present, the sorbed (and dissolved) concentrations would be significantly higher. However, ignoring these very localized effects in proximity to the NAPL locations results in an insignificant difference in the estimate of total sorbed TCE mass in the overall source area.

Deductions from Dissolved/Sorbed Mass Estimates

The estimated total TCE mass in the dissolved and sorbed phases in the water-saturated soil within the source zone at Building I-1-23 is 191.4 lb (58.4 lb dissolved + 133.0 lb sorbed, from estimates above). This estimate does not include the much smaller amount of additional TCE mass that is likely to be present in the unsaturated soil. From Subsection 4.2.1, the mass flux of dissolved TCE that is currently migrating from the source area in the groundwater flow is 0.377 lb/day. Therefore, making the simplifying assumption that this mass flux rate would continue until all TCE source mass is removed via natural groundwater transport, all remaining dissolved and sorbed TCE would be removed from the source area within approximately 500 days (191.4 lb/0.377 lb per day).

It is probably unreasonable to conclude that, after several decades of substantial groundwater contamination from a continuous source of TCE at the Building I-1-23 area, the circumstances at this site are now so fortunate that the majority of the remaining TCE mass in the source area is within only 500 days of being completely removed by natural processes. The combined dissolved and sorbed TCE mass in the source area may account for only a certain percentage of the total mass remaining. The majority of the remaining mass is likely to be present in the form of residual NAPL.

It is also worthwhile to note that the previous estimate of total VOC mass in the Building I-1-23 source area within the 1 mg/kg concentration contours as determined with the EVS software (110 lb)(RMT, 2002) compares relatively well with the estimated dissolved + sorbed TCE mass noted above (191.4 lb). This further supports the conclusion that the VOC mass estimates provided from the EVS software do not account for NAPL present in the soil, thus likely underestimating the total VOC mass.

4.2.4 Total TCE Mass in Source Area

Residual Saturation

Attempting to estimate the mass of residual NAPL remaining in source area soil is a particularly challenging task, as has been documented in the technical literature. A helpful starting point is to consider published values for residual saturation of non-wetting fluids similar to chlorinated solvents. Below the water table, residual saturation (s_r) of NAPL is the saturation (V_{NAPL}/V_{voids}) at which NAPL is immobilized (trapped) by capillary forces as discontinuous ganglia under ambient groundwater flow conditions (Cohen and Mercer, 1993). At concentrations above s_r, NAPL will be mobilized in the soil. Residual saturation values in the saturated zone generally exceed those in the vadose zone. Although published values of s_r for TCE in soil types similar to Site 32/33 soil are limited in number, a typical range of s_r values for vadose zone soil is 0.10 to 0.20. In the water-saturated zone, s_r is typically in an approximate range of 0.20 to 0.25 (Cohen and Mercer, 1993). In other words, the maximum amount of NAPL that could be present in water-saturated soil in the source area (without being present as a dense NAPL pool) is approximately only 20 to 25% of the total pore volume (voids) of the soil.

TCE Solubility

Additional perspective on the potential presence of NAPL is provided by considering the effective solubility of TCE in groundwater, with the soil characteristics found at this site. An estimation method developed by Feenstra et al. (1991) allows calculation of the total soil concentration of TCE that should occur at the maximum hypothetical pore-water concentration of TCE (the effective solubility of TCE). The pure-phase solubility of TCE in water at 20°C is reported to be 1,400 mg/L (Pankow and Cherry, 1996). The effective solubility of TCE in a used solvent mixture (the likely condition of the released liquid) is somewhat less than the pure-phase solubility. A value of 1,100 mg/L is often used as the effective TCE solubility. Other parameters that are used in the partitioning calculation include: dry bulk soil density (measured value = 1.68 g/cm^3); organic carbon weight fraction of the soil (measured value = 0.0013); organic carbon/water partition coefficient for TCE = 126 mL/g carbon; and soil porosity (measured value = 0.379).

Using the partitioning calculation method and parameter values noted above, the hypothetical total TCE concentration in water-saturated soil at the Building I-1-23 area that would be in equilibrium with dissolved-phase TCE at its effective solubility concentration is 352 mg TCE/kg soil. In other words, measured soil concentrations greater than 352 mg TCE/kg soil (wet weight basis) would exceed the effective dissolved-phase solubility of TCE, indicating the potential presence of residual NAPL in the sample. However, it must be noted that this estimation method provides only a rough, hypothetical value that is based on empirical correlations, which is useful only as one of several estimation methods that may provide a point of comparison for evaluating the possible presence and quantity of NAPL.

Several soil samples in the Building I-1-23 source area showed TCE concentrations in the range of 10 to 30 mg/kg; the highest reported concentration is 44 mg/kg. The highest reported groundwater TCE concentration in this area is 66.0 mg/L. Although the soil and groundwater sampling data do not show TCE concentrations that exceed the empirical (non-NAPL) soil capacity or the effective solubility for TCE, this does not indicate that residual NAPL cannot be present in the soil. The sampling data only show that in the discrete volumes of soil samples collected, actual NAPL may not have been present. The heterogeneous distribution of NAPL that is likely to have occurred in the soil at this site makes it entirely feasible that evidence of residual NAPL was not detected during sampling.

General Location of NAPL in Source Area

As noted in Subsection 4.2.3, the water-saturated soil volume within the overall "source zone" at Building I-1-23 used in the groundwater model was estimated from the approximate dimensions of the soil zone within the 1 mg/kg total VOC concentration contour shown on drawings from the Preliminary Design Report. Since the soil sampling results provide no direct indication of the location of NAPL in the soil, it is necessary to use some other basis or rationale for estimating the likely location of the NAPL within the overall source area. It was assumed that the VOC concentration contours representing the predesign program soil sampling results provide a general indication of the locations where NAPL is most likely to be present. In other words, the soil zones with higher measured VOC concentrations are considered more likely to be the zones containing the majority of the NAPL. It was assumed that the majority of the NAPL would be located within the approximate dimensions of the soil zone encompassing the 10 mg/kg total VOC concentration contour. However, the actual distribution of NAPL within the three-dimensional volume of source area soil within the 10 mg/kg VOC contour is not known and cannot be accurately determined. After accounting for the large volume of soil that was excavated from the source area during the PCB remedial action in 1996, a rough estimate was made of the total soil volume where NAPL may be present.

Approach for Estimating Total TCE Mass in Source Area

As described above, TCE may be present in the saturated soil in the source areas in three forms: dissolved in the groundwater; sorbed to the soil particles; and as NAPL within the soil pores. The TCE mass present in the dissolved and sorbed form within the overall source area at Building I-1-23, as discussed above, is 58.4 lb dissolved and 133.0 lb sorbed mass, for a total of 191.4 lb TCE. To provide some perspective regarding the significance of TCE mass present as NAPL, it is helpful to consider the total volume of water-saturated soil that would contain a mass of pure TCE equivalent to only the estimated dissolved and sorbed portion of the TCE mass (191.4 lb).

The specific gravity of TCE is 1.46 at 25 degrees C. One pound of pure TCE occupies 0.011 ft^3 at standard conditions. Therefore, the volume of 191.4 lb of TCE is 191.4 lb x 0.011 $ft^3/lb = 2.11\ ft^3$. The measured porosity (V_{voids}/V_{total}) of the Upper Clay (0.37) was approximately the same as the measured porosity of the Upper Sand. The volume of voids (pore space) in 1 ft^3 of soil in the source area is 0.37 ft^3. The soil volume that would contain 191.4 lb of TCE, if pure TCE occupied all of the soil pores, is 2.11 ft^3 TCE/0.37 ft^3 voids/ft^3 soil = 5.70 ft^3 soil. However, as discussed above, the soil may be capable of retaining NAPL only up to roughly 20 percent of the total pore volume (the residual saturation capacity). Therefore, the total soil volume that may contain 191.4 lb of TCE (the estimated total dissolved and sorbed TCE mass in the source area) is 5.70 $ft^3/0.20 = 28.5\ ft^3$, or approximately only 1 cubic yard of soil.

This type of analysis helps to demonstrate why it is so difficult to identify the presence of NAPL from soil sampling programs, and to estimate the total TCE mass in a source area when NAPL is present. It also provides a frame of reference that helps show why the presence of NAPL in only a very small fraction of the pore volume of the soil represents a large mass of source material that can cause significant levels of groundwater contamination often for decades or centuries.

To make an estimate of the total TCE mass that is currently remaining in the Building I-1-23 source area, it is necessary to make an assumption, on some rational basis, regarding the mass of NAPL that is present. This is probably the most difficult, and yet the most important, of all the estimates and assumptions that are necessary. As previously noted, there is limited historical information available from which to estimate, or even to gain an insight into, the quantity of TCE that was released at the source area. The best approach available is to rely on the types of information and comparisons presented above in this section in making an assumption that allows calculation of an estimated mass of remaining NAPL. The assumption that was made is that the remaining NAPL (assumed to be all TCE) occupies 1.0 percent of the total pore volume within the soil volume that was considered the most likely location where NAPL would be present. This approach for estimating residual NAPL and total TCE mass remaining in the source area was used for making further estimates regarding effectiveness of the various remedial alternatives and for other purposes in the remaining sections of this report. Additional information regarding the estimates of total TCE mass is included in Section 7 and Appendix B.

Distribution of TCE in Source Area

Having developed an estimate for the total TCE mass and the general location of NAPL at the Building I-1-23 source area, it was also necessary to make further assumptions to estimate the vertical distribution of the TCE mass within the soil geologic units. These estimates were needed for use as "source term" input data for the groundwater model, and for the various evaluations and comparisons of remedial alternatives. Additional information regarding the estimated TCE mass distribution within the source areas is included in Appendix B.

4.3 Building I-1-2/I-1-3 Source Areas

4.3.1 TCE Mass Flux

Similar to the estimation approach used for the Building I-1-23 source area, the calibrated groundwater flow model provides estimates of dissolved TCE mass flux that is required to create and sustain the observed VOC plume originating at the Building I-1-2/I-1-3 source areas. These model-derived estimates are as follows:

- Building I-1-2 Area: 25.5 g TCE/day (0.056 lb TCE/day)
- Building I-1-3 Area: 30.9 g TCE/day (0.068 lb TCE/day)
- Building I-1-2/I-1-3 Areas Combined: 56.4 g TCE/day (0.124 lb TCE/day)

The mass flux from the Building I-1-2/I-1-3 areas is considerably lower than the TCE flux from the Building I-1-23 area (0.377 lb/day) primarily due to the absence of a substantial Upper Sand unit beneath these areas.

4.3.2 TCE Mass Transported Over Time

The manufacturing operations that caused the releases of VOCs were associated with a former large building located immediately adjacent to Building I-1-2. Similar to the Building I-1-23 source area, it is likely that the VOC releases resulted from regular or routine production or maintenance operations, rather than from a few isolated spill events. The specific time period during which manufacturing occurred in this building is not known. To provide input for the groundwater model simulations, and for estimating the effectiveness of the remedial alternatives, it was assumed that the manufacturing operations occurred over 30 years, and the dissolved TCE mass that may have migrated from the Building I-1-2/I-1-3 source areas with the groundwater flow at the mass flux noted above (0.124 lb TCE/day; 45.3 lb TCE/year) over that time period was calculated.

The lower dissolved mass flux at the Building I-1-2/I-1-3 areas (relative to the mass flux at the Building I-1-23 area) provides a more limited basis for estimating remaining mass than for the Building I-1-23 area, where a much larger amount of TCE is estimated to have migrated from the source area. Nevertheless, the estimate of TCE mass transported over time provides some insight that is helpful in attempting to characterize the current conditions at the Building I-1-2/I-1-3 source areas. The knowledge that the rate of loss of TCE source mass is relatively low, and other factors such as the overall size of the source areas and the VOC levels found throughout the full depth of the clay soil, leads to a hypothesis that the great majority of the TCE that was released and did not evaporate is still present in the Building I-1-2/I-1-3 source areas, except for the significant (although not quantified) amount of VOC mass that was removed with the PCB soil excavations in 1996.

4.3.3 Dissolved and Sorbed TCE Mass in Source Areas

TCE Mass in Unsaturated Soil

Similar to the Building I-1-23 source area, a substantial quantity of VOCs was removed from the Building I-1-2 source area with the soil excavated in 1996 for the soil-PCB remediation. At the Building I-1-3 area, soil sampling demonstrated that the primary zone of VOC releases is not coincident with locations of PCB-soil excavations in 1996, and therefore, significant near-surface VOC concentrations are present in the Building I-1-3 source area, although these concentrations are of relatively limited lateral extent. However, the soil sampling data also indicate that the great majority of the VOC source mass in the Building I-1-3 area is present at greater depths, in the saturated clay. The groundwater table is shallow in these source areas (5 to 7 feet), and the unsaturated soil depth is a relatively small percentage of the overall depth of the VOC-contaminated clay soil. For these reasons, the estimates of TCE mass remaining in the overall source areas focused on the saturated portion of the soil.

Dissolved Phase Mass

The water-saturated soil volume within the overall "source zone" at Buildings I-1-2/I-1-3 used in the groundwater model was estimated from the approximate dimensions of the soil zone within the 1 mg/kg total VOC concentration contour shown on drawings from the Preliminary Design Report. With this source zone volume, the measured porosity of the soil, and the uniform dissolved TCE concentrations over the source zone as determined from the calibrated model, the calculated mass of dissolved TCE within the source areas is as follows:

- Building I-1-2 Area: 157.5 lb TCE
- Building I-1-3 Area: 128.3 lb TCE
- Building I-1-2/I-1-3 Areas Combined: 285.8 lb TCE

Sorbed Phase Mass

Using a procedure similar to the estimates made for the Building I-1-23 area, the mass of TCE sorbed to the surface of soil particles in equilibrium with dissolved TCE that is expected to be present in the water-saturated soil (in the absence of NAPL) is as follows:

- Building I-1-2 Area: 165.0 lb TCE
- Building I-1-3 Area: 134.4 lb TCE
- Building I-1-2/I-1-3 Areas Combined: 299.4 lb TCE

Deductions from Dissolved/Sorbed Mass Estimates

The estimated total TCE mass in the dissolved and sorbed phases in the water-saturated soil within the source zones at Buildings I-1-2/I-1-3 is 285.8 + 299.4 = 585 lb TCE (from estimates above), which is less than the contents of a single drum of pure TCE. This estimate does not include additional TCE mass that is likely to be present in the unsaturated soil. From Subsection 4.3.1, the mass flux of dissolved TCE that is currently migrating from the source areas in the groundwater flow is 0.124 lb/day. Therefore, making the simplifying assumption that this mass flux rate would continue until all TCE source mass is removed via natural groundwater transport, all remaining dissolved and sorbed TCE would be removed from the source area within approximately 13 years (585 lb/0.124 lb per day).

As suggested for the Building I-1-23 source analysis above, it seems unreasonable to conclude that after several decades of substantial groundwater contamination from continuous sources of TCE at the Building I-1-2/I-1-3 areas, the circumstances at this site would allow the majority of the remaining TCE mass in the source areas to be completely removed by natural processes within the next 13 years.

The total VOC mass in the Building I-1-2/I-1-3 source areas within the 1 mg/kg concentration contours as previously determined with the EVS software (RMT, 2002) is 1,150 lb VOCs. This estimate compares relatively well with the estimated dissolved + sorbed TCE mass noted above (585 lb TCE), after recognizing that the TCE mass estimate does not account for other VOCs that are represented in the EVS software estimate. This supports the conclusion that the VOC mass estimates provided from the EVS software do not account for NAPL present in the soil, thus likely underestimating the total VOC mass. The combined dissolved and sorbed TCE mass in the source area likely accounts for only a percentage of the total mass remaining. The remaining mass is present in the form of residual NAPL.

The numerical values for the TCE mass estimates presented above and elsewhere in Section 4 are not intended to represent, or imply, a level of accuracy or absolute knowledge regarding the TCE mass quantities that is consistent with the "significant figures" used in the numerical values. The numerical mass values presented in Section 4 and elsewhere in this report are subject to the cumulative uncertainties inherent in all of the various assumptions, approximations, clarifications, and estimates used to derive or calculate the numerical values, as discussed throughout the report.

4.3.4 Total TCE Mass in Source Areas

General Location of NAPL in Source Areas

As noted above, the water-saturated soil volume representing the overall "source zone" at Buildings I-1-2/I-1-3 used in the groundwater model was estimated from the approximate dimensions of the soil zone within the 1 mg/kg total VOC concentration contour shown on drawings from the Preliminary Design Report. It was assumed that the VOC concentration contours representing the predesign program soil sampling results provide a general indication of the locations where NAPL is most likely to be present. In other words, the soil zones with higher measured VOC concentrations are considered more likely to be the zones containing the majority of the NAPL.

It was also assumed that the NAPL would be located at each of the source areas within the approximate volume of soil defined by the 10 mg/kg total VOC concentration contour, and extending from the ground surface to the full soil depths where VOCs were observed from the soil sampling program.

Total TCE Mass in Source Areas

To make an estimate of the total TCE mass that is currently remaining in the Building I-1-2/I-1-3 source areas, it is necessary to make an assumption regarding the mass of NAPL that is present. There is limited historical information available from which to estimate, or even to gain an insight into, the quantity of TCE that was released at the source areas. It is necessary to rely on the types of information and comparisons presented above in this section in making an assumption that allows the mass of remaining NAPL to be estimated. The assumption that was made is that the remaining NAPL (assumed to be all TCE) occupies 0.1 percent of the total pore volume within the soil volume that was considered the most likely location where NAPL would be present. This approach for estimating residual NAPL and total TCE mass remaining was used for making further estimates regarding effectiveness of the various remedial alternatives and for other purposes in the remaining sections of this report. However, it is important to recognize that there is a relatively high level of uncertainty in the source area mass estimates presented in this section. Additional information regarding the estimates of total TCE mass, and its distribution in the source areas, is included in Section 7 and Appendix B.

Distribution of TCE in Source Areas

Having developed estimates for the total TCE mass and the general locations of NAPL at the Building I-1-2/I-1-3 source areas, it was also necessary to make further assumptions to estimate the vertical distribution of the TCE mass. These estimates were needed for use as "source term" input data for the groundwater model, and for the various evaluations and comparisons of remedial alternatives.

4.4 Area 9 Repository Source Area

As presented in Section 6 of this FS Report, remedial alternatives that include "active" measures for remediating the VOC source zones beneath the Repository have not been developed. (The rationale for this approach is also discussed in Section 6.) Therefore, preparation of specific numerical estimates of the VOC mass remaining beneath the Repository was not necessary for evaluation and comparison of the remedial alternatives for the Repository source area and associated VOC plume.

Although TCE mass estimates were not made, it is possible to draw some conclusions regarding the general nature of the VOC source that is likely to remain beneath the Repository. The former Area 9 Landfill (now the location of the Repository) was used from the 1950s until it was closed in 1964. During the period of use, a wide variety of wastes were disposed in the 2.5-acre landfill area (O'Brien & Gere, 1988). Chemistry data from samples of soil collected beneath the former landfill clearly indicate that liquid solvents were also disposed in the landfill. It has not been documented whether the solvents were disposed in drums or other containers that eventually leaked, or the waste solvents or solvent solutions were disposed in bulk liquid form.

The landfill waste material was removed from the site during the PCB remedial action in the mid-1990s. After removing the waste material, large quantities of soil were excavated beneath the landfill footprint to remove soil containing PCBs and metals of concern. Similar to the circumstances at the contaminant source areas near the site buildings, it is expected that large quantities of VOCs were also removed coincident with the excavated PCB-soil. The excavations were backfilled with clean clay soil from an off-site borrow area and with ash from the on-site incinerator used for the PCB-soil/sediment. After backfilling to original grade levels, the materials that comprise the existing Repository were placed on the former landfill footprint.

Soil samples collected from the clay soil beneath the Repository during the predesign fieldwork investigation in 2000 showed widespread zones of VOCs at concentrations that are generally comparable to the concentrations at the VOC source areas near the site buildings. The soil sampling data and the observed VOC concentrations in groundwater beneath the Repository tend to indicate that residual VOC source material is likely to be present in the soil beneath the Repository. However, from the calibrated groundwater flow model, the estimated dissolved TCE flux that is migrating from the source area with the groundwater flow that passes beneath the Repository (10.8 lb TCE/year) is substantially less than the estimated dissolved TCE mass entering the plumes at the Building I-1-23 source area (138 lb/year) and at the Building I-1-2/I-1-3 source area (45 lb/year). The VOC source material remaining beneath the Repository is likely to be present for a long time period due to the low mass flux from the source zones. However, the dissolved-phase VOCs that are transported from the source zones are significantly degraded by natural attenuation processes (as discussed in Sections 6 and 7).

Section 5
Identification and Screening of Remedial Technologies

The objective of this section is to identify specific technologies that may be appropriate to accomplish the remedial action objectives. After a general discussion, the technologies are screened to eliminate those that are inappropriate for inclusion in the site-specific integrated alternatives. The universe of remedial technologies includes those that have been widely applied using standard construction and operating techniques, as well as those that have been recently developed to address specific remedial situations. Remediation of VOC contamination of groundwater at Sites 32/33 is the focus of this feasibility study. Remediation of soil at specific areas, or other measures to control or isolate VOC source material in the soil, may be an additional component of the remedial action for the site, since VOC residuals remaining within the soil provide a continuing source of dissolved VOCs in the groundwater. Therefore, technologies for remediation of VOC contamination of both soil and groundwater have been identified and screened.

Technologies are grouped into four categories: containment, removal, treatment, and disposal. Each of these categories includes individual potential response action technologies that can be linked together to provide comprehensive remedial alternatives. In addition, institutional controls, such as fencing, deed restrictions, and monitoring, can be incorporated with any of the potential response actions.

Identification of remedial technologies is provided in Subsections 5.1 through 5.4. This identification is based on the following:

- A review of recent technical literature
- A review of USEPA REACH IT and CLU-IN databases
- A review of recent USEPA guidance documents
- A review of USEPA Superfund Innovative Technology Evaluation (SITE) program results
- On-line remediation information database services
- Discussions and correspondence with commercial vendors of specific technologies
- Field observations of specific technology applications, both through the SITE program and private cleanups

- RMT experience on similar projects involving remediation of VOC contamination of soil and groundwater

A screening of technologies to identify those that are appropriate for inclusion in specific remedial alternatives is summarized in Table 5-1. This screening is based on the criteria of "effectiveness," "implementability," and "comparative cost." These criteria are used since they address the general appropriateness of a specific technology for the site conditions, and site-specific questions and potential concerns related to implementation.

Characteristics of the site and affected media, and the technology limitations that were considered for the screening assessment, are described as follows:

- **Site characteristics** – The available site data were evaluated to identify conditions that may limit or promote the use of certain technologies. Specific factors considered included the current use of the property at and near the various remediation target areas; the proximity of the areas to existing buildings, structures, and people who work at the site; the uncertainty associated with locations of subsurface utilities; and the current site features. Those technologies that were considered to be ineffective or not implementable, based on site characteristics, were eliminated from further consideration.
- **Characteristics of affected media** – Soil and groundwater characteristics that limit the effectiveness of a given technology were identified. For this evaluation, considerations included the chemistry of the groundwater at Sites 32/33, the variability in subsurface soil conditions and the low permeability of the clay units, the presence of VOC-impacted soil and groundwater under the building footprints, the concentrations of VOCs in the groundwater, and the predesign pilot testing results/findings. Technologies clearly limited by these characteristics were eliminated from further consideration. In particular, the soil and groundwater characteristics affect the feasibility of certain *in situ* methods, direct treatment methods, and land disposal.
- **Technology limitations** – During the preliminary screening process, the following factors were reviewed for each technology: the level of technology development; the performance record; the failure and safety implications; the ability to meet proposed RAOs; and the constructibility, operation, and maintenance requirements. Technologies that were considered to be ineffective or that had a poor performance record were eliminated from further consideration. Innovative technologies were identified as such, but were not eliminated if additional information (e.g., predesign studies) was needed to assess their potential effectiveness. State and federal regulations that may limit or preclude the implementation of a specific technology were also considered.

General screening ratings for the purposes of evaluating implementability, effectiveness, and comparative cost are as follows:

- Implementability
    - **Implementable** – The technology has been readily implemented at other sites with similar physical and affected media characteristics. Site or affected media characteristics at one or more Site 32/33 areas suggest that minor or no modifications to the conventional technology will be necessary prior to implementation.
    - **Moderately implementable** – Site or affected media characteristics suggest that major modifications to the conventional technology will be necessary prior to implementation at any Site 32/33 area.
    - **Not implementable** – Site or affected media characteristics preclude this technology from being implemented at any Site 32/33 area. Those technologies with a very limited potential for being implementable are given this rating.
- Effectiveness
    - **Potentially effective**– The technology has consistently achieved RAOs at other sites with similar physical and affected media characteristics. The technology provides a practicable approach for attempting to restore groundwater quality over time for one or more of the Site 32/33 areas, either alone or in combination with other remedial technologies.
    - **Not effective** – Physical or performance limitations eliminate this technology as a practicable approach for attempting to restore groundwater quality at this site.
- Comparative Cost
    - **Low** – The technology has been implemented at other similar sites at a capital and estimated present value cost of less than $500,000.
    - **Medium** – The technology has been implemented at other similar sites at a capital and estimated present value cost that may be several factors greater than the "low" cost category.
    - **High** – The technology has been implemented at other similar sites at a capital and estimated present value cost that may be several factors greater than the "medium" cost category.

5.1 Containment Technologies

Containment can be used in conjunction with other remedial response actions or as a sole means of site stabilization. The containment approach may address soil as well as groundwater at or downgradient of a VOC source. In either case, it is essential to incorporate a well-designed post-closure monitoring program with the containment component of a remedial action.

Subsurface barriers are used to isolate and contain soil with residual VOC source material, and to redirect or contain groundwater flow to minimize groundwater contact with this soil or with water that has leached through the contaminated soil from surface water infiltration. Ground surface barriers or "caps" can also be used to prevent surface water infiltration and the leaching of VOCs from the soil. To control the groundwater head within or upgradient of subsurface barriers, pumping wells or subsurface drains are frequently used. To effectively control migration of constituents of concern within the groundwater, a perimeter barrier wall must be keyed into a confining soil or bedrock layer of low permeability at its base, must extend upward to an elevation above the groundwater level, and must completely encompass the area of concern. Physical containment, unless accompanied by groundwater extraction, does not address the actual removal of waste constituents.

The Lower Clay appears to be continuous over Sites 32/33, with a relatively uniform average thickness of 40 feet. The top of the Lower Clay is present at depths of approximately 30 to 50 feet below ground surface over the site. The groundwater within the Lower Clay has not been significantly impacted by VOCs. This clay unit should function adequately as a low-permeability confining layer to be used with vertical subsurface barriers to encompass and contain a zone of impacted groundwater or soil within the Upper Sand and Upper Clay units. To be effective, a remedial action that relied on the containment of VOC source areas would need to include a perimeter barrier wall, some portions of which would have to reach depths of 50 feet or more at some locations, to allow for adequate "keying" into the Lower Clay Unit.

Because of the site-specific conditions at Sites 32/33, physical containment of the VOC source areas using vertical subsurface barriers, alone, without some form of hydraulic head control, is unlikely to maintain contained conditions. Some form of groundwater extraction in the area inside the containment cell, at a relatively low flowrate, would be required to maintain an inward and upward groundwater flow gradient and to control potential contaminant migration from the containment area.

A discussion of common containment technologies is presented below.

5.1.1 Slurry Walls

This technology involves excavating a trench to the depth of a confining base layer while adding a slurry into the excavation. The slurry generally consists of a bentonite/water mixture. The slurry holds the excavation open while creating a low-permeability cake on the sidewalls of the trench. The wall is usually completed by backfilling with a soil/bentonite mixture. The effectiveness of slurry walls depends on the control of proper excavation procedures and proper proportioning and placement of the soil/bentonite and select backfill material. In addition to soil/bentonite mixtures, cement-bentonite mixtures have been used, or a synthetic membrane may be placed in the trench in a "U" configuration by filling it with a permeable sand material. With the synthetic membrane installation, observation wells may then be placed within the sand backfill material, to detect infiltration and thereby determine the integrity of the synthetic membrane.

5.1.2 Sheet Piles

This technology involves driving steel sheet piles around the perimeter of the area to be contained. The piles are driven until the tips reach and penetrate an underlying low-permeability layer. The sheet piling sections can be made watertight at the section joints by incorporating sealants. Recent advancements in the application of plastics for subsurface containment include construction methods to install sheets of high-density polyethylene (HDPE) with interlocking, watertight sheet sections as vertical barrier walls around contaminated soil areas.

5.1.3 Injected Screens

This technology also includes driving steel sheet piles into the soil around an area of concern. The sheet piles are then subsequently extracted one at a time, and the resulting void is filled with a grout injected under pressure.

5.1.4 Grout Curtains

This technology involves drilling holes along the perimeter of the area to be contained until an underlying low-permeability layer is reached. The drill is then extracted, and grout is injected under pressure through the drill hole. The drill holes are spaced along a line at distances such that the cemented zone of each grout hole overlaps the preceding zone.

5.1.5 Vibrating Beam

This technology is the grouting method most suitable for shallow soil treatment depths. A vibratory pile driver is used to drive a modified H-beam into the subsurface. The pile has injection nozzles at the tip. As the beam is withdrawn, grout is injected through the nozzles into the void. Cement-bentonite grouts are used most often. A continuous barrier can be formed by successively overlapping beam penetrations.

5.1.6 Surface Caps

This technology aids in controlling or reducing vertical infiltration into a targeted, capped area, or volume of underlying soil. Low-permeability engineered surface caps utilized to reduce infiltration can consist of pavement (concrete or asphalt), compacted clay, or manufactured geomembranes (HDPE, PVC, etc.), or can be a composite cap containing multiple layers of the above materials.

5.1.7 Hydraulic Containment

This technology consists of groundwater collection points to hydraulically contain a targeted area by encompassing the area within a hydraulic capture zone. Wells or trenches and extraction pumps are used to withdraw groundwater and create an inward gradient toward the extraction pump. Saturated zones within the effective capture zone of the extraction point will be thereby hydraulically contained.

5.2 Removal Technologies

5.2.1 Soil Excavation and Consolidation

This technology involves the excavation of soil from an identified area followed by the disposal or treatment of the soil. Excavation is generally considered to be a remedial technology for soil. It is also included as a means of groundwater remediation since it would remove a portion of the contaminant mass from the source areas at the site, thereby potentially reducing the duration of continued leaching of VOCs to the groundwater.

Excavation of VOC-contaminated soil is a readily implementable technology at this site, except for the known source areas located beneath the Area 9 Repository and the potential VOC source material that may be located beneath portions of site buildings. However, several factors that may affect the feasibility or effectiveness of this approach at various site locations include the method of excavation, especially with respect to the required excavation depth; disposal options owing to the uncertainties regarding VOC concentrations in the excavated soil; the need to excavate beneath the groundwater table elevation; the presence of the confined Upper Sand Unit; and the uncertainties regarding the lateral and vertical locations of VOC residuals at each source area. Each of these issues also has a direct bearing on the overall cost of excavation.

It is possible to excavate to the range of depths that may be required at this site (up to 35 to 40 feet bgs), but equipment with a greater reach capability than that offered by a conventional tracked excavator (e.g., clamshells or draglines) would be required. Alternatively, sheeting or shoring could be installed to allow excavations at these depths with tracked excavators. However, at any of the VOC source areas, excavation of soil that contains VOC residual source material beneath the groundwater table would be necessary. Where the Upper Sand Unit is present beneath the Upper Clay, excavation of the clay will be limited to depths necessary to prevent heaving of the saturated sand as a result of the removal of the clay overburden pressure.

For dry materials, dust suppression may be necessary to reduce the release of airborne particulates. Water and/or synthetic covers can be used as suppressants. Although tests of soil from the VOC source areas to determine the expected soil classification for waste disposal purposes were not performed, some of the excavated soil may be classified as a toxicity-characteristic hazardous waste (40 CFR 261.24), based on the available data. This waste material classification presents cost, administrative, and health and safety issues regarding the transportation and disposal of the excavated soil.

Finally, CERCLA includes a statutory preference for the treatment of contaminants (as opposed to simply transferring contaminants from one location to another), making excavation and direct land disposal less preferable than other technologies that provide treatment.

In general, the technology would be viable and effective in reducing the duration of the future transfer of residual VOC mass from soil into groundwater, assuming that all significant VOC sources are located, and that the potential construction difficulties can be overcome.

5.2.2 Groundwater Extraction

Extraction wells can be used to remove groundwater with VOCs for treatment and/or disposal. This technology can also be used to control hydraulic gradients in the vicinity of a source area, limiting the migration of VOCs in groundwater, or reducing flow through subsurface areas. Extraction wells are frequently used in conjunction with subsurface barriers to physically and hydraulically isolate contaminated soil areas. The spacing, sizing, and design of extraction wells are determined by the extent of groundwater to be controlled and by aquifer properties. Extraction wells can be installed in a standard vertical configuration, or can be installed horizontally in preferential geologic units using horizontal drilling technology.

As an alternative, groundwater collection trenches can sometimes be used. This technology serves the same general purpose as that of pumping wells—to remove impacted groundwater or to provide hydraulic control for other remediation purposes. Subsurface drains are generally limited to shallow depths, and thus may serve as a substitute for pumping wells only in shallow aquifer conditions. Subsurface drains normally include a drain pipe or gravel bed, protective filter media to prevent clogging by fine solids, manholes or wet wells for collecting the water, and pumping equipment to remove the accumulated water. Drain trenches are typically situated transverse to the direction of groundwater flow, and may be placed downgradient of contaminant source areas to collect groundwater, or upgradient to minimize groundwater contact with contaminated soil areas.

Use of vertical or horizontal extraction wells would be feasible for capture and removal of contaminated groundwater from the sand deposits at Sites 32/33. Collection trenches would not be practical for extraction of groundwater from the low-permeability Upper Clay. However, trenches could potentially be feasible for the interception and extraction of groundwater from the Upper Sand at the shallower elevations.

5.2.3 Multiphase Extraction

Multiphase extraction (MPE) involves the simultaneous removal of contaminated groundwater, soil vapors, and under specific circumstances, non-aqueous-phase liquid (NAPL), from extraction wells under vacuum conditions. This provides a means for accelerating the removal of NAPL and dissolved groundwater contamination, remediating capillary fringe and smear zone soil, and facilitating the removal of vadose zone soil contaminants. Originally, in the June 2000 Explanation of Significant Differences (ESD) (USEPA, 2000a), USEPA selected MPE as a final component for PCBOU sites. Site-specific conditions at Sites 32/33 meet criteria for using MPE as a presumptive remedy. As stated in the ESD, "multiple phase extraction is a combination of proven technologies that can remove significant volumes of the TCE and other VOCs from the subsurface soil."

MPE enables venting of soil vapors through previously saturated and semisaturated (capillary fringe) soil by lowering the groundwater table around the points of vapor extraction (MPE wells). There are three basic types of MPE wells: drop-tube entrainment extraction, where extraction of total fluids (liquid and vapors) is conducted via vacuum applied to a tube inserted within the extraction well; well-screen entrainment extraction, where extraction occurs from boreholes screened in the saturated and vadose zones; and downhole-pump extraction, where extraction is performed using a groundwater pump with concurrent application of vacuum to the extraction well (groundwater and vapor are removed in separate pipe manifolds and treated). MPE is most commonly used for sites that have VOC contamination; soil, groundwater, and NAPL phases requiring remediation; and low to moderate hydraulic conductivity soil (silty sand, silt, and clayey silt).

MPE may have certain limitations for the remediation of VOCs at some sites, owing to specific site conditions. MPE is less cost-effective for permeable soil types. Operating costs may be relatively high, depending on requirements for vacuum pump horsepower and groundwater treatment. Short-circuiting of the airflow from the ground surface may limit effectiveness. Recovery enhancement methods, such as pneumatic or hydraulic fracturing of the soil, may be required in low-permeability and/or high surface tension soil. As determined from pilot-scale pre-design MPE tests performed at Sites 32/33, some form of technology enhancement would be required for effective use of MPE at Sites 32/33.

5.3 Treatment Technologies

For soil and groundwater treatment, many new technologies are being introduced at various stages of development, and existing technologies are being applied in alternative ways. Unlike the more conventional technologies for containment and removal, treatment technologies (or process options) are frequently patented and proprietary, and available only through a limited number of vendors. In some cases, technologies exist at a "full-scale" stage of development, but have yet to be permitted by regulatory agencies for specific applications. In all cases, a treatment technology is specific to particular chemical compounds or classes of compounds.

5.3.1 *In Situ* Treatment

Significant research, development, and commercialization efforts have occurred in the last several years in the field of *in situ* treatment technologies for soil and groundwater. Many of these recently developed technologies, as well as other more proven *in situ* processes and equipment, are applicable to remediation of VOC contamination. *In situ* technologies available today apply a wide range of biological, physical, and chemical processes and principles, often as part of an integrated remediation approach tailored to site-specific physical conditions. Many companies offer specialty equipment, chemicals, and services for the field application of various technologies, often using proprietary and patented equipment and materials. A list of *in situ* treatment technologies for soil and/or groundwater considered for application at Sites 32/33 is presented below, using commonly accepted terminology in the environmental remediation field. Some examples of proprietary trade names or process names that utilize certain technologies are also listed.

- Natural attenuation
- Soil vapor extraction
- Air sparging

- Enhanced biological treatment, aerobic and anaerobic (GT-1000®, Bio Luxing®, Biopim®, BioInjection™, pressurized fluidized bed reactors [PFBR], Butane Biosparging Butane Injector™, Fyrezyme™, Edible Oil Substrate (EOS™), CAP-18™, Oxygen Release Compound [ORC], Hydrogen Release Compound [HRC], Bac-Terra™)
- Chemical oxidation (Clean OX®, TR-DETOX™, OxyVAC™, Geo-Cleanse Process®, ISOTEC®, Solerox R2K™, DUOX™)
- Permeable reactive barrier (Envirometal®, Forager™ Sponge, Ferox™)
- Fracturing, pneumatic and hydraulic (BioLuxing®, Pneumatic Fracturing Extraction [PFE®], Injection Vac™, Ferox™)
- Electro-osmosis/Electromigration (Lasagna™ and ElectroKinetic Aided Remediation [EKAR™])
- Phytoremediation
- In-well aeration (UVB™ and Accelerated Remediation Technologies [ART™], NoVOCs™, DDC™, and C-Sparger™)
- In-well bioremediation (CleanWater™)
- Soil flushing (Injectsol®, Biosolve®)
- Stabilization/Immobilization/Soil mixing (ReCon™, GeoCon™, *In Situ* Fixation™, MecTool™)
- Vitrification (GeoMelt™)
- Thermal desorption, low and high temperature (Steam Enhanced Remediation [SER], Six Phase Heating [SPH™] or Electrical Resistive Heating [ERH], *In Situ* Thermal Desorption [ISTD], Heated Soil Vapor Extraction [HSVE], Radio Frequency Heating [RFH], Dynamic Underground Stripping/Hydrous Pyrolysis [DUS/HP], Microwave Heating)

In Situ Thermal Technologies

In situ thermal treatment encompasses several new, innovative technologies, including conductive heating, dynamic underground stripping/hydrous pyrolysis, microwave heating, radio frequency heating, hot air/steam injection, and electro-heating (six-phase and three-phase electric power). All of these technologies consist of methods for heating the soil to the boiling point of liquids of concern within the soil, or higher temperatures, to vaporize volatile contaminants by a number of mechanisms, including evaporation into the soil vapor induced by application of vacuum, steam distillation into the water vapor stream, boiling, oxidation, and pyrolysis. The vapor-phase contaminants are then typically removed from the soil using soil vapor extraction (SVE) wells.

Conductive heating is a process in which heat and vacuum are applied either with an array of vertical heater/vacuum wells or surface heater blankets. The USEPA REACH-IT database identifies several full-scale sites at which this technology has been used for VOC remediation.

Dynamic underground stripping/hydrous pyrolysis (DUS/HP) combines two methods to heat the soil: by steam injection (for permeable soil), and by electric current (for more impermeable soil). The USEPA REACH-IT database identifies only one full-scale site at which this technology has been used for VOC remediation.

Microwave heating employs microwave energy to generate the required subsurface heat for contaminant vaporization. The USEPA REACH-IT database does not list any sites at which this technology has been used at full scale for VOC remediation.

Much like the microwave heating approach, radio frequency heating generates an electrical field at frequencies typically used in industrial, scientific, and medical applications (6.68, 13.56, 27.12, or 40.68 megahertz). Specially designed electrode rods are placed in either vertical or directionally-drilled holes for optimum "excitation" of the contaminant treatment zone, thereby vaporizing VOCs beyond their boiling points for capture in a vacuum extraction system. Although the USEPA REACH-IT database does not list any sites at which this technology has been used at full scale for VOCs, it has been used at several petroleum contaminant sites as an enhancement to bioremediation or soil vapor extraction. The technology was first used in the 1980s for the relatively successful removal of crude oil from shale oil rock formations in Utah.

Hot air/Steam injection technology uses hot air or steam that is injected below the contaminated zone to heat contaminated soil, thus enhancing the release of contaminants by volatilization into the soil vapor phase. Some of the VOCs are stripped from the contaminated zone and brought to the surface using an SVE extraction well system. The USEPA REACH-IT database lists three full-scale sites at which steam injection was used for VOC remediation.

Electro-heating (three-phase or six-phase heating [SPH™]) includes licensed, registered, patented technologies that use electrical resistive heating and *in situ* steam stripping to remediate contaminated zones. These proprietary technologies use common three-phase electric power supply or convert three-phase electricity into six separate phases. The electric current is then delivered throughout the specific treatment zone by electrodes that are inserted into the soil using standard drilling techniques. This proprietary technology was specifically developed for low-permeability water-saturated soil. The USEPA REACH-IT database lists several full-scale sites at which electro-heating was used for VOC remediation.

5.3.2 *Ex Situ* Treatment

Soil

After excavation of saturated or unsaturated soil contaminated with VOCs and/or other contaminants, several technologies are available for treatment, using many of the same biological, physical, and chemical processes discussed above that are often applied for *in situ* soil treatment. Categories of *ex situ* soil treatment technologies potentially applicable for use at Sites 32/33 include the following:

- Biological treatment
- Chemical treatment
- Thermal destruction/incineration
- Solidification/Chemical fixation
- Physical treatment (VOC volatilization)

Several of these technologies are described in Table 5-2.

Groundwater

Extracted groundwater often requires some form of treatment prior to discharge to surface water or to groundwater via subsurface injection, or for other forms of water reuse. Many types of groundwater treatment processes exist, and are based on proven wastewater treatment technologies. *Ex situ* groundwater treatment technologies potentially applicable for use at Sites 32/33 include the following:

- Biological treatment
- Carbon adsorption
- Air or steam stripping

- Precipitation/flocculation/sedimentation
- Reverse osmosis
- Ion exchange
- Chemical oxidation

Of these technologies, only biological treatment, carbon adsorption, air or steam stripping, and chemical oxidation are generally appropriate for the treatment of VOCs in groundwater. Some of these technologies are briefly discussed in Table 5-2.

Soil Vapor/Air/Steam

Extracted vapor, air, or steam from treatment processes also may require some form of treatment prior to atmospheric discharge. Several types of treatment processes exist for vapor treatment. *Ex situ* vapor treatment technologies potentially applicable for use at Sites 32/33 include the following:

- Condensation (for steam)
- Biofiltration
- High-energy destruction
- Membrane separation
- Oxidation (catalytic, IC, thermal, UV)
- Carbon adsorption

Considering anticipated site-specific concentrations and flow rates, carbon adsorption is likely the most efficient and cost-effective vapor-phase treatment for Sites 32/33.

5.4 Disposal Technologies

5.4.1 Soil Disposal

Land disposal of both hazardous and nonhazardous soil or solids is a proven technology that has been used for many years. Excavated solids could be disposed in engineered off-site or on-site landfill facilities, although such options are only appropriate when waste volumes are limited. In any case, disposal must comply with the federal and state regulations applicable to RCRA-regulated hazardous wastes, if such wastes will be placed in disposal units. Direct off-site transport and disposal without treatment is generally the least favored alternative where practicable treatment technologies are available, and the waste volume is comparatively large, in accordance with USEPA policy. Both off-site and on-site disposal are discussed further below.

Off-Site Facility

Excavation of material would be performed by a backhoe or other mechanical means. Excavated material would then be transported by licensed waste haulers to an off-site, permitted disposal facility. Imported fill material would be required to backfill the excavated areas. Long-term management of the removed material would become the responsibility of a third party; however, the liability associated with the material often remains that of the generator.

On-Site Facility

Beyond the excavation and on-site consolidation and possibly treatment of contaminated solids, this technology could involve the construction of a completely new disposal facility on-site. A newly constructed land disposal unit would have to meet applicable or relevant and appropriate land disposal design requirements. Sufficient land area must be available, and future land use in the disposal area would be restricted.

5.4.2 Groundwater Disposal

Groundwater that is extracted via pumping wells or collection trenches can be disposed by one of the following options:

Discharge to On-site Surface Water Drainage

This option is applicable to both treated and untreated groundwater, provided that both the quality and quantity meet the relevant and appropriate discharge requirements for surface water as regulated under federal and state standards. Sampling of the groundwater to be discharged would be required to determine its quality and to identify whether or not it meets the allowable discharge requirements.

Discharge to POTW

Discharge to a Publicly Owned Treatment Works (POTW) is applicable to both treated and untreated water, provided that the quality and quantity of the water meet the pretreatment requirements of the local regulatory agency or authority. The quantity allowed would likely depend on the capacity of the discharge system and the POTW. Sampling and analysis of the groundwater to be discharged would be required to determine its quality.

Reinjection

This option may be appropriate for disposal of treated groundwater, dependent on obtaining regulatory approval or permits. Reinjection of treated groundwater may serve as a means of hydraulic control in limiting the further migration of a plume, as well as in providing flushing of residual constituents from impacted soil. Extraction and injection wells can be sized and spaced based on aquifer properties for effective containment.

Reuse

In some site-specific situations, reuse of treated groundwater may be appropriate. Potential uses include process supply water for nonpotable industrial uses, irrigation, and potable use after polishing treatment and disinfection.

5.5 Technologies Suitable for Further Development

A screening of potential technologies for soil and groundwater treatment is summarized in Table 5-2. Each technology was screened on the basis of site-specific effectiveness, implementability, and comparative cost, and a determination was made of whether it is appropriate for application as part of a broader remedial alternative.

Section 6
Development of Remedial Alternatives

The purpose of this section of the FS is to develop a range of remedial alternatives assembled from the appropriate individual treatment technologies identified in Section 5. The primary design concepts for each alternative are described, including the major system components and the intended performance objectives or effects of the alternative. Specific design details of the selected alternatives will be determined during the design phase.

The alternatives developed to address the VOC source areas and associated plumes are identified and generally described as follows:

- Building I-1-23 Source Area and Plume
  - Alternative A1 – Excavation (within 10 mg/kg VOC contour, to 12 feet depth), Groundwater Extraction and Treatment, and Phytoremediation
  - Alternative A2 – Excavation (within 1 mg/kg VOC contour, to varying depths within the Upper Clay), Groundwater Extraction and Treatment, and Phytoremediation
  - Alternative B – Excavation (within 10 mg/kg VOC contour, to 12 feet depth), Permeable Reactive Barrier, and Phytoremediation
  - Alternative C – Multiphase Extraction with Pneumatic Fracturing, Groundwater Extraction and Treatment, and Phytoremediation
  - Alternative D – Excavation (within 10 mg/kg VOC contour, to 12 feet depth), Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits
  - Alternative E – Phytoremediation Including Engineered Wetland and Alternate Concentration Limits
  - Alternative F – Excavation (within 10 mg/kg VOC contour, to 12 feet depth), *In Situ* Reductive Dechlorination, Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits
  - Alternative G – Electrical Resistive Heating and Phytoremediation
- Buildings I-1-2/I-1-3 Source Area and Plume
  - Alternative A – Limited Excavation (Building I-1-3 hot-spot) and Multiphase Extraction with Pneumatic Fracturing
  - Alternative B – Permeable Reactive Barrier

  - Alternative C – Alternate Concentration Limits
  - Alternative D – Excavation (within 10 mg/kg VOC contour, to 10 feet depth) and Alternate Concentration Limits
  - Alternative E – Excavation (within 10 mg/kg VOC contour, to 10 feet depth), *In Situ* Reductive Dechlorination with Pneumatic Fracturing, and Alternate Concentration Limits
  - Alternative F - Electrical Resistive Heating
- Area 9 Repository Source Area and Plume
  - Alternative A – Phytoremediation and Monitored Natural Attenuation
  - Alternative B – Phytoremediation and Alternate Concentration Limits

The primary components of these alternatives are described in this section and are summarized in Tables 6-1 and 6-2. The design concepts for the Building I-1-23 alternatives are shown on Figures 6-1 through 6-7. The design concepts for the Buildings I-1-2/I-1-3 alternatives are shown on Figures 6-8 through 6-11. The design concepts for the Repository - Alternatives A and B are shown on Figure 6-12.

Remedial alternatives to address groundwater contamination associated with the separate primary VOC source areas at Sites 32/33 are described in this section. The remedial alternatives that were previously developed and evaluated in the Focused Feasibility Study - Revision 1 (RMT, 2000) were based on the preferred approach of applying a common type of remedial technology for all of the VOC source areas at the site. This approach resulted in the selection of multiphase extraction (MPE) as the technology to be applied at each VOC source area, as documented in the Explanation of Significant Differences (USEPA, 2000a). The design concepts presented in the Preliminary Design Report – Rev. 0 (RMT, 2001d) were also based on application of MPE at each of the primary VOC source areas. However, information developed during the predesign field investigation in 2000 indicated that the physical differences among the separate VOC source areas at Sites 32/33 are sufficiently significant to warrant an independent evaluation of remedial alternatives and the selection of a preferred alternative for each of the primary VOC source areas.

6.1 Components Common to Several Alternatives

To eliminate redundancy in the presentation of alternatives, this subsection describes components that are common to several of the remedial alternatives.

6.1.1 Institutional Controls and Monitoring

All alternatives, excluding the No Action alternative, include the use of institutional controls and the requirement for groundwater monitoring as common components. Institutional controls, in the form of a pending Land Use Control Plan for the Refuge being prepared by F&WS, will formally preclude the potable use of groundwater from the aquifers beneath Sites 32/33 within the VOC plume areas. Additional provisions may also be incorporated into the Land Use Control Plan to limit potential human health risk from other exposure routes.

Except for the No Action alternative, each alternative will also have an alternative-specific monitoring program. The monitoring programs may include groundwater quality compliance points and may also include performance monitoring points for the remedial action. Estimates of the monitoring well network required for each alternative were made to provide a basis for assessing operation, maintenance, and monitoring costs. Development and presentation of a detailed compliance and performance monitoring program for the selected alternatives will be included in the remedial design phase.

6.1.2 Phytoremediation

Phytoremediation is a relatively recent and accepted technology that uses vegetation for *in situ* treatment of shallow contaminated soil, sediment, and groundwater. Phytoremediation is applicable at sites containing organic pollutants that can be accessed by the roots of plants and sequestered, degraded, immobilized, or metabolized in-place (GWRTAC, 2002). Phytoremediation is popular because of its cost-effectiveness, aesthetic advantages, and long-term applicability (Schnoor, et al., 1995). Through phytoremediation processes, organic chemicals may undergo root sorption, uptake, translocation, metabolic transformation, and/or volatilization. Specifically, chlorinated solvents are typically remediated by phytotransformation, and phytovolatilization, and in the case of treatment wetlands, by rhizosphere bioremediation (as wetland plants and organic-rich sediment provide the environment for bacteria to flourish and degrade organics).

Phytotransformation refers to the uptake of organic and nutrient contaminants from soil and groundwater and the subsequent transformation by plants. This transformation depends on the direct uptake of contaminants from soil water and the accumulation of metabolites in plant tissue. Direct uptake by plants of organic compounds present in relatively shallow groundwater is an efficient removal mechanism for sites with contaminants consisting of moderately hydrophobic organic chemicals, including most

BTEX compounds, chlorinated solvents, and short-chain aliphatic compounds (Schnoor, 1997).

The direct uptake of a chemical into the plant through roots depends on the uptake efficiency, transpiration rate, and the concentration of the chemical in soil water (Burken and Schnoor, 1996). Uptake efficiency, in turn, depends on physical-chemical properties, chemical speciation, and the plant itself. Transpiration is a key variable that determines the rate of chemical uptake for a given phytoremediation design; it depends on the plant type, leaf area, nutrients, soil moisture, temperature, wind conditions, and relative humidity (Schnoor, 1997).

When an organic compound has been translocated, the plant may incorporate the compound and its fragments into new plant structures via lignification, or it can volatilize, metabolize, or mineralize the compound completely to carbon dioxide and water. Chlorinated aliphatic compounds such as TCE have been reported to be mineralized to carbon dioxide and less toxic aerobic metabolites (Schnoor, 1997). The form of phytotransformation whereby volatile compounds or their metabolic products are released to the atmosphere through plant transpiration is known as phytovolatilization.

Poplar trees have been found to be capable of taking-up TCE and degrading it to several known metabolic products, including trichloroethanol, trichloroacetic acid, and dichloroacetic acid. Poplars have also been shown to transpire TCE in measurable amounts (Newman et al., 1997). In addition to poplars, other types of phreatophytic trees, such as cottonwoods and willows, are also capable of VOC uptake or phytovolatilization.

Upland area phytoremediation should be performed in areas where groundwater is typically deep enough to allow the soil physical properties to support vegetative growth, but shallow enough to allow for groundwater interception by roots. Constructed wetland "phytoremediation" can be performed where the groundwater table is near the soil surface to maintain saturated conditions year-round, and is capable of supporting the desired wetland vegetation.

Phytoremediation Objectives

The primary remedial objectives for the use of phytoremediation at Sites 32/33 are as follows:

- To reduce the volume of contaminated groundwater and the mass of chlorinated VOCs (CVOCs) discharging to Crab Orchard Lake or other surface water locations by slowing down or reversing shallow groundwater flow toward the drainage swales and the lake, and by the uptake of dissolved CVOCs.

- To accomplish the objective above while creating an ecosystem that complements the site's function as a wildlife preserve.

Conceptual Design Overview

A phytoremediation component (phreatophyte tree stand, savanna/prairie area, and/or treatment wetland) is contained within one or more remedial alternatives for the groundwater plume associated with the VOC source area at Building I-1-23 and at the Repository. The conceptual designs address the East Swale and Center Swale (Repository source area), and the West Swale and adjacent lake embayment (Building I-1-23 source area).

Phreatophytic Tree Stands (Building I-1-23 and Repository Source Area Plumes)

Phreatophytic trees such as hybrid poplars, cottonwoods, and willows have rapid growth rates and high evapotranspiration rates and thus are ideal candidates for phytoremediation. In addition to relatively high water volume uptake, these trees can metabolize, incorporate, mineralize, transpire (volatilize), and degrade dissolved TCE and other VOCs in the rhizosphere.

Tree roots require oxygen and should grow to at least 2 feet in depth to prevent wind throw (tree toppling during wind storms); therefore, the trees should not be planted in areas where groundwater is consistently less than 2 feet below ground surface (bgs). However, trees can be planted in areas that experience periodic groundwater table fluctuations to depths of less than 2 feet, including flooding conditions. Although specialized techniques, such as auguring, air injection, and deep trenchers can be employed to encourage rooting into deep (>10 feet) groundwater, these techniques are more expensive than traditional methods. An effective but less-expensive planting method is to use modified industrial trenchers to plant trees in trenches up to 6 feet deep. Thus, the phreatophyte tree phytoremediation at Sites 32/33 should be (and can be) focused on areas in which the groundwater table is typically 2 to 6 feet bgs.

Phreatophytic trees, including cottonwood, poplar, or willow, are recommended for use at Sites 32/33 because of their high water uptake rates, rapid growth rates, deep rooting potential, ease of planting, regrowth from the cut stump, ability to uptake near-surface groundwater, and survival mechanisms for temporary flooding conditions. Native eastern cottonwoods (*Populus deltoides*) or the DN-34 (*deltoides x nigra*) hybrid poplar, which is a cross between an eastern cottonwood and a black cottonwood, are most suitable for this site, depending on the availability of planting stock in the required sizes (expected to be 6 to 10 feet tall rooted stock). These species have a proven performance record at a number of TCE sites and other organic contaminant research and field sites (Burken and Schnoor, 1996 and Lee et al., 2000). They have demonstrated rapid growth rates and drought/disease/pest resistance (Vose et al., 2000), are recommended by nursery and forestry professionals for planting in the Midwest (Dickmann and Isebrands, 1999), and can have lifespans of over 50 years (Isebrands, 2000). A potential planting plan for the site could consist of 80 percent eastern cottonwood or poplar, 10 percent native willow, and 10 percent other (nut-bearing trees for wildlife diversity, birch, flowering crab, maple, etc.). F&WS has expressed a preference for the use of eastern cottonwoods for the phytoremediation at Sites 32/33, rather than the use of hybrid poplars, because eastern cottonwoods would be more compatible with other indigenous species of trees at the Refuge than nonnative hybrid poplars.

Constructed Prairie (Repository Source Area Plume)

In 1820, at least 60 percent of Illinois' land area, mainly in the northern part of the state, was grasslands of one type or another, but by the end of the nineteenth century, much of Illinois' original prairie was converted to farmland. Industrialization and the growth of cities removed much of what remained, and today 99.99 percent of the original Illinois prairie is gone (Chicago Academy of Sciences, 2003).

Prairies are open grasslands that can survive in relatively dry climates. Grasses and wildflowers typically dominate the prairie ground cover. Vegetation of prairie areas can range from tall, dense grasses and wildflowers to sparse, short grassland areas. Many prairie grass species have root systems that can reach 10 to 15 feet below ground surface level, and many of these grass species have high water-uptake and transpiration rates (ITRC, 2001).

A potential planting/seeding plan for the site could consist of a mixture of deep rooting, Illinois-native prairie grass species such as Indian Grass (*Sorghastrum nutans*), Big Bluestem (*Andropogon gerardii*), and Switch Grass (*Panicum* *virgatum*). These tall grasses can range in height from 3 to 7 feet and can root and effectively draw water from up to 10 feet or more below ground surface.

Constructed Wetland (I-1-23 Source Area Plume)

Extensive recent field and laboratory research has shown that anaerobic degradation of TCE does occur in wetland sediment, and wetlands are ideal environments for natural attenuation of organic contaminants because the sediment typically has a large diversity of microorganisms and a large amount of natural organic material to sorb contaminants and provide substrates for microorganisms (USGS, 1997).

Wetland systems are those in which the water is near enough to the soil surface to maintain saturated conditions year-round and is capable of supporting the related wetland vegetation (Christensen-Kirsh, 1996). Constructed wetlands are complex systems that can be used to treat water, including impacted groundwater, by providing anaerobic zones as well as subsurface oxygenation zones and microbe colonies that promote the bioremediation of organic contaminants, including TCE and all associated breakdown products, in the rhizosphere.

Wetlands are one of the few soil and groundwater environments where both anaerobic *and* aerobic degradation of chlorinated VOCs can occur naturally. Both methanogens and methanotrophs are typically active in wetland microenvironments, and both anaerobic *and* aerobic biodegradation of VOCs is possible, thus resulting in conditions conducive to complete TCE and associated daughter product breakdown (including vinyl chloride). Aerobic oxidation of 1,2-DCE and vinyl chloride can occur either through direct or cometabolic microbial reactions and volatilization close to the air-water interface or near plant roots where oxygen is available.

A potential planting plan for the constructed wetland that would intercept and treat the VOC plume originating from the Building I-1-23 source area could consist of a mixture of Illinois-native wetland species such as bullrush (*Scirpus acutus*), cattail (*Typha latifolia*), and common rush (*Jancus roemerianus*). These wetland species should thrive in this environment and could develop an effective, dense root mass that provides favorable conditions for anaerobic reductive dechlorination and sorption/retardation of dissolved VOCs.

Conceptual designs using phytoremediation as a component of an overall remedial action are described below for several of the remedial alternatives developed in this section.

6.1.3 Previously Completed VOC Source Removal

Investigations of soil and groundwater at Sites 32/33 have determined that the locations of past releases of VOCs generally coincide with the locations of past PCB releases. Therefore, it is likely that large quantities of residual VOC source mass were removed with the PCB-contaminated soil excavated during the remedial action performed in 1996. Because the VOC sources were found to be generally in the same locations as the primary PCB sources, it is likely that a large percentage of the soil containing VOCs excavated in 1996 was processed through the temporary on-site Thermal Treatment Unit, thereby destroying the VOCs and PCBs. Unfortunately, the amount of VOC source mass removed and destroyed was not measured or documented. Nevertheless, the previous removal of VOCs from the currently identified source areas likely made a substantial contribution toward remediation of groundwater at Sites 32/33. Removal of VOC source mass during the previously completed PCB remedial action should be acknowledged as a valuable component that is common to all remedial alternatives for groundwater evaluated in this feasibility study.

6.2 Building I-1-23 Source Area and Plume

6.2.1 No Action

A No Action Alternative is evaluated as a baseline option for comparison to other alternatives. Under this alternative, no remedial actions for soil or groundwater would be performed at the site, and no monitoring would be required. Groundwater contamination would attenuate very slowly by natural physical and biochemical processes.

6.2.2 Alternative A1 – Excavation (within 10 mg/kg VOC contour), Groundwater Extraction, and Phytoremediation

This alternative includes partial source area remediation through soil excavation and hydraulic source removal using groundwater extraction and *ex situ* treatment. Some groundwater remediation will also be provided via phytoremediation. As presented in Table 6-1, this alternative includes the following major components:

- Excavation of Upper Clay within 10 mg/kg VOC contour
- Groundwater extraction and treatment

- Phytoremediation
- Institutional controls

Excavation

This alternative includes excavation and off-site disposal of VOC-contaminated clay soil from the Upper Clay unit, followed by construction and operation of a groundwater extraction and treatment system. Excavation of the clay will remove a substantial portion of the VOC source material remaining in the Upper Clay that was not removed during the PCB soil remedial action in 1996.

Alternative A1 includes excavation of the Upper Clay in one area adjacent to, and along the western side of, Building I-1-23. The excavation area is generally centered around the locations of soil borings SB-201, SB-202, and SB-203 near the side of the building; this area has been designated "Area 201" (see Figure 6-1). Only relatively small and shallow soil excavations were completed in Area 201 in 1996 as part of the PCB remedial action. Approximately 100 cubic yards (cy) of uncontaminated soil (clean backfill placed in the excavations in 1996) will have to be removed in Area 201 to access the VOC-impacted soil present beneath the uncontaminated soil. The excavation in Area 201 will remove soil to a depth limit of approximately 12 feet.

It is assumed that relocation or temporary removal of existing buried utilities to complete the excavation will not be required, based on a brief review of site utility maps and the absence of documentation to the effect that this type of action was required during the PCB soil excavations in the same general areas in 1996.

The three-dimensional boundaries of excavation Area 201 have been defined based on the extent of clay containing $\geq$ 10 mg/kg VOCs. This extent was derived from the soil characterization sampling performed during the predesign fieldwork in the fall of 2000 (RMT, 2001d). It is estimated that approximately 15 percent of the total VOC mass present in this source area would be removed with the excavation in Area 201. The objective of soil excavation under Alternative A1 is to remove soil that contains the higher concentrations of VOCs detected during previous investigations, thereby removing the soil volume that is most likely to contain residual NAPL, and therefore a substantial portion of the VOC mass in the Upper Clay. An excavation depth of 12 feet bgs was selected based on the depth of "hot spots" discovered during the investigations. From an analysis of excavation limits versus soil volume and contaminant mass removal, it was concluded that excavating much beyond the approximate 10 mg/kg VOC contour would result in a four- to six-fold increase in excavation volume, while likely providing only a limited corresponding increase in the total VOC mass removed.

The excavated VOC-impacted clay would be transported to a licensed off-site disposal facility. For development and evaluation of the alternatives for the Building I-1-23 source area, the assumption has been made that 50 percent of the excavated soil would be managed as a non-hazardous waste for off-site disposal, and 50 percent would be managed as a "characteristically" hazardous waste. This assumption provides a common basis for estimating costs for all alternatives for the Building I-1-23 source area that include a soil excavation component.

Groundwater Extraction and Treatment

After completing the soil excavation portion of the work, a groundwater extraction and treatment system would be installed at the Building I-1-23 source area. Groundwater flow modeling has shown that a single vertical extraction well screened in the confined Upper Sand unit at the location of the highest VOC concentrations in the source area would effectively cut off and remove dissolved VOCs migrating from the source area in groundwater, owing to source material remaining after the soil excavation portion of the work. The modeling has shown that the single vertical well should establish a hydraulic capture zone approximately 900 feet wide at the source area well location.

Groundwater flow and contaminant transport modeling of the Building I-1-23 source area and plume, as well as the results of pilot testing performed in 2000, have also indicated that relatively short-term groundwater extraction from the Upper Sand unit at the source area should be capable of removing dissolved VOC mass at a substantial rate. This dual capability of mass removal and effective hydraulic containment/capture resulting from groundwater extraction provides optional remediation objectives for this component of Alternative A1. An extraction well system could be installed to pump groundwater from the Upper Sand (1) at the minimum rate needed for long-term containment of contaminated groundwater in the source area (approximately 10 gpm), or (2) at the optimum rate for short-term removal of VOC source mass (with the optimum rate determined during system operation). For the long-term pumping option, the purpose is hydraulic containment of the remaining dissolved VOC source material, which will allow concentrations in the downgradient plume (beyond the capture zone of the extraction well) to be substantially reduced over time. For the short-term hydraulic source removal option, the purpose is to remove dissolved VOC source mass from the Upper Sand unit (and VOCs that slowly leach from the Upper Clay unit into the Upper Sand) until the incremental VOC mass removal rate compared with the cumulative mass removed since the start of pumping is less than a predetermined percentage of the cumulative mass removed, indicating that further pumping would produce minimal additional mass removal benefit.

For either groundwater extraction objective (long-term containment or short-term mass removal), the physical system required for groundwater extraction and treatment (and thus the associated capital costs) would be the same. A new Treatment Building would be constructed on the northern side of the existing fence near the source area. Treatment equipment consisting primarily of a packaged liquid-phase activated carbon system would be used. The treated groundwater would be conveyed through a buried force main from the Treatment Building to a suitable discharge point in the West Swale, or possibly to an outfall at the lake.

Phytoremediation

An additional component of Alternative A1 includes planting phreatophytic trees across the West Swale near the lake, for phytoremediation of the shallow groundwater.

West Swale Area Setting - Depth to groundwater increases with distance from the lake. Groundwater typically fluctuates between 2 to 5 feet bgs at 200 feet south of the lake (near wells 33MWC-30 and 33MWC-31), and 5 to 11 feet bgs at 500 feet south of the lake (near well 33MWC-08). Groundwater conditions and quality for this area are suitable for vegetative uptake.

West Swale Area Conceptual Design - This area is located generally between monitoring wells 33MWC-08 and 33MWC-30 (Figure 6-1). It is bounded to the west by an existing tree line and to the east by existing trees and large aboveground tanks. The targeted area measures approximately 100 feet by 220 feet. Based on these dimensions, 11 rows of trees would be planted 5 feet apart in rows spaced 10 feet apart. Approximately 500 trees would be planted in the West Swale area.

Aerial topography data and historical groundwater elevation data will be used in the design phase to more accurately determine where the depth to groundwater normally ranges 2 to 6 feet below ground surface. Additional water balance calculations will be performed in one or more of the areas to predict water uptake potential by the trees. This additional information will be used to refine the design for the phytoremediation area.

Based on these groundwater and tree density conditions, current groundwater VOC concentrations, and an assumed annual groundwater uptake of 400 gallons per tree (equivalent to approximately 15 inches groundwater uptake for a tree density of 1,000 trees per acre), an annual TCE mass removal of approximately 1,100 grams (2.42 lb) is estimated.

6.2.3 Alternative A2 – Excavation (within 1 mg/kg VOC contour), Groundwater Extraction, and Phytoremediation

As with Alternative A1, this alternative primarily includes source area remediation through soil excavation and hydraulic source removal using groundwater extraction and *ex situ* treatment. Some groundwater remediation will also be provided via phytoremediation. As presented in Table 6-1, this alternative includes the following major components:

- Excavation of Upper Clay within 1 mg/kg VOC contour
- Groundwater extraction and treatment
- Phytoremediation
- Institutional controls

Excavation

This alternative differs from Alternative A1 in that the target excavation zone will extend to the lateral extent of the previously defined 1 mg/kg VOC contour in excavation Areas "201," "208," and "212," and the excavation depths are greater than in Alternative A1. The excavation "Area 212" is generally centered around the location of soil boring SB-212 (Figure 6-2). At this location, the VOC source material is believed to be primarily located beneath 7 feet of "clean" clay backfill placed in the PCB-soil excavation in 1996. Therefore, removal of a relatively large amount of this backfill will be required to access the clay with the higher VOC concentrations. The clean backfill will be stockpiled for reuse after removal of the VOC-impacted clay. The majority of the VOC mass at Area 212 is expected to exist in the saturated clay, from approximately 7 to 24 feet bgs, and extends into the Upper Sand, making excavation at Area 212 more difficult than at Area 201. Excavation to the top of the Upper Sand presents more of a construction challenge than excavations that would terminate within the Upper Clay, because groundwater will flow into the excavation when the clay overburden is removed, as experienced during the PCB soil remedial action in 1996. Although a target excavation depth of 24 feet has been defined for Area 212, the actual excavation depth that can be achieved would be determined in the field based on practical limitations of the excavation equipment and methods.

Excavation "Area 208" is centered around the location of soil boring 208 (Figure 6-2). At this location, the VOC source material is believed to be primarily located beneath 8 feet of "clean" clay backfill. Therefore, as with Area 212, removal of this backfill will be required to access the clay with the higher VOC concentrations. The majority of the VOC mass at Area 208 is believed to exist in the saturated clay from approximately 8 to 15 feet bgs. Excavation of Areas 208 and 212 is included as an addition to the main excavation Area 201 under Alternative A1. The target depths of excavation are 17 feet in Area 201, 15 feet in Area 208, and 24 feet (to the estimated top of the Upper Sand unit) in Area 212 in this alternative. Excavation of Areas 201, 208, and 212 is estimated to be capable of removing approximately 40 to 50 percent of the total VOC mass present in the source area (in the Upper Clay and Upper Sand).

The soil excavation included under Alternative A2 is intended to ensure that the bulk of the VOC contamination, including NAPLs, would be removed from the Upper Clay. The soil VOC concentration contour of 1 mg VOCs/kg dry soil was used as a practicable limit for defining the excavation areas. The probability of encountering significant VOC source mass outside of these approximate areas is expected to be relatively low. This conclusion is based on the results of soil borings/sampling and groundwater sampling in the source area, and on the fact that the past VOC and PCB releases appear to have been at common locations at the Building I-1-23 area. Based on the extensive amount of investigation sampling data for both VOCs and PCBs in soil in this area, and with the knowledge of the actual limits of the PCB-soil excavations in 1996, the approximate lateral excavation limits represented by a total VOC concentration of 1 mg/kg are expected to encompass the bulk of contamination.

Groundwater Extraction and Treatment

The physical components of the groundwater extraction and treatment system for Alternative A2 would be identical to that presented above for Alternative A1. However, the groundwater extraction in the Upper Sand unit would continue for only 11 years, at which point the NAPL mass is expected to have been removed from the Upper Sand.

Phytoremediation

The phytoremediation component of Alternative A2 would be identical to that presented above for Alternative A1.

6.2.4 Alternative B – Excavation (within 10 mg/kg VOC contour), Permeable Reactive Barrier, and Phytoremediation

This alternative includes partial source area remediation through soil excavation, and groundwater remediation via passive *in situ* treatment with a "permeable reactive barrier (PRB)." Some downgradient groundwater remediation will also be provided via phytoremediation. As presented in Table 6-1, this alternative includes the following major components:

- Excavation of Upper clay within 10 mg/kg VOC contour
- PRB for VOC source containment and *in situ* groundwater treatment
- Phytoremediation
- Institutional controls

Excavation

The excavation component of Alternative B is identical to that presented above for Alternative A1.

In Situ Groundwater Treatment

To provide cut-off and *in situ* treatment of VOCs, a continuous PRB consisting of a mixture of zero-valent iron (ZVI) and sand would be installed immediately downgradient of the VOC source area across the width of the VOC plume, after completing the soil excavation portion of the remedy. The length of the PRB would be approximately 350 feet (Figure 6-3). The reactive zone of the PRB containing the ZVI would be placed across the full depth of the Upper Sand, from the top of the Lower Clay to the bottom of the Upper Clay. A biopolymer slurry would be used to keep the trench open in the sand while the ZVI is placed in the trench. As the groundwater flows through the PRB under natural gradients, the dissolved VOCs would be destroyed by chemical reactions with the ZVI. The PRB provides *in situ* passive groundwater treatment that does not require regular maintenance or operator attention.

The reactive ZVI placed into the ground is not a "barrier" to groundwater flow. It is a "barrier" to the migration of VOCs in the groundwater, because the VOCs are destroyed by chemical reactions as the groundwater passes through the iron-filled PRB. A PRB is actually more permeable than the surrounding natural soil formation, which promotes groundwater flow to and through the reactive ZVI zone. The following description of PRB technology is an excerpt from an Explanation of Significant Differences issued in 1998 by USEPA – Region 3 for a Superfund site in Virginia (USEPA, 1998a):

> *A Permeable Reactive Subsurface Barrier (PRSB) is an in situ passive groundwater treatment option, which should achieve the groundwater remedial objectives while providing a cost-effective alternative to the traditional groundwater pump and treat system selected in the 1991 ROD...PRSB consist of trenches that are excavated and backfilled with reactive iron (Fe) filings. As groundwater flows through the trenches, the contaminants in the water are degraded, adsorbed, and/or precipitated, depending on the oxidation-reduction reaction that occurs when the chlorinated solvents come into contact with the metallic (zero-valent) iron in the absence of oxygen. The contaminants are broken down to relatively harmless end products such as carbon dioxide, water, and hydrocarbons. Hydrocarbons, such as methane and ethane, may be further reduced by naturally occurring bacteria...PRSBs are, in effect, in situ reactors which achieve the same type of mass transfer reactions that are used in an above-ground system during pump and treat operations. Slow moving groundwater passing through PRSBs can provide relatively long residence times within the in situ "reactor." The required residence time will be determined based on the contaminant concentrations moving into the reactive zone, the respective contaminant-specific degradation rate (i.e., the most resistant contaminant will be the basis of design), and the groundwater flowrate.*
>
> *The specific location, thickness, and/or number of reactive barriers will be determined during the remedial design...The final configuration of the PRSB system will be designed to ensure: 1) contaminated groundwater exceeding performance standards passes through the PRSB system; and*

> *2) the residence time within the in situ reactor is sufficient to achieve the treatment goals.*
>
> *Significant advantages are realized by the PRSB because the contaminated groundwater is not brought to the surface for treatment. EPA remains confident that the pump and treat system identified in the ROD could be safely implemented with minimal cross-media transfer of contaminants to air and surface water. Nevertheless, the PRSB technology provides for water treatment at depth, thus eliminating issues related to handling contaminated groundwater, managing air emissions and treatment plant residuals, and maintaining a surface water discharge...which is safe for aquatic life.*

Phytoremediation

The phytoremediation component of Alternative B would be identical to that presented above for Alternative A1.

6.2.5 Alternative C – Multiphase Extraction with Pneumatic Fracturing, Groundwater Extraction, and Phytoremediation

This alternative primarily includes source area remediation through contaminant removal via multiphase extraction after pneumatic fracturing of the clay, followed by hydraulic containment/control using groundwater extraction and *ex situ* treatment. Some downgradient groundwater remediation will also be provided via phytoremediation. As presented in Table 6-1, this alternative includes the following major components:

- Multiphase extraction with pneumatic fracturing and dewatering
- Groundwater extraction and treatment
- Phytoremediation
- Institutional controls

Multiphase Extraction with Pneumatic Fracturing and Dewatering

This alternative uses multiphase extraction (MPE) wells with enhancement by pneumatic fracturing to treat the VOC sources within the Upper Clay unit. The Upper Sand unit would also be treated using MPE wells, soil vapor extraction (SVE) wells, and horizontal groundwater extraction wells to dewater the sand and to help promote dewatering of the Upper Clay. The MPE/SVE system would eventually reach a point of diminished or "asymptotic" VOC removal effectiveness. Many factors and variables would determine the length of time the system must be operated until these "asymptotic" performance conditions occur. Some of these factors include the effectiveness and rate of the dewatering process, the effectiveness of pneumatic fracturing in the Upper Clay, the MPE/SVE system design criteria (vacuum pressures, well spacing, etc.) and operating methods, and the amount and distribution of VOC source material. For evaluation of this alternative, it has been assumed that the remediation system may reach asymptotic performance conditions within approximately 2 years after startup. Therefore, after approximately 2 years of operation, the effectiveness of the MPE/SVE system would be evaluated to determine whether continued operation of the system, possibly with modifications to enhance performance, would be warranted. When it is determined that further operation of the MPE/SVE system is not warranted, the groundwater extraction and treatment system used during the MPE operation would be modified because of the required flowrate reduction from approximately 80 gpm (for dewatering, with MPE) to approximately 10 gpm (for hydraulic containment).

MPE is an *in situ* technology that uses a high-vacuum pump(s) to extract liquid and vapor simultaneously from the subsurface through a well(s). Extracted liquid and vapor are treated and disposed, or discharged. The vacuum applied to the subsurface with MPE systems creates pressure gradients in the soil toward the vacuum well. These pressure gradients are transmitted to the subsurface liquids and soil pore gas, which will flow toward the vacuum well in response to the imposed gradient. The higher the applied vacuum, the larger the pressure gradient that can be achieved in both vapor and liquid phases, and thus, the greater the vapor and liquid recovery rates.

Several extraction wells can be connected to a single high-vacuum pump, usually a liquid-ring vacuum pump capable of over 400 inches water column (in. H_2O), or 29 inches mercury (in. Hg) vacuum. In each well, an extraction tube (also known as a "spear" or "stinger pipe") is installed with its tip at the elevation to which drawdown of the groundwater is to occur. The extraction tubes are connected to the vacuum pump via manifold piping. This configuration differs from that of dual-phase extraction (DPE) in that DPE uses a submersible pump in each well to create drawdown of the water table, while vacuum is induced at the well by separate, vapor-only piping connected at the wellhead and manifolded to a vacuum blower. The vacuum blowers used in DPE applications are typically not expected to extract groundwater by vacuumlift pumping. For this reason, a different type of vacuum blower is used (usually either a regenerative or a positive-displacement type) that is capable of higher flow, but that has only about half of the vacuum capability (or less) of a liquid-ring pump. MPE is therefore preferred over DPE in lower permeability formations, such as the Upper Clay at this site.

To enhance recovery of fluids, pneumatic fracturing (PF) of the Upper Clay will be conducted in the target MPE areas before beginning MPE treatment. PF is a proven remediation-enhancement method adapted from the petroleum industry, used to create additional soil fractures to improve the performance of extraction or injection wells. PF involves the pulse-injection of gas (air or nitrogen) to increase the soil permeability in the area around an injection well, thereby allowing increased rates of VOC removal and potentially more cost-effective remediation.

PF under this alternative would involve the pulse-injection of a relatively large volume of nitrogen gas at moderate pressures into the clay soil to "dilate" fractures and create a secondary network of conductive subsurface fissures and channels. The enhanced network of fractures increases the exposed surface area within the contaminated soil matrix as well as its permeability to liquids and vapors.

It is assumed that, for the Building I-1-23 area, PF of the Upper Clay would be done in multiple vertical intervals per MPE well borehole. This configuration would provide a high degree of permeability enhancement throughout the VOC-impacted areas. This configuration will also likely result in a radius-of-influence of greater than the desired 20 feet for the MPE well network. PF would be performed at depths ranging from 10 to 20 feet bgs, and a total of 4 PF points/MPE well are assumed for the Upper Clay target area. Each individual PF vertical interval is 3 feet, and a total of 12 intervals are assumed for the targeted clay zone in the Building I-1-23 area. In addition, eight MPE extraction wells are assumed for the Upper Sand unit. These wells would be placed up to an estimated 45-foot depth in the targeted area.

At each of the previously identified source zones, a combination of vertical MPE and horizontal dewatering wells would be installed. Three horizontal dewatering wells would be installed using directional drilling techniques at the bottom of the Upper Sand layer. Conventional vertical MPE extraction wells would be installed in the Upper Clay layer only, and vertical SVE wells would be installed in the Upper Sand. Based on trial runs using the calibrated groundwater flow model to estimate optimum pumping configurations, a total of 12 vertical MPE and SVE wells and three horizontal groundwater extraction wells would be installed at the Building I-1-23 area (Figure 6-4A). All vertical wells would be constructed of nominal 2-inch or 4-inch–diameter PVC pipe, while the horizontal wells would be constructed of nominal 4-inch–diameter HDPE pipe. A preliminary schematic diagram of the MPE system is shown on Figure 6-4B.

The extracted groundwater would be treated using granular activated carbon, and subsequently pumped to a new outfall at the lake, or possibly to a suitable discharge point in the West Swale, via a force main constructed from the treatment building to the lake. Vapors recovered via the liquid-ring pump would also be treated using granular activated carbon, as needed, and exhausted to the atmosphere. A preliminary schematic diagram of the groundwater treatment system is shown on Figure 6-4C.

The new treatment building would be sized to house all of the treatment equipment needed for both the MPE/SVE operation period, and for the long-term groundwater extraction/treatment system that would follow. After the MPE/SVE operation period, some of the MPE treatment equipment would remain for use in treating the groundwater from the single vertical extraction well located in the source area (described below), particularly the liquid-phase activated carbon system and associated controls/instrumentation.

Groundwater Extraction and Treatment

As described above, when further operation of the MPE/SVE system is deemed unwarranted, the groundwater extraction and treatment system used during the MPE operation would be modified because of the required flowrate reduction from 80 gpm (for dewatering, with MPE) to approximately 10 gpm (for long-term containment). The modified groundwater extraction and treatment system would be used to provide effective hydraulic cut-off and removal of dissolved VOCs in the groundwater within the Upper Sand unit, thus preventing the VOCs from migrating toward the lake with the groundwater flow.

The extracted groundwater would continue to be treated using granular activated carbon, and subsequently discharged to the lake. The same force main and outfall used during the MPE operations would continue to be used for discharge of the treated groundwater from the long-term groundwater extraction/treatment system (approximately 10 gpm flowrate), following shut-down of the MPE/SVE system.

Phytoremediation

The phytoremediation component of Alternative C would be identical to that presented above for Alternative A1.

6.2.6 Alternative D – Excavation (within 10 mg/kg VOC contour), Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits

This alternative includes partial source area remediation through soil excavation, phytoremediation to address VOC impacts on surface water caused by groundwater discharge to the West Swale and to the lake, and the use of Alternate Concentration Limits (ACLs) for groundwater. As presented in Table 6-1, this alternative includes the following major components:

- Excavation of Upper Clay within 10 mg/kg VOC contour
- Phytoremediation (phreatophytic tree stand and engineered wetland)
- Alternate Concentration Limits
- Institutional controls

Excavation

The excavation component of Alternative D is identical to that presented for Alternative A1, as described in Subsection 6.2.1 above.

Phytoremediation

The phytoremediation component of Alternative D using phreatophytic trees would be identical to that presented in Subsection 6.2.1 above for Alternative A1. In addition, this alternative would include a constructed engineered wetland "treatment zone" within a portion of the existing Crab Orchard Lake bay to intercept the VOC-impacted groundwater where it currently discharges into the bay, and to treat the discharging groundwater and surface water runoff that passes through the West Swale to reduce VOC concentrations to nondetectable levels before the water enters the main body of Crab Orchard Lake.

The conceptual design of the engineered wetland would consist of extensive regrading and the construction of a shallow-water emergent wetland treatment zone planted with a mixture of Illinois-native wetland species, including bullrush (*Scirpus acutus*), cattail (*Typha latifolia*), and common rush (*Jancus roemerianus*). These wetland species should thrive in this environment, and develop an effective dense root mass that would harbor favorable microbial communities for biodegradation of VOCs.

The conceptual footprint of this wetland contains two wetland cell, the emergent wetland cell, which is approximately 237,000 sf (5.4 acres), and the open water cell, which is approximately 55,000 sf (1.25 acres) (Figure 6-6). The constructed wetland would span the estimated width of the Building I-1-23 VOC plume currently discharging into Crab Orchard Lake. The average water depths in the constructed wetland treatment zone would be approximately 1.5 feet in the emergent cell and 5 feet in the open water cell. The wetland area would be overexcavated (or filled) to an average ground surface elevation of approximately 403.5 feet (approximately 1.5 feet below the average water surface elevation of Crab Orchard Lake) in the emergent cell and approximately 400 feet (approximately 5 feet below the average water surface elevation of Crab Orchard Lake) in the open water cell. Additional information regarding the engineered wetland is included in Subsection 6.1.2.

Alternate Concentration Limits (ACLs)

The establishment of ACLs provides an enforceable limit for contamination levels in groundwater. The Superfund Amendments and Reauthorization Act (SARA) provides for a process for establishing ACLs in Section 121(d)(2)(B)(ii). Pursuant to this section, ACLs may be used where

- there are known and projected points of entry of such groundwater into surface water;
- on the basis of measurements or projections, there is or will be no statistically significant increase of such constituents from such ground water in such surface water at the point of entry or at any point where there is reason to believe accumulation of constituents may occur downstream; and
- the remedial action includes enforceable measures that will preclude human exposure to the contaminated groundwater at any point between the facility boundary and all known and projected points of entry of such groundwater into surface water.

ACLs are also addressed in the National Contingency Plan (NCP) (55 FR 8754), where it states that "ACLs may be used if the conditions of CERCLA Section 121(d)(2)(B)(ii) are met and cleanup to Maximum Contaminant Levels (MCLs) or other protective levels is not practicable. If these statutory criteria for ACLs, including a finding that active restoration of the groundwater to MCLs or non-zero Maximum Contaminant Level Goals (MCLGs) is deemed not to be practicable, documentation of these conditions for the ACL is sufficient and additional documentation of a waiver of the MCL or MCLG is not necessary."

The known or projected points at which the Building I-1-23 plume enters surface water bodies are the West Swale and the associated bay of Crab Orchard Lake.

ACLs are established by developing baseline groundwater quality levels for the shallow aquifer near the groundwater/surface water interface within the plume discharge area, and then employing an analytical method to determine what level of groundwater contamination would constitute a statistically significant increase in VOC concentrations at a selected point(s) of compliance for groundwater quality. If future groundwater monitoring confirms a statistically significant increase in the concentrations of the constituents of interest, the need to implement a subsequent remedial action would be evaluated. For each of the remedial alternatives for the Building I-1-23 source area and plume that include establishing ACLs (Alternatives D, E, and F), it has been assumed that the ACLs will be developed using existing groundwater quality data.

A monitoring program for surface water in the Crab Orchard Lake bay would also be included to ensure that there is no statistically significant increase in VOC impacts from the Building I-1-23 source area on Crab Orchard Lake following implementation of the phytoremediation component of Alternative D. If a significant increase in VOC concentrations is detected in surface water, then the need for additional measures to enhance the treatment effectiveness of the wetland would be evaluated.

6.2.7 Alternative E – Phytoremediation Including Engineered Wetland and Alternate Concentration Limits

This alternative primarily includes enhanced phytoremediation to address VOC impacts on surface water caused by groundwater discharge to the West Swale and to the Crab Orchard Lake bay, and the use of ACLs for groundwater. An "active" remediation component to address the VOC source area at Building I-1-23 is not included in this alternative. As presented in Table 6-1, this alternative includes the following major components:

- Phytoremediation (phreatophytic tree stand and engineered wetland)
- Alternate Concentration Limits
- Institutional controls

Phytoremediation

The phytoremediation component of Alternative E is identical to that presented above for Alternative D.

Alternate Concentration Limits

The ACL component of Alternative E is identical to that presented above for Alternative D.

6.2.8 Alternative F – Excavation (within 10 mg/kg VOC contour), *In Situ* Reductive Dechlorination, Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits

This alternative includes remediation of the VOC source area using two methods: excavation of Upper Clay soil, and the addition of a substrate into the source area soil and groundwater to stimulate the *in situ* destruction of VOCs in both the Upper Sand and Upper Clay through biological reductive dechlorination. The alternative also includes enhanced phytoremediation to address VOC impacts on surface water caused by groundwater discharge to the West Swale and to the lake, and the use of ACLs for groundwater. As presented in Table 6-1, this alternative includes the following major components:

- Excavation of Upper Clay within 10 mg/kg VOC contour
- *In situ* biological reductive dechlorination
- Phytoremediation (phreatophytic tree stand and engineered wetland)
- Alternate Concentration Limits
- Institutional controls

Excavation

The excavation component of Alternative F is identical to that presented above for Alternative A1.

In Situ Reductive Dechlorination

Many common organic groundwater contaminants can be treated *in situ* by enhanced biological processes. These types of contaminants include chlorinated solvents (e.g., PCE, TCE, DCA, etc.), certain chlorinated aromatics, nitroaromatics, inorganics (e.g., nitrate and perchlorate), and metals (e.g., hexavalent chromium). With anaerobic biodegradation, the target contaminants are "reduced" with hydrogen, unlike in chemical oxidation or aerobic processes, where oxygen is the functional chemical. For optimal anaerobic degradation to occur, more energetically favorable electron acceptors, such as oxygen, nitrate, manganese, ferric iron, and sulfate, must first be consumed. There also must be sufficient "food," or electron donors, for the bacteria to thrive. Microorganisms, like humans, breath electron acceptors and eat electron donors. To optimize anaerobic biodegradation, the goal is to choke the plume (deplete the oxygen and other electron acceptors) before it starves (depletes food or electron donors).

Electron donors can include co-contaminants such as petroleum hydrocarbons or natural organic matter. If these donors are not available or are not in sufficient concentrations (which is the case at Sites 32/33), the anaerobic process can be enhanced by introducing a food source into the subsurface. One of the most effective and environmentally benign food sources is fatty acids, such as sodium lactate or inorganic lactate salts. Although numerous electron donor materials exist, sodium lactate (commonly used as an additive in the dairy industry) is readily available, environmentally acceptable, and relatively inexpensive. The cost estimates prepared for this alternative assume that sodium lactate would be used as the electron donor material. However, the actual substrate(s) to be used for full-scale remediation would be determined during the pre-design phase.

At the Building I-1-23 source area, a small number of injection wells would be installed into the Upper Sand, to thoroughly disperse a liquid bio-substrate throughout the sand unit. The substrate solution would also include chemical additives to react with and reduce the competing effects of dissolved oxygen and other electron acceptors. The required duration and optimum frequency of the periodic substrate injections would be determined based on evaluation of the ongoing remediation effectiveness. The cost estimates prepared for this alternative are based on an assumed injection frequency of every 3 to 4 months, over an assumed duration of 5 years.

After the VOC "hot spots" have been excavated in the Upper Clay, the substrate liquid would also be placed in bulk form into the open excavation, and blended into the clean backfill as the excavation is filled. This will allow the substrate to function as a "slow-release" food source to stimulate anaerobic degradation of the VOCs remaining in the clay outside of the excavated area.

Phytoremediation and ACLs

The use of phytoremediation and ACLs as components of Alternative F are identical to the use of these components in Alternative E.

6.2.9 Alternative G – Electrical Resistive Heating (within 1 mg/kg VOC contour) and Phytoremediation

This alternative includes remediation of the VOC source areas using electrical resistive heating (ERH). As presented in Table 6-1, this alternative includes the following major components:

- ERH in the source area within estimated 1 mg/kg VOC zones, through full depth of Upper Clay and Upper Sand units.
- Phytoremediation
- Institutional controls

Electrical Resistive Heating

The ERH technology is a thermally enhanced soil vapor extraction (SVE) technique that targets both contaminated soil and groundwater. When electricity is applied, the soil is heated due to resistance to the flow of electrical current, thereby boiling the soil moisture and increasing the vapor pressure of VOCs. Contaminants are mobilized by direct volatilization and in situ steam stripping, removed by SVE, and treated appropriately before the extracted soil vapor is vented to the atmosphere. Heating has also been reported to accelerate in situ degradation mechanisms such as biodegradation, hydrolysis, oxidation, or reduction.

The preliminary conceptual design for use of ERH at the Building I-1-23 VOC source area primarily consists of the electric heating, drip-wetting, and vapor/steam collection systems.

The conceptual heating network for targeting soil zones of 1 mg/kg or greater total VOCs (Figure 6-7A) would consist of an estimated 20 to 25 electrodes constructed in 12-inch boreholes at approximately 20-foot spacing. The estimated depth of the treatment zone varies from a minimum of 8 feet below ground surface (bgs) to a maximum of 40 feet bgs. The electrical power requirement is estimated to be approximately 807 kW (power supply rating of 750 kW) with a 1,867 amp draw and 480V, 3-phase service. A conceptual schematic diagram of the ERH system is shown on Figure 6-7B.

For efficient heating operation, it is expected that a drip-wetting system would be required for the electrodes. This system would consist of approximately 50 to 75 drip assemblies, with an average wetting rate of approximately 0.5 gpm using a potable water supply. The subsurface temperature would be monitored by a system of approximately 10 to 15 temperature monitoring wells located within the treatment zone(s).

The conceptual soil vapor extraction system design consists of approximately 50 vapor extraction vent wells. The estimated horizontal spacing of the vent wells is approximately 20 feet. These vents would collect generated VOC-laden vapor/steam and convey it to a condenser and vapor treatment system. Additional technical and engineering evaluation of the implementation details during the final design phase might require modifications of this conceptual design plan for the ERH step under Alternative G.

The estimated soil heating time is approximately 100 to 120 days, the base treatment time (after obtaining the target temperature) would be approximately 20 days for an overall treatment time of approximately 120 to 140 days. This time estimate does not include time for mobilization, a demonstration/pilot test, construction, demobilization, or work area restoration; only estimated treatment time is included. The total electrical energy consumption is estimated to be 1,800,000 kW-hr. Vendor estimates for the final treatment results include the complete removal of NAPL and a 99 percent or greater reduction of dissolved phase VOC contamination.

Phytoremediation

The phytoremediation component of Alternative G would be identical to that presented above for Alternative A1.

6.3 Buildings I-1-2/I-1-3 Source Area and Plume

6.3.1 No Action

A No Action Alternative is again evaluated as a baseline option for comparison to other alternatives. Under this alternative, no remedial actions for soil or groundwater would be performed at the site, and no monitoring would be required. Groundwater contamination would attenuate very slowly by natural physical and biochemical processes.

6.3.2 Alternative A – Limited Excavation and Multiphase Extraction with Pneumatic Fracturing

Similar to Alternative C for Building I-1-23 above, this alternative primarily includes source area remediation through contaminant removal via a system of MPE wells in the VOC source zones in the Upper Clay and Lower Clay at Buildings I-1-2 and I-1-3, preceded by pneumatic fracturing to enhance the ability of the MPE wells to extract VOCs in both soil vapor and groundwater. As presented in Table 6-1, this alternative includes the following major components:

- Limited excavation
- Multiphase extraction with pneumatic fracturing
- Institutional controls

Limited Excavation

A limited amount of soil excavation in the Upper Clay (approximately 550 cy) is also included to remove a shallow (depth limit of 6 feet), but relatively concentrated, VOC source "hot spot" that was located adjacent to Building I-1-3 during the predesign fieldwork investigation in 2000. The excavation is included because pneumatic fracturing is not effective in the relatively shallow depth where this hot spot is present, and removal of this VOC source by limited or "focused" excavation is a more direct and efficient method than MPE.

The excavated VOC-impacted clay would be transported to a licensed off-site disposal facility. For development and evaluation of the alternatives for the Buildings I-1-2/I-1-3 source area, the assumption has been made that 50 percent of the excavated soil would be managed as a non-hazardous waste for off-site disposal, and 50 percent would be managed as a "characteristically" hazardous waste. This assumption provides a common basis for estimating costs for all alternatives for the Buildings I-1-2/I-1-3 source area that include a soil excavation component.

Multiphase Extraction with Pneumatic Fracturing

As with Alternative C for the Building I-1-23 source area, this alternative uses MPE wells with enhancement by pneumatic fracturing to treat the VOC sources within the Upper Clay and Lower Clay units. A treatment building would be constructed to house the vacuum pumps and air/water treatment equipment. The building would be located approximately between the Building I-1-2 and I-1-3 source areas on the eastern side of the buildings (Figure 6-8A). The gas phase containing VOCs collected by the MPE system will be treated using gas-phase activated carbon and exhausted to the atmosphere. The groundwater will be treated using liquid-phase activated carbon and discharged to the upstream end of the East Swale, via a force main installed from the treatment building to the swale.

The conceptual design for the Buildings I-1-2/I-1-3 source area consists of three PF points (boreholes) installed per MPE well at roughly 15 feet from the planned MPE well locations. This configuration would provide a high degree of permeability enhancement throughout the VOC-impacted areas. This configuration will also likely result in a radius-of-influence of greater than the desired 20 and 25 ft for the MPE wells, respectively. PF would be conducted at depths ranging from 10 to 45 feet bgs, and a total of 66 PF points are assumed for 22 assumed MPE extraction wells. The MPE well depths would range from 10 to 42 feet bgs. Each individual PF vertical interval is 3 feet, and a total of 312 PF intervals are assumed for the Buildings I-1-2/I-1-3 source area. A preliminary schematic diagram of the MPE and groundwater treatment systems is shown on Figure 6-8B.

As discussed above for Building I-1-23, Alternative C, it has been assumed that the MPE system may reach a point of diminished or "asymptotic" VOC removal effectiveness within approximately 2 years after startup of the system. Therefore, after 2 years of operation, the MPE system would be evaluated to determine whether continued operation of the system, possibly with modifications to enhance performance, would be warranted.

6.3.3 Alternative B – Permeable Reactive Barrier

Similar to Alternative B for Building I-1-23 above, this alternative includes VOC source area containment and groundwater remediation via passive *in situ* groundwater treatment with a permeable reactive barrier. As presented in Table 6-1, this alternative includes the following major components:

- PRB for VOC source containment and *in situ* groundwater treatment
- Institutional controls

In Situ Groundwater Treatment

A PRB would be installed across the width of the VOC plume that extends to the west from the source areas on the eastern side of Buildings I-1-2 and I-1-3. On the basis of information in a preliminary proposal submitted by a contractor with PRB design experience, a PRB with zero-valent iron (ZVI) and sand would be constructed across the plume's path through the Upper Sand unit. The conceptual design and construction approach for the PRB under this alternative includes placing ZVI in the PRB throughout the full depth of the Upper Sand, and replacing the excavated Upper Clay as backfill in the trench above the ZVI. This approach is expected to provide *in situ* groundwater treatment by intercepting and treating VOC-contaminated groundwater flowing through the Upper Sand to the west from the VOC source area.

ZVI filings or a ZVI/sand mixture would be placed in a PRB trench from the top of the Lower Clay surface (average of 27.5 to 35 feet bgs), through the Upper Sand, and into the base of the Upper Clay. The PRB would be installed along a line approximately 650 feet long across the width of the plume, located parallel to, and along the western side of, the main plant access road. The approximate location of the PRB is shown on Figure 6-9. The improvements in groundwater quality resulting from *in situ* VOC treatment provided by the PRB would be monitored over time.

6.3.4 Alternative C – Alternate Concentration Limits

This alternative includes the use of ACLs for groundwater. An "active" remediation component to address the VOC source areas at Buildings I-1-2/I-1-3 is not included in this alternative. As presented in Table 6-1, this alternative includes the following major components:

- Alternate Concentration Limits
- Institutional controls

Alternate Concentration Limits

ACLs are presented and discussed in Subsection 6.2.6. For the Buildings I-1-2/I-1-3 area, ACLs would be established by developing baseline groundwater quality levels for the shallow aquifer near the groundwater/surface water interface within the plume discharge area, and then employing an analytical method to determine what level of groundwater contamination would constitute a statistically significant increase in VOC concentrations at a selected point of compliance for groundwater quality. If future groundwater monitoring confirms a statistically significant increase in the concentrations of the constituents of interest, the need to implement a subsequent remedial action would be evaluated.

The known or projected points at which the Buildings I-1-2/I-1-3 plume enters surface water are the intermittent stream (swale) that extends from near Buildings I-1-2/I-1-3 to Highway 148, and the low-lying areas along the western side of Highway 148 and within Heron Flats (see Figure 1-1). For each of the remedial alternatives for the Buildings I-1-2/I-1-3 source area and plume that includes establishing ACLs (Alternatives C, D, and E), the installation of four new monitoring wells in the groundwater discharge area on the western side of Highway 148 has been included. These new wells would be installed and sampled twice during the predesign phase of the remedial action, to provide additional groundwater quality data to assist in developing the ACLs.

6.3.5 Alternative D – Excavation (within 10 mg/kg VOC contour) and Alternate Concentration Limits

This alternative includes partial source area remediation through soil excavation, and the use of ACLs for groundwater. As presented in Table 6-1, this alternative includes the following major components:

- Excavation within 10 mg/kg VOC contour
- Alternate Concentration Limits
- Institutional controls

Excavation

This alternative includes excavation and off-site disposal of VOC-contaminated clay soil. Excavation of the clay will remove a portion of the VOC source material remaining in the clay that was not removed during the PCB soil remedial action in 1996.

Alternative D includes excavation of the Upper Clay in two areas adjacent to Buildings I-1-2 and I-1-3. The excavation areas are generally in the locations of soil boring SB-126 and Building I-1-5 near the side of Building I-1-3, and generally in the locations of soil borings SB-100, 102, 103, and 104 near the side of Building I-1-2 (see Figure 6-10). Shallow soil excavations were completed in these areas in 1996 as part of the PCB remedial action. Approximately 1,440 cy of uncontaminated soil will have to be removed to access the VOC-impacted soil (approximately 1,280 cy) known to be present beneath the uncontaminated soil from the Building I-1-2 and I-1-3 areas, respectively. The excavation in these areas will remove soil with concentrations > 10 mg/kg VOCs to a depth limit of approximately 12 feet.

It is assumed that relocation or temporary removal of existing buried utilities to complete the excavation will not be required, based on a brief review of site utility maps and the absence of documentation to the effect that this type of action was required during the PCB soil excavations in the same general areas in 1996.

The boundaries of the excavation areas have been defined based on the extent of clay containing ≥ 10 mg/kg VOCs. This extent was derived from the soil characterization sampling performed during the predesign fieldwork in the fall of 2000 (RMT, 2001d). A minimum total of approximately 290 pounds of VOC source material was previously estimated to be present within the Building I-1-2 source area, and a minimum total of approximately 860 pounds of VOC source material were estimated to be present within the Building I-1-3 source area. It is estimated that approximately 5 to 10 percent of the total VOC mass present in the Building I-1-2 source area would be removed with the conceptual excavation at that area, and approximately 15 percent of the total VOC mass present in the Building I-1-3 source area would be removed under the conceptual excavation plan for that area.

The excavated VOC-impacted clay would be transported to a licensed off-site disposal facility. For development and evaluation of the alternatives for the Buildings I-1-2/I-1-3 source areas, the assumption has been made that the clay would be managed as a non-hazardous waste for off-site disposal, to provide a common basis for estimating costs for all alternatives that include a source area soil excavation component.

Alternate Concentration Limits

The ACL component of Alternative D is identical to that described above for Alternative C.

6.3.6 Alternative E – Excavation (within 10 mg/kg VOC contour), *In Situ* Reductive Dechlorination with Pneumatic Fracturing, and Alternate Concentration Limits

This alternative includes remediation of the VOC source areas using two methods: excavation of Upper Clay soil, and the addition of a microbiological substrate into the source area soil to stimulate the *in situ* destruction of VOCs through biological reductive dechlorination. The alternative also includes the use of ACLs for groundwater. As presented in Table 6-1, this alternative includes the following major components:

- Excavation of Upper Clay within 10 mg/kg VOC contour
- *In situ* biological reductive dechlorination with pneumatic fracturing
- Alternate Concentration Limits
- Institutional controls

Excavation

The excavation component of Alternative E is identical to that presented above for Alternative D.

In Situ Reductive Dechlorination

As described above for Building I-1-23, Alternative F, *in situ* biological reductive dechlorination is also an appropriate technology for the treatment of the VOC source areas at Buildings I-1-2/I-1-3. To increase the effectiveness of dispersing the liquid substrate into the clay formation, this alternative also includes an initial step of pneumatic fracturing (PF) of the clay using nitrogen gas. The liquid substrate would then be injected into the enhanced porosity within the VOC source area using the same boreholes installed to perform the pneumatic fracturing.

The preliminary conceptual design for completing the PF step required for injection of the substrate under this Alternative E is the same design as presented for the PF component of Alternative A above (using MPE). The same number, locations, and depths estimated for PF with the MPE system are assumed to be necessary to provide thorough dispersing of the bio-substrate to stimulate *in situ* reductive dechlorination under Alternative E. Additional technical and engineering evaluation of the implementation details during the final design phase might require modifications of this conceptual design plan for the PF step under Alternative E.

Similar to the approach used at the Building I-1-23 source area, after the VOC "hot spots" have been excavated in the Upper Clay at Buildings I-1-2/I-1-3, the bio-substrate liquid would also be placed in bulk form into the open excavations, and blended into the clean backfill as the excavations are filled. This will place additional substrate into the Upper Clay to supplement the pressure-injected substrate, providing additional substrate to stimulate anaerobic degradation of VOCs remaining in the clay after excavation is completed.

A type of liquid "food" substrate will be selected for injection into the fractured clay and bulk addition to the soil excavations at the source areas that will provide a long-lasting electron donor substance, consistent with the relatively low hydraulic conductivity of the soil in and near the VOC source areas.

Alternate Concentration Limits

The use of ACLs as a component of Alternative E is identical to the use of ACLs as described above in Alternative D.

6.3.7 Alternative F – Electrical Resistive Heating (within 10 mg/kg VOC contour) and Groundwater Monitoring

This alternative includes remediation of the VOC source areas using electrical resistive heating (ERH). As presented in Table 6-1, this alternative includes the following major components:

- ERH in the source areas within estimated 10 mg/kg VOC zones
- Institutional controls

Electrical Resistive Heating

The ERH technology is a thermally enhanced soil vapor extraction (SVE) technique that targets both contaminated soil and groundwater. When electricity is applied, the soil is heated due to resistance to the flow of electrical current, thereby boiling the soil moisture and dramatically increasing the vapor pressure of VOCs. Contaminants are mobilized by direct volatilization and in situ steam stripping, removed by SVE, and treated appropriately before the extracted soil vapor is vented to the atmosphere. Heating has also been reported to accelerate in situ degradation mechanisms such as biodegradation, hydrolysis, oxidation, or reduction.

The preliminary conceptual design for use of ERH at the Buildings I-1-2/I-1-3 VOC source areas primarily consists of the electric heating, drip-wetting, and vapor/steam collection systems.

The conceptual heating network for targeting soil zones of 10 mg/kg or greater total VOCs (Figure 6-11) would consist of an estimated 35 to 50 electrodes constructed in 12-inch boreholes at approximately 17.5-foot spacing. The estimated depth of the treatment zone varies from a minimum of 8 feet below ground surface (bgs) to a maximum of 48 feet bgs (at the Building I-1-3 source area). The electrical power requirement is estimated to be approximately 2,535 kW (power supply rating of 2,500 kW) with a 3,060 amp draw and 480V, 3-phase service.

For efficient heating operation, it is expected that a drip-wetting system would be required for the electrodes. This system would consist of approximately 100 to 120 drip assemblies, with an average wetting rate of approximately 3 gpm using a potable water supply. The subsurface temperature would be monitored by a system of approximately 10 to 15 temperature monitoring wells located within the treatment zone(s).

The conceptual soil vapor extraction system design consists of approximately 100 vapor extraction vent wells. The estimated horizontal spacing of the vent wells is approximately 15 feet. These vents would collect generated VOC-laden vapor/steam and convey it to a condenser and vapor treatment system. Additional technical and engineering evaluation of the implementation details during the final design phase might require modifications of this conceptual design plan for the ERH step under Alternative F.

The estimated soil heating time is approximately 40 to 50 days, the base treatment time (after obtaining the target temperature) would be approximately 20 to 30 days, and additional time required for multiphase extraction would be approximately 20 to 30 days, for an overall treatment time of approximately 80 to 110 days. This time estimate does not include time for mobilization, construction, demobilization, or work area restoration; only estimated treatment time is included. The total electrical energy consumption is estimated to be 3,500,000 kW-hr. Vendor estimates for the final treatment results include the complete removal of NAPL and a 99 percent or greater reduction of dissolved phase VOC contamination.

6.4 Area 9 Repository Source Area and Plume

As reported in a previous site document (RMT, 2001d), two groundwater VOC plumes for which specific soil source areas were not identified are present in the general area to the south of the Repository. One of these plumes appears to originate upgradient of Building I-1-36A, and the origin of the other plume appears to be an isolated source in a wooded area on the southern side of the Repository. Although a good deal of effort was expended to locate the sources of these plumes in the pre-design investigation in 2000, the specific locations likely cannot be determined.

The plumes that originate in the vicinity of Building I-1-36A and in the woods to the south of the Repository merge with the more substantial VOC plume that originates from sources beneath the Repository, in an area generally to the southeast of the Repository, between the Center Swale and the East Swale. The VOC concentrations in these two plumes were found to naturally attenuate quite substantially prior to and within the area where these plumes merge with the main Repository plume, where the total VOC concentrations after all three plumes have merged are generally less than 50 µg/L. This rapid attenuation is likely related to a substantial thinning and change in physical properties of the Upper Sand layer in this area, which is the primary geologic unit where contaminant transport occurs in groundwater at the site.

Both of the alternatives described in Subsection 6.4 (Alternatives A and B) were developed to address the combined VOC plume from the three separate source areas (located in the vicinity of Building I-1-36A, in the woods south of the Repository, and directly beneath the Repository). For convenience of discussion, the merged plumes are identified in this report as the Repository source area and plume.

6.4.1 No Action

Similar to the other VOC source areas, the No Action Alternative is evaluated as a baseline option for comparison to other alternatives developed for the Area 9 Repository source area and plume.

6.4.2 Alternative A – Phytoremediation and Monitored Natural Attenuation

This alternative relies on the use of natural attenuation processes within the plume downgradient of the Repository to continue to mitigate the impacts of the VOC source zones on groundwater and surface water quality. Additional groundwater remediation will also be provided via phytoremediation. As presented in Table 6-1, this alternative includes the following major components:

- Phytoremediation
- Monitored Natural Attenuation
- Institutional controls

Phytoremediation

Planting trees and constructing a prairie area to provide phytoremediation of the VOCs remaining in the shallow groundwater near the swales that receive the groundwater discharge containing the Repository plume will assist in intercepting and removing VOCs before the groundwater discharges into the swales.

East Swale Area Setting - Since the nearest monitoring well near the area in which the Repository plume discharges into the East Swale lies approximately 160 feet west of the swale, no historical depth-to-groundwater information exists for this area. A backhoe test pit dug on September 13, 2000, to collect phytoremediation design information revealed groundwater at 6.2 feet bgs. This depth is greater than expected, since the surface grade at this location lies only 2 to 3 feet above the East Swale grade. However, there were relatively severe drought conditions during the summer and early fall of 2000, so the water table elevation in the backhoe pit is likely not representative of more typical seasonal levels. Monitoring well 33MWC-39, which is just west of this test pit, has historical groundwater depths of 9 to 12 feet bgs, which is consistent with the water table elevation observed in the test pit, given the rise in topography at 33MWC-39. Groundwater conditions and quality for this area are suitable for vegetative uptake.

Center Swale Area Setting - Depth to groundwater at the low point of this swale is typically between 0.1 and 1 foot bgs. Monitoring well 33MWC-18, which is near the swale low point, has historical groundwater depths of 2 to 6 feet bgs. Groundwater conditions and quality for this area are suitable for vegetative uptake.

East Swale Area Phreatophytic Tree Stand Conceptual Design - This area is located between the East Swale and the Center Swale (Figure 6-12). Trees will be planted where groundwater normally occurs at 2 to 6 feet bgs. The north-south–oriented knoll that divides this area somewhat limits tree planting to the lower areas at the base of the knoll. Up to four rows of trees (based on groundwater elevation data), approximately 570 feet long, will be planted along the base on each side of the knoll. Trees will be planted 5 feet apart in each of eight total rows. The rows will be spaced 10 feet apart. Approximately 900 trees will be planted in the East Swale area.

Aerial topography data and historical groundwater elevation data will be used in the design phase to more accurately determine where the depth to groundwater is normally in the range of 2 to 6 feet bgs. Water balance calculations will be performed in one or more of the areas to predict water uptake potential by the trees. This additional information will be used to refine the design in all phytoremediation areas.

Based on these groundwater conditions and preliminary tree planting density, and an assumed annual groundwater uptake of 400 gallons per tree, an annual TCE mass removal of approximately 18 grams (0.04 lb) is estimated for the East Swale phreatophytic tree stand area. This modest uptake is due in part to the existing low TCE concentrations in the shallow groundwater plume (assumed average TCE concentration of 20 μg/L for tree uptake).

Treatment Prairie Conceptual Design - These areas are located between the two tree stands constructed in the East Swale area and between the Center Swale and the Repository footprint (Figure 6-12). The specific purpose of the prairie grasses is to aid in the interception and uptake of impacted groundwater beneath the knoll that divides the area between the tree stands and between the Repository and the Center Swale. A mixture of native deep-rooting tall grass species, such as Indian Grass (*Sorghastrum nutans*), Big Bluestem (*Andropogon gerardii*), and Switch Grass (*Panicum virgatum*), will be planted in a 3.2-acre area roughly 250 ft by 550 ft between the East Swale tree stands and in a 0.5-acre area between the Repository and the Center Swale. The existing areas would be cleared, tilled, broadcast with prairie grass seed, and mulched for erosion protection until seeds have germinated and plants are established. Stabilizing mats of natural or synthetic materials may also be used.

Based on the existing groundwater conditions, grass characteristics, and an assumed average groundwater uptake of 1 mm/day by the deep-rooted grasses, the estimated annual TCE mass removal for the constructed prairie areas is approximately 80 grams (0.18 lb).

Monitored Natural Attenuation

Monitored natural attenuation (MNA) consists of regular, periodic monitoring of groundwater and surface water to assess the attenuation of contaminant plumes via natural chemical, physical, and biological processes. The monitoring data are evaluated to determine if the groundwater contaminant plumes are stable or receding, and to determine the rate of change of the VOC concentrations. Selected wells in the VOC source zones and in the plume area will be monitored for VOCs and for other parameters that support lines-of-evidence for biodegradation of chlorinated solvents, such as changes in levels of nitrate, sulfate, iron, methane, ethane, ethene, dissolved oxygen, E_H, pH, chloride, DOC, and temperature. The existing wells, or the locations of new monitoring wells that may be required, will be selected to best represent conditions at the following locations:

- One or two upgradient (or sidegradient) wells with no recorded impacts from historical sampling data
- One well in or near the previously identified VOC source areas
- Two wells in the plume, downgradient of the source areas
- One or two wells in the general area where the groundwater discharges to surface water

The physical conditions at the Repository currently produce a relatively stable and confined situation with respect to groundwater impacts from the VOC sources present beneath the Repository. Natural attenuation processes currently provide very effective destruction and containment of VOCs in groundwater beneath and in the vicinity of the Repository. Monitored natural attenuation would be used as a component of the long-term remediation of groundwater impacted by VOC source materials beneath the Repository, for the following reasons:

- Significant levels of natural attenuation of the VOCs are occurring in the relatively thin Upper Clay unit beneath the Repository, where the VOC source material is present. Concentrations of total VOCs in groundwater beneath the Repository of > 35,000 μg/L are being reduced to 10 to 30 μg/L within a distance of only approximately 200 feet along the groundwater flow path.
- The secondary line of evidence, *"Documented loss of contaminant mass at the field scale,"* is evident in the ratio of a daughter product (DCE) to parent material (TCE) downgradient of the source area:

- Source area (33MWC-09): TCE = 32,000 µg/L; DCE = 2,400 µg/L
  Ratio DCE:TCE = **0.075 (7.5%)**
- ~200 ft downgradient (33MWC-17): TCE = 11 µg/L; DCE = 2 µg/L
  Ratio DCE:TCE = **0.18 (18%)**
- ~300 ft downgradient (GP-13E): TCE = 9 µg/L; DCE = 25 µg/L
  Ratio DCE:TCE = **2.8 (280%)**

- The groundwater flow velocity in the Upper Clay beneath the Repository is very low (approximately 9 feet/year), thus minimizing the VOC mass flux from the source zones and helping to promote natural attenuation.
- The extent of affected groundwater outside of the Repository footprint is relatively small. Nearly all groundwater affected by the VOC sources beneath the Repository discharges into the Center and East Swales within approximately 300 feet of the base of the Repository sideslope. (This is the area in which trees and prairie grass will be planted for phytoremediation of the shallow groundwater.)
- The Lower Clay unit, which is present beneath the entire Repository, provides an effective barrier preventing downward migration of VOCs from the Upper Clay.
- It is likely that, for several decades, natural attenuation processes have been effectively minimizing the extent of groundwater impacts from the VOC source material present in soil within the footprint of the former Area 9 Landfill. The clay soil comprising the Repository placed above these VOC source locations in 1996 will assist in maintaining the long-term effectiveness of these natural attenuation processes by minimizing the infiltration of surface water over the area and by generally stabilizing the VOC source conditions.

An estimated total of 7 to 9 monitoring wells would be sampled for the parameters listed above, semiannually for the initial 2 years of the remedial action, and annually thereafter.

6.4.3 Alternative B – Phytoremediation and Alternate Concentration Limits

This alternative includes the use of ACLs for groundwater, with some groundwater remediation provided by phytoremediation. The same natural attenuation processes that mitigate the impacts on groundwater quality due to VOC sources beneath and upgradient of the Repository will continue to occur under both Alternatives A and B. However, rather than performing extensive long-term monitoring and detailed technical evaluations of the natural degradation following prescribed MNA guidelines, Alternative B includes establishing ACLs with associated monitoring requirements to accomplish the same remediation benefit. As presented in Table 6-1, this alternative includes the following major components:

- Phytoremediation
- Alternate Concentration Limits
- Institutional controls

Phytoremediation

The phytoremediation component of Alternative B would be identical to that presented above for Alternative A.

Alternate Concentration Limits

ACLs are presented and discussed in Subsection 6.2.6. For the Repository area, ACLs would be established by developing baseline groundwater quality levels for the Repository plume near the groundwater/surface water interface within the plume discharge area using existing groundwater quality data, and then employing an analytical method to determine what level of groundwater contamination would cause a statistically significant increase in VOC concentrations at a selected point(s) of compliance for groundwater quality. If future groundwater monitoring confirms a statistically significant increase in the concentrations of the constituents of interest, the need to implement a subsequent remedial action would be evaluated.

The known or projected points at which the Repository plume enters surface water are the Center and East Swales.

Section 7
Modeling Simulations of Remedial Alternatives

The remedial alternatives developed in Section 6 were simulated using calibrated groundwater flow and contaminant transport models to compare the effectiveness of the various designs in limiting and reducing the extent of TCE and related compounds in the groundwater over time. The calibrated model can be a useful tool for comparison, because it quantitatively estimates the extent of contaminants in the groundwater over time for each of the remedial alternatives. However, because of the substantial uncertainties inherent in modeling remedial alternatives that have not been field-tested at the site, and the additional uncertainties regarding the quantity and distribution of VOC source material present in the identified source areas, caution should be exercised in using these results. The results should be considered as a "semiquantitative" evaluation, and predicted concentrations should be considered more in a relative, rather than an absolute, sense. Nonetheless, within the limits of accuracy of the assumptions and estimates that were required to be made, the contaminant transport model provides a useful means of projecting the relative effectiveness of various remedial options in lowering contaminant concentrations in the groundwater.

Time periods of up to 500 years following the start of remediation were selected for simulation. The longest time periods were chosen to reveal significant differences among the remedial alternatives, and take into account the long time for some alternatives to remove residual source material. However, several of the remedial alternatives are expected to show significant beneficial effects within a 20-year time span following initial implementation.

Groundwater flow and contaminant transport modeling simulations that were conducted previously for this site (RMT, 2000 [Groundwater Investigation Report]; RMT, August 2001b and 2001c [Addenda 2 and 3 to the Preliminary Design Report]) were updated to simulate new and revised remedial alternatives that are described in this report. The conceptual framework, model setup, and results for each simulation are presented below. Additional model output documentation for the simulations is included in Appendix B.

For each alternative, the presence of NAPL residuals in the source areas at Buildings I-1-23, I-1-2, I-1-3, and the Repository is simulated by setting specified-concentration nodes in the model, for the time period over which NAPL is estimated to be present. Because a specified dissolved phase "source" concentration is used to simulate the source areas for as long as NAPL residuals remain in the source area, removal of NAPL-impacted soil is simulated by reducing the number of years that a specified concentration is assigned to nodes in the source zone. The rationale for this approach is discussed below.

7.1 General Approach to Simulating Remedial Alternatives

A wide variety of remedial alternatives were simulated by adapting a groundwater flow and transport model to simulate estimated conditions that would be present with each alternative. The widely-used model codes Modflow (McDonald and Harbaugh, 1988) and MT3D (Zheng, 1990) were used to simulate groundwater flow and contaminant transport, respectively. These codes were used because they are versatile, well documented, thoroughly tested, and approved for use by USEPA. They are the most widely used and accepted groundwater flow and contaminant transport model codes in use today.

7.2 Simulating the Presence and Removal of Source Material

The likely presence of NAPL residuals at Buildings I-1-23, I-1-2, I-1-3, and the Repository must be considered in all modeling simulations, because it represents a long-term, ongoing source of subsurface contaminants. Previously, the conservative approach to consideration of NAPL presence at the site was to simulate it as a constant, persistent source. This approach was taken because there was little information on the extent or form of NAPL at each of the areas, and because literature studies have shown that NAPL can persist for decades or longer. However, the evaluation of remedial alternatives for the site should attempt to estimate the effectiveness in achieving the long-term overall remediation goals. Therefore, the current approach to the modeling includes estimates of the time it would take to remove NAPL residuals from each of the source areas under the various alternatives. However, a substantial degree of uncertainty is associated with these estimates, because of unknown or poorly-defined variables, such as the actual mass of NAPL residuals, the form of NAPL (in ganglia or pools), and the achievable removal effectiveness of the various remedial alternatives.

7.2.1 Current Rates of Removal of NAPL Residuals from the Source Zones Under Ambient Conditions

Removal of the NAPL residual mass from the source zones currently occurs under ambient conditions by the ongoing process of dissolution into the groundwater. For each remedial alternative, the estimate of the time it would take to remove NAPL residuals utilizes estimates of the NAPL mass remaining in each area, and the calculated TCE mass flux rate in groundwater that flows through the source zone over time. With this method, the time to remove the NAPL is simply the estimated mass of NAPL present divided by the dissolved flux rate from the source area as obtained from the calibrated model. If the mass flux rate from dissolution decreases from the estimated current rate as NAPL is removed, the time needed to remove NAPL would increase.

The mass of TCE that is currently being removed from the source zones has been estimated using the mass flux calculated by the calibrated model. A United States Geologic Survey (USGS) flow mass balance subroutine called Zbud that works in conjunction with Modflow was used to calculate the total volumetric rate of groundwater flow through the specified-concentration zones in the Upper Clay and the Upper Sand units. In the calibrated flow model, approximately 400 liters per day (L/day) of groundwater migrate from the Upper Clay unit source area at Building I-1-23, and approximately 21,000 L/day of groundwater migrate from the source area in the Upper Sand. With specified-concentration nodes of 20,000 μg/L TCE in the Upper Clay and Upper Sand units at Building I-1-23, this represents a mass flux of about 8 g/day (0.02 lb/day) from the Upper Clay, and 420 g/day (0.9 lb/day) from the Upper Sand. This estimate of the mass flux from the source areas at Building I-1-23 results in a simulated groundwater plume that accurately represents the observed concentrations at the site, as well as the observed flow conditions (heads and hydraulic conductivity) for the aquifer units.

7.2.2 Time To Remove NAPL Under Various Remedial Alternatives

The estimated TCE mass flux rate from the Building I-1-23 source area has also been calculated under low flowrate pumping conditions (10 gpm), to simulate both the short-term and long-term groundwater extraction component of specific remedial alternatives. Under the increased velocities associated with pumping at a low rate from the confined Upper Sand unit, the mass flux rate from the source area will increase in proportion with the rate of pumping, provided there is sufficient contact time for VOC concentrations to reach a steady-state value. Laboratory batch, column, and tank experiments have shown that water in direct contact with NAPL approaches equilibrium concentrations within minutes to hours (Schwille, 1988; Imhoff et al., 1994). Groundwater modeling of flowlines at the site indicates that groundwater will have substantial contact time in the defined source zones. Within the Upper Clay unit at Building I-1-23, flowline analysis indicates that the groundwater migrates for approximately 200 days or more within the source zone area in the Upper Clay, under both pumping and nonpumping conditions. Within the Upper Sand unit, groundwater residence time within the source zone is approximately 20 to 30 days under pumping conditions of 10 gpm.

Groundwater concentrations currently found in the Building I-1-23 and I-1-2/I-1-3 source areas range up to 50 mg/L, and these concentrations are not expected to change significantly under the influence of a low pumping flowrate, until nearly all of the NAPL is removed. On a macro scale of meters to tens of meters, the steady-state concentration in the Building I-1-23 source area will generally be substantially below the typical effective equilibrium concentration of TCE in water (1,100 mg/L), because the NAPL is not present uniformly everywhere throughout the source zone soil. If NAPL is present as pools, groundwater concentrations would drop significantly over short distances from the pool.

The assumption of constant TCE concentration in the source area groundwater over time is conservative in one respect, in that it assumes that the source concentrations do not decrease until the NAPL is completely removed; however, the actual time it would take to remove the NAPL may be somewhat longer than simulated, since the rate of mass transfer probably will decline as the overall NAPL mass declines. Without knowing how much NAPL mass is present, and whether it is present as thin pools or ganglia, or both, it is impossible to accurately estimate how long the NAPL will persist. However, an assumption of constant mass flux over time until the NAPL is removed will likely overestimate concentrations in the groundwater, but may underestimate the time for complete removal of NAPL residuals.

In addition to removal by ambient groundwater flow and by pumping of groundwater, NAPL mass can also be actively removed or destroyed by other remedial alternatives being considered, including soil excavation, multiphase extraction, a permeable reactive barrier, and *in situ* reductive dechlorination. The time it would take to remove NAPL from the Upper Clay and Upper Sand units in the buildings source areas, under various remediation scenarios, is estimated to range from one to three decades for the Upper Sand unit, and up to several hundred years for the Upper Clay unit. Estimates of the time it would take to remove NAPL from the source area for each alternative incorporate the reduced NAPL mass that is estimated to remain after a remedial alternative is implemented. For example, Alternative A1 at Building I-1-23 involves excavation of impacted soil in the Upper Clay to a concentration of 10 mg/kg, followed by pumping at 10 gpm using an extraction well located in the Upper Sand unit. Soil excavation is estimated to remove a substantial quantity of TCE NAPL; the time it would take to remove the remaining NAPL in the Upper Sand at a groundwater pumping rate of 10 gpm is estimated to be approximately a decade. For the Upper Clay unit, the TCE removal flux rate is substantially lower, and the time it would take to remove NAPL is consequently much longer. Further discussion of the estimated time to remove residual source mass from the source areas is presented in Appendix B.

7.2.3 Simulating Remedial Alternatives in the Contaminant Transport Model

Groundwater extraction is simulated directly with the groundwater flow and transport model, to simulate extraction wells operating at specific flowrates. The location, depth, rate, and duration of pumping are input directly into the model, allowing for accurate simulation of the effects of the groundwater extraction component of a remedial alternative.

Soil excavation in the source areas is simulated indirectly by reducing the number of years that specified-concentration nodes are kept "active" in the source zones, to account for the decreased mass of source material accomplished by the excavation. As discussed above, the reduction in source mass shortens the time needed for groundwater flow to remove the remaining residual mass through dissolution processes.

Multiphase extraction (MPE) is simulated by taking into account the change in groundwater concentrations at the source, and the estimated mass of TCE source material that would be removed, based on RMT's experience, published data from other sites, information provided by technology vendors, and professional judgment. An assumption is made in the modeling that the source of TCE in the groundwater remains until the NAPL is totally removed. However, the reduction in source mass shortens the time needed for groundwater flow to remove the remaining residual mass. Moreover, the effect of MPE on the magnitude of groundwater concentrations in the source areas is also considered to be substantial. Unlike some other remedial alternatives, MPE is assumed to substantially affect groundwater concentrations in the source area because it will likely remove dispersed ganglia of residual TCE, which can be a major source of the groundwater concentrations. The effect of MPE on source area groundwater concentrations is accounted for by assuming a reduction of 70 percent in the specified-concentration nodes in the source areas. This assumption is based on published values in the literature from other sites, information provided by technology vendors, and on professional judgment.

A permeable reactive barrier (PRB) is simulated as a thin, vertical plane in the aquifer where contaminant degradation rates are substantially increased, reflecting typical published rates of contaminant degradation in PRBs. A zone that approximates the size of the PRB is designated within the model grid with appropriate reaction rate constants to achieve representative rates of contaminant removal.

Phytoremediation is simulated using groundwater extraction wells in the uppermost model layer, pumping at a low rate that approximates the average rate of groundwater extraction per unit area within the phytoremediation zone, over the course of a year.

The area that was simulated with phytoremediation "wells" is shown on Figures 6-1 through 6-6 and on Figure 6-12. Information on the uptake of water by hybrid poplar trees or cottonwood trees from published studies or experience of a phytoremediation contractor was used. A net water uptake rate of approximately 15 inches per year (1.25 cubic feet of water per square foot of ground surface area) was simulated.

Reductive dechlorination is simulated in a similar fashion as MPE, by considering the effect of the alternative on both the duration and magnitude of specified-concentration nodes in the source areas. Because reductive dechlorination will reduce the mass of source material in the soil, an estimate of 50 percent removal of the estimated source mass was made. The duration of the source was then adjusted accordingly, taking the reduced source mass into account, and applying the mass transfer rate that is currently occurring at the source. Source area concentrations were estimated to be reduced by approximately 90 percent, based on published case histories in the literature. Specified-concentration nodes in the source areas were then assigned, based on these estimates of duration and magnitude.

Electric resistive heating (ERH) is not simulated directly in the groundwater flow and transport model. Rather, the effect of ERH is calculated external to the model, by estimating the effectiveness of the ERH on both residuals in the source zone, and on source zone concentrations in the groundwater. A 90-percent reduction in the residual NAPL mass in the source zone was estimated, based on case studies reported in the literature. This effect was simulated by adjusting the duration of the constant concentration nodes in the source zones to reflect the reduced length of time the smaller mass of residuals would persist in the source zones. As with other alternatives that directly remove source mass, it was assumed that the residuals were removed by dissolution only, at the current rate, based on groundwater flowrates and concentrations in the source zone. It was also assumed that the rate of dissolution of the residuals would continue at the current rate, until the residuals were totally removed. In addition, the effect of ERH on reducing dissolved TCE concentrations in the source zone was estimated to be 90 percent, based on case studies in the literature. The values of the constant concentration nodes in the source zones were reduced by an order of magnitude to reflect this estimated reduction in concentrations.

7.3 Building I-1-23 Source Area and Plume

7.3.1 Alternative A1 – Excavation (to 10 mg/kg VOC Contour), Groundwater Extraction, and Phytoremediation

This alternative involves the excavation of a volume of soil in the source area (within the 10 mg/kg VOC contour) to a depth of 12 feet, and then the operation of a 10-gpm groundwater extraction well for long-term containment of contaminated groundwater or short-term removal of VOC source mass. For long-term groundwater containment, the model simulates low-rate pumping (10 gpm) for as long as NAPL residuals are estimated to exist in the source area (see Appendix B). For shorter-term source removal simulations, the model simulates pumping at the same 10 gpm flowrate, but for durations of 11 and 40 years, long enough to exceed the estimated time required for NAPL removal in the Upper Sand unit (but not the Upper Clay). Phytoremediation at the downgradient end of the West Swale is also included.

Figure 7-1 shows the model simulation of the current extent of the TCE plume in the Upper Sand unit, that is calibrated to existing conditions at the site. Figures 7-2 and 7-3 show the extent of the TCE plume after source area soil excavation and 15 and 40 years of groundwater extraction at 10 gpm, respectively. The plume shrinks dramatically in size as the extraction well cuts off the flow of contaminated groundwater at the source. A graph of TCE concentrations in groundwater over time (years following the start of long-term groundwater extraction) at a point near Crab Orchard Lake is shown on Figure 7-4. The graph shows that groundwater TCE concentrations would fall substantially near the lake to values near the detection limit. The cut-off of contaminated groundwater at the source would effectively keep downgradient concentrations at near-zero levels, even though NAPL residuals would still persist in the source zone. The shaded area around the curve on Figure 7-4 is a qualitative estimate of uncertainty in the projected concentrations, owing to the inherent uncertainties in the modeling, in the effectiveness of the groundwater extraction, and in the location and quantity of source material. Because of the broad effect of groundwater extraction, the effects of these uncertainties on the projections of groundwater quality over time are expected to be relatively small compared to the effects of uncertainties on some other remedial alternatives.

A simulation of limited (40 years) groundwater extraction is presented on Figures 7-5 and 7-6. Figure 7-5 shows that if the groundwater extraction system is turned off after 40 years, a reduced TCE plume will regenerate, as seen on the figure representing 30 years after extraction ceases. Figure 7-6 is a graph of TCE concentrations versus time, showing the rebound of concentrations in groundwater located near the lake, from near-zero values to about 100 μg/L. Although the groundwater concentrations rebound to about 100 μg/L, this range is substantially below the 1,500 μg/L that the model shows for current average conditions in groundwater near the lake. These substantially lower concentrations (following a small rebound) result, in part, from the NAPL residuals being eliminated from the Upper Sand unit, as discussed in Appendix B. In the source area, groundwater seeping slowly downward through the remaining NAPL in the Upper Clay unit would be mixed with larger rates of groundwater flow in the Upper Sand, resulting in the lower projected concentration (of 100 μg/L) in the Upper Sand unit.

A third simulation of more limited (11 years) groundwater extraction was also made. In this scenario, groundwater extraction ceases 1 year after NAPL residuals are estimated to have been removed from the Upper Sand unit. Figures 7-7, 7-8, and 7-9 show the resulting TCE concentrations in the groundwater plume, at times of 5, 15, and 49 years after pumping commences, respectively. Figure 7-10 shows a graph of TCE concentrations over time in groundwater located in the core of the plume, near Crab Orchard Lake. As Figure 7-10 shows, concentrations decrease from about 1,500 μg/L to 100 μg/L, and then persist at this level for as long as residual NAPL mass remains in the Upper Clay unit.

7.3.2 Alternative A2 – Excavation (within 1 mg/kg VOC contour), Groundwater Extraction, and Phytoremediation

This alternative is similar to Alternative A1, except that excavation of contaminated soil in the source zone would be to the 1 mg/kg VOC contour, rather than the 10 mg/kg VOC contour, and the excavation depths would be greater. This alternative would remove a greater quantity of NAPL residuals from the Upper Clay than under Alternative A1, due to the substantially increased excavated soil volume. Groundwater flow through the remaining VOC residuals and percolation of water from precipitation through the clay would then slowly remove mass until all residuals were removed from the Upper Clay unit.

As discussed previously, the large majority of NAPL present in the Upper Clay is expected to be within the three-dimensional zone defined by the approximate 1 mg/kg total VOC concentration contour. However, it is also possible, and perhaps likely, that some VOC residuals are present in the Upper Clay outside of this arbitrarily defined concentration zone. For preparing the model simulations, it was estimated that 97% of the NAPL residual mass in the Upper Clay would be removed by the excavation component of Alternative A2, versus 24% under Alternative A1.

Alternative A2 yields nearly identical results in the modeling simulations to that of Alternative A1 during the years that the groundwater extraction system would be in operation under both alternatives because groundwater extraction cuts off the source of high concentrations in the source area. After shutdown of the extraction system, when all NAPL is expected to be removed from the Upper Sand unit (estimated to be accomplished within 10 to 15 years of pumping), there would be some VOC plume "rebound" due to the VOC residuals remaining in the Upper Clay unit. This estimated scenario is based on the assumption (supported by numerous published technical references) that groundwater VOC concentrations within a geologic unit will remain essentially constant in the vicinity of NAPL in a source area until all NAPL residuals are removed from that unit. The estimated time required to remove NAPL remaining in the Upper Clay after shutdown of the extraction well system (operating in the Upper Sand) is approximately 14 years. The model results show a decrease in VOC concentrations in the plume to near zero relatively soon after the NAPL residuals have been totally eliminated from the source area. The model simulations of plume concentrations over time for Alternative A2 are shown on Figures 7-11 through 7-13. Figure 7-14 shows a graph of TCE concentrations over time in groundwater located along the centerline of the plume, near Crab Orchard Lake.

7.3.3 Alternative B – Excavation (within 10 mg/kg VOC contour) and Permeable Reactive Barrier

Alternative B is simulated in a similar manner to Alternative A1, except that a permeable reactive barrier (PRB) is used instead of groundwater extraction to control migration of dissolved VOCs in groundwater from the source zone. With this alternative, the PRB is simulated within the Upper Sand unit, where most lateral contaminant migration occurs, as a zone with accelerated degradation rates. A reaction half life of 0.3 day in the 2-foot–wide PRB resulted in a representative reduction in concentrations, based on actual case studies reported in the literature, and on information provided by remediation contractors experienced in designing and installing PRBs for treating chlorinated VOCs.

Figures 7-15, 7-16, and 7-17 show plume TCE concentrations at 5, 15, and 50 years after implementation of Alternative B, respectively. Figure 7-18 shows the decrease over time of groundwater TCE concentrations at the lake, from the current 1,500 µg/L to below 20 µg/L. The model assumes that the rate of contaminant degradation remains constant over time, with PRB maintenance or replacement as necessary. The shaded zone on Figure 7-18 is a qualitative indication of the degree of uncertainty associated with this alternative. Factors such as the potential presence of a large number of thin pools of NAPL residual, and the decreasing effectiveness of the PRB over time, could cause groundwater concentrations to rise substantially above the values given by the model, if the PRB deteriorates or if there are numerous thin pools of NAPL residuals.

7.3.4 Alternative C – Multiphase Extraction with Pneumatic Fracturing, Groundwater Extraction, and Phytoremediation

The effects of multiphase extraction (MPE) of groundwater and soil vapor in the source areas were simulated, in conjunction with groundwater extraction, and with phytoremediation in the groundwater discharge zones. With this scenario, MPE wells would be placed in the Upper Clay unit in the VOC source area of Building I-1-23. In addition, three horizontal extraction wells would be installed into the Upper Sand unit in the source zone, to simulate dewatering of the Upper Clay and Upper Sand units during MPE. Finally, a long-term groundwater containment scenario with a single source zone extraction well removing groundwater at 10 gpm following use of MPE was also included in the simulation.

MPE wells would be screened over both the saturated and unsaturated portions of the Upper Clay and the Upper Sand units, after pneumatic fracturing of the clay. The model did not simulate the MPE wells explicitly; rather, the estimated effect of MPE on NAPL removal was incorporated into the model by selecting the length of time specified-concentration nodes were assigned to the source zone in the Upper Clay and Upper Sand. The horizontal wells in the Upper Sand unit were simulated explicitly, operating for a period of 2 years at a combined flowrate of approximately 80 gpm. After 2 years, the horizontal extraction wells were assumed to be shut down, and the long-term groundwater containment scenario began, with operation of the single 10-gpm vertical extraction well in the Upper Sand.

The results of this simulation are presented on Figures 7-19, 7-20, and 7-21. As seen on Figure 7-21, the plume after 50 years is predicted to have decreased substantially in size and concentration, such that the 5 µg/L TCE contour has receded almost back to the source area. As shown on the graph on Figure 7-22, the model predicts that the TCE concentration in the groundwater near the lake would be reduced from over 1,500 µg/L to near the detection limit, as long as the single extraction well operated, until NAPL residuals were removed from the source zone.

If groundwater extraction continues at the 10-gpm rate for only a short (3-year) period after the MPE system is shut down, model results indicate that the plume will be diminished, but that it would likely persist at higher concentrations over an area similar to its current extent, compared to longer pumping scenarios. Figures 7-23, 7-24, and 7-25 show the plume concentrations and extent at 5, 15, and 49 years after implementation of

Alternative C, respectively. Figure 7-26 shows that groundwater TCE concentrations at the lake would decrease from about 1,500 μg/L to about 30 μg/L, and then would remain steady until the NAPL residuals were removed by natural processes.

7.3.5 Alternative D – Excavation (within 10 mg/kg VOC contour), Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits

This alternative is physically similar to Alternative A1, but without groundwater extraction, and with an enhanced level of phytoremediation and ACLs. Although not directly simulated, the effect of excavation on the time it would take to remove all NAPL residuals has been estimated (see Appendix B). Assuming that source area groundwater TCE concentrations remain constant until the NAPL residuals are nearly completely removed, the plume would not change substantially from current conditions until the NAPL residuals are totally removed from the geologic units, first from the Upper Sand unit (in an estimated two to three decades under ambient conditions) and then from the Upper Clay (over potentially several hundred years). Based on results for Alternative A1 (with 11 years of pumping), it is expected that the concentrations in the plume near the lake would decrease from 1,500 μg/L and approach 100 μg/L within 60 to 80 years. The trend of concentrations would be expected to resemble the pattern shown on Figure 7-10, but the declining trend would be delayed by 15-20 years.

7.3.6 Alternative E – Phytoremediation Including Engineered Wetland and Alternate Concentration Limits

This alternative was not simulated directly. This alternative differs from Alternative D only in that there is no soil excavation; therefore, the time it would take to remove NAPL residuals from the source zone would be longer, since only ambient groundwater flow would be removing residual source mass. It is estimated that the time it would take to remove NAPL residuals from the Upper Clay unit may be up to several hundred years, based on estimates of the residual source mass present and the calculated rates of mass removal (see Appendix B). Again, assuming that groundwater concentrations change little until the NAPL residuals are nearly completely removed, the plume would not change substantially from current conditions until the NAPL residuals are totally removed from the geologic units, first from the Upper Sand unit (in an estimated two to three decades under ambient conditions), and then from the Upper Clay (potentially over a few hundred years). Based on results for Alternative A1 (with 11 years of pumping), it is expected that the concentrations in the plume near the lake would decrease from 1,500 μg/L as residual source mass is removed from the Upper Sand unit, and approach 100 μg/L within approximately 100 years.

7.3.7 Alternative F – Excavation (within 10 mg/kg VOC contour), *In Situ* Reductive Dechlorination, Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits

This alternative involves enhanced biodegradation through the reductive dechlorination process, coupled with soil excavation to 10 mg/kg that is a part of several other alternatives presented here. To set model boundary conditions for this alternative, published literature was reviewed for details of the effectiveness of full-scale remediation efforts involving reductive dechlorination at a number of sites. A number of case studies with full-scale remedial actions involving reductive dechlorination have reported decreases of 90 percent or more in the groundwater concentrations in the source zones, at chlorinated solvent sites where NAPL was known, or strongly suspected, to be present. Based on these case histories, a 90 percent reduction in source area concentrations was assumed, compared to those in the calibrated model (current conditions). By setting the value of constant-concentration nodes in the model to be 90 percent lower in the source zone, this simulates the effect of enhanced biodegradation on dissolved and sorbed TCE. In addition, enhanced biodegradation will reduce the mass of residual NAPL present in the source area, and thereby reduce the time to remove this source. Although the exact percentage of source mass removed at most sites is poorly known, a number of case studies have shown that, following treatment, concentrations in the source area remain much lower, which suggests that a substantial fraction of the source mass must have been removed. Conservatively, a 50 percent reduction in source mass following soil excavation was assumed for the reductive dechlorination portion of this alternative. The duration of the specified-concentration nodes was adjusted in the model to account for a loss in source mass by excavation and reductive dechlorination. In addition, the effect of soil excavation on the mass of TCE remaining in the source zone was also used to estimate the length of time during which specified-concentration nodes were held operative in the source zones.

Figures 7-27, 7-28, and 7-29 show the predicted extent of the plume at I-1-23 at 5 years, 15 years, and 47 years after implementation of this alternative, based on model results. Figure 7-30 is a graph of the predicted maximum TCE concentration over time in the groundwater near the lake. The figures indicate that groundwater concentrations are expected to fall substantially in the Building I-1-23 plume, decreasing from 1,500 µg/L to below 20 µg/L within approximately 30 years. The results indicate that the concentrations will then remain relatively steady until the residual source material is removed. Appendix B presents a discussion of the estimated time it may take to remove residual source material from the Building I-1-23 area.

7.3.8 Alternative G – Electrical Resistive Heating

This alternative involves the use of electrical current transmitted through the contaminated soil zones in the Upper Clay and Upper Sand units, using a large number of metal electrodes to heat the groundwater to the boiling point, with removal of the resulting steam and hot soil vapor using a soil vapor extraction system, and processing/treatment of the extracted steam/water/vapor for removal of VOCs. Although ERH was not simulated directly by the model, the model was set up with the assumption that ERH would be used to treat a volume of soil in the source area (within the 1 mg/kg VOC contour) through the entire thickness of the Upper Clay and the Upper Sand units.

With the assumptions presented in Section 6 and conceptual design estimates made for this alternative as described in Appendix B, a mass removal efficiency of 90% is estimated for this technology. This removal efficiency translates to a 90% reduction in source area NAPL mass at the beginning of model simulation (which begins at the completion of the ERH remediation effort). Calculations presented in Appendix B show that with estimated mass removal rates of 0.363 lb/day in the Upper Sand and 0.0133 lb/day in the Upper Clay, the NAPL and sorbed VOC mass in the Upper Sand would be fully removed within approximately three years after the start of ERH treatment, and the NAPL and sorbed mass would be removed from the Upper Clay in approximately 65 years from the start of treatment. In addition, an estimated 90% reduction in source zone concentrations was simulated, with adjustment of the constant concentration nodes used to simulate the source zone.

Figures 7-32 through 7-34 show the model-predicted extent of the TCE plume in the Upper Sand unit from the source area to the lake at elapsed times of 5, 15, 50, and 75 years after startup of the ERH system. These projections show that the TCE concentrations in the Building I-1-23 plume would be expected to steadily dissipate over several decades, and reach the specified Cleanup Standards over the entire current plume area within approximately 75 years. A graph of the predicted TCE concentration over time in the groundwater at the groundwater/surface water interface zone near the lake is shown on Figure 35. This graph indicates that the TCE concentration in the groundwater at the lake should be reduced by approximately 90% in 20 years, and 99% in 35 years.

7.4 Buildings I-1-2/I-1-3 Source Area and Plume

7.4.1 Alternative A – Limited Excavation and Multiphase Extraction with Pneumatic Fracturing

This alternative includes limited excavation of source area soil and then implementation of multiphase extraction (MPE) in the source areas. Pneumatic fracturing would be implemented in the Upper Clay unit to increase the soil permeability and the effectiveness of MPE. MPE wells would be screened over both the saturated and unsaturated portions of the Upper Clay and Lower Clay units. The model does not simulate the MPE wells directly, but it incorporates the estimated effect of MPE on residual source mass removal, by selecting the length of time assigned to specified-concentration nodes assigned to the source zone in the Upper and Lower Clay units. These estimates assume a 70 percent reduction in groundwater TCE concentrations following MPE and excavation of a concentrated VOC hot spot in soil near Building I-1-3. Although the specific percentage reduction in groundwater concentrations following MPE is uncertain, published data from other sites indicate that substantial reductions in groundwater concentrations are likely to occur, because dispersed TCE ganglia, which can contribute substantially to groundwater concentrations, are removed more quickly than the remnant thin pools that may also potentially be present.

Figure 7-36 shows the calibrated model representation of the current extent of TCE concentrations in the groundwater at the Buildings I-1-2/I-1-3 area. The plume originates in the source zones near the buildings and then extends westward, approximately to Highway 148, before attenuating as a result of discharge to surface water in the low-lying areas west of Highway 148. Figures 7-37, 7-38, and 7-39 show the projected extent of the TCE plume at 5, 14, and 47 years after implementation of this alternative, respectively. Figure 7-40 is a graph of projected TCE concentrations versus time in the core of the plume (approximately 900 feet west of the Building I-1-3 source area). The model results suggest that groundwater concentrations will be reduced substantially, but will still remain relatively high in the plume for decades, until the residual NAPL is removed. However, the graph also shows a large shaded area that indicates a substantial range of potential results that could occur. Without detailed knowledge of the quantity, locations, extent, and shape of the residual NAPL mass in the source area, accurately predicting groundwater concentrations is difficult, at best, and likely impossible.

7.4.2 Alternative B – Permeable Reactive Barrier

The permeable reactive barrier (PRB) alternative for the Buildings I-1-2/I-1-3 plume includes placement of a PRB into the more permeable, more sandy portion of the clay subsurface, equivalent in depth to the Upper Sand unit. The model approach to simulating the PRB is essentially the same as discussed in Alternative B for the Building I-1-23 area, with the reaction rate in the PRB designed to yield contaminant reductions that are consistent with those experienced at similar sites.

Figures 7-41, 7-42, and 7-43 show the predicted effect of this alternative on the plume at 5, 15, and 50 years after installation of the PRB, respectively. The figures show a sharp reduction in concentrations immediately downgradient of the PRB, and a minor reduction in the overall extent of the plume. Figure 7-44 shows a graph of predicted TCE concentrations versus time in the core of the plume located approximately 900 feet west of the Building I-1-3 source area, and approximately 600 feet downgradient of the PRB. The model results indicate that a reduction in concentrations in the core of the plume from over 1,300 μg/L to less than 300 μg/L would occur over a period of approximately 20 to 30 years, and then remain relatively constant until the residual NAPL in the source areas is removed by natural dissolution processes. The shaded area of the graph indicates uncertainties that result from a possible decline in the long-term effectiveness of the PRB, as well as potential decreases in source concentrations as the residual NAPL mass is removed.

7.4.3 Alternative C – Alternate Concentration Limits

This alternative was not simulated because it does not include active remediation measures. Therefore, the plume would not be expected to change substantially from its present condition until the residual NAPL mass in the source areas is removed, over a long period of time.

7.4.4 Alternative D – Excavation (within 10 mg/kg VOC contour) and Alternate Concentration Limits

The active remedial measure in this alternative includes excavation of impacted soil in the source area. The effect of soil excavation in the source area would be to substantially shorten the time before the residual NAPL is removed in the Upper Clay unit. However, the mass in the Lower Clay would not be affected. If it is assumed (conservatively) that the groundwater concentrations in the source area would not change appreciably until nearly all of the residual NAPL mass is removed, there would be little change in groundwater concentrations for up to several hundred years (see Appendix B for a discussion of estimated time to remove the residual source mass).

However, it is likely that excavation would yield some improvement in groundwater quality over a shorter time period, although this effect is difficult to quantify.

This alternative was not simulated because it was assumed that excavation does not affect groundwater concentrations until the residual source mass is completely removed. Therefore, the model would predict essentially no change in the plume from current conditions for decades to potentially centuries, under the conservative assumptions that have been used.

7.4.5 Alternative E – Excavation (within 10 mg/kg VOC contour), *In Situ* Reductive Dechlorination with Pneumatic Fracturing, and Alternate Concentration Limits

This alternative involves enhanced biodegradation through the reductive dechlorination process, coupled with soil excavation to 10 mg/kg VOCs, similar to Alternative F for the Building I-1-23 plume. Subsection 7.3.7 discusses changes in specified-concentration boundary conditions that were used to simulate reductive dechlorination in the source area. An identical 90 percent reduction in source area concentrations, coupled with a 50 percent reduction in the source mass was assumed for the Building I-1-2/I-1-3 plumes. The effect of soil excavation on the mass of TCE remaining in the source zone was also estimated and was used to help establish the length of time during which constant-concentration nodes were held operative in the source zones.

Figures 7-45, 7-46, and 7-47 show model-predicted plume extents at 5, 15, and 47 years after implementation of this alternative. Figure 7-48 shows predicted maximum concentrations at the western access road at the building complex, located approximately 900 feet west of the Building I-1-3 source area. The model results indicate that the maximum groundwater concentrations will fall from over 1,300 µg/L to near 100 µg/L over a period of about 30 years, and will then remain relatively steady (or slowly decreasing) until the residual NAPL source mass is removed from the Upper and Lower Clay units. Following source mass removal, concentrations would be expected to steadily decrease to values near zero.

7.4.6 Alternative F – Electrical Resistive Heating

The physical facilities and method of application for use of ERH technology at the Buildings I-1-2/I-1-3 source area (Alternative F) would generally be the same as at the Building I-1-23 area (Alternative G). Although ERH was not simulated directly by the model, the model was set up with the assumption that ERH would be used to treat a volume of soil in the source area (within the 10 mg/kg VOC contour) through the entire thickness of the Upper Clay and the Lower Clay units.

With the assumptions presented in Section 6 and conceptual design estimates made for this alternative as described in Appendix B, a mass removal efficiency of 90% is estimated for this technology. This removal efficiency translates to a 90% reduction in source area NAPL mass at the beginning of model simulation (which begins at the completion of the ERH remediation effort). Calculations presented in Appendix B show that with mass removal rates in the Upper Clay of 0.0396 lb/day at I-1-3 and 0.0186 lb/day at I-1-2, the NAPL and sorbed VOC mass in the Upper Clay would be fully removed within approximately 14 years and 59 years from the start of treatment, respectively. With mass removal rates in the Lower Clay of 0.072 lb/day at I-1-3 and 0.0492 lb/day at I-1-2, the NAPL and sorbed VOC mass in the Upper Clay would be fully removed within approximately 31 years and 12 years from the start of treatment, respectively. In addition, an estimated 90% reduction in source zone concentrations was simulated by adjusting the constant concentration node values that were used to simulate the source zones.

Figures 7-49 through 7-52 show the model-predicted extent of the TCE plume at 5, 15, 50, and 87 years after startup of the ERH system. These projections show that the TCE concentrations in the plume would be expected to steadily dissipate over several decades, and reach the specified Cleanup Standards over the entire current plume area within approximately 90 years. A graph of the predicted TCE concentration over time in the groundwater at an arbitrarily selected location of 900 feet west of the Buildings I-1-2/I-1-3 source area is shown on Figure 53. This graph indicates that the TCE concentration in the groundwater at that location should be reduced by approximately 90% in 24 years, and 99% in 79 years.

7.5 Area 9 Repository Source Area and Plume

7.5.1 Alternative A – Phytoremediation and Monitored Natural Attenuation

This alternative involves phytoremediation along the downstream portions of the Center Swale and East Swale and in the area between the two swales. The approach to simulating phytoremediation using "pumping wells" to simulate the uptake of impacted groundwater is described above in Subsection 7.2.3.

Figure 7-1 shows the results of the calibrated model simulating current conditions in the Repository area. Substantial natural attenuation occurs in the plume emanating from the Repository, caused by the biodegradation and discharge of shallow groundwater to the swales. This results in a plume that is limited in extent, with concentrations decreasing substantially over relatively short distances. While the calibrated model shows a relatively good fit to the current plume data, it is overly conservative in that it does not accurately reproduce the observed rapid decline in VOC concentrations over a very short distance in the area north of the Repository.

Figures 7-15 and 7-17 show the model simulation of future concentrations in the groundwater at 5 years and 50 years after implementation of this alternative. The results suggest relatively minor effects of the phytoremediation, in that the plume does not appear to change substantially from current conditions. This projected effect is believed to occur because some impacted groundwater is removed by the plants instead of discharging to the swales, yet the effect is similar in terms of removing the contaminants from the groundwater plume. The natural attenuation that is currently effectively restricting the extent of the plume at the Repository is expected to continue, and will be enhanced by the vegetation provided by the phytoremediation component of the alternative. A beneficial effect of phytoremediation will be to remove some of the VOCs before the groundwater discharges to the swales, thereby assisting in mitigating impacts on surface water quality.

7.5.2 Alternative B – Phytoremediation and Alternate Concentration Limits

This alternative is similar to Alternative A in that phytoremediation would be the active remedial measure that is implemented. The results discussed for Alternative A and shown on Figures 7-15 and 7-17 are also appropriate for this alternative.

Section 8
Screening of Remedial Alternatives

As outlined in USEPA's RI/FS guidance document (USEPA, 1988), after developing an appropriate range of site-specific remedial alternatives, the alternatives are initially evaluated against the short- and long-term aspects of the following three broad criteria:

- *Effectiveness* – Addresses the question of how effective this alternative is at achieving the remedial objective(s), from both a short-term and a long-term perspective
- *Implementability* – Evaluates the technical and administrative feasibility of the alternative
- *Cost* – Evaluates the capital and operation, maintenance, and monitoring costs of the alternative, based on the design concepts

As defined in the RI/FS guidance, the intent of this initial screening step for multiple alternatives developed during a "standard" feasibility study is to retain only those alternatives with the most favorable composite evaluation of all factors for further consideration during a detailed analysis of a "short list" of alternatives. In keeping with the "focused" format of this feasibility study, all of the remedial alternatives identified and developed in Section 6 are evaluated in this section against the three screening criteria, and all alternatives are then carried forward to a comparative analysis in Section 9.

Estimated costs to implement each alternative are presented. Breakdowns of the costs with supporting assumptions are included in Appendix A. The estimates have been prepared in accordance with the formats shown in the current USEPA guidance for developing FS-level cost estimates (USEPA, 2000b), and in accordance with other USEPA guidance documents regarding definitions of capital and operation and maintenance costs (USEPA, 2001). As discussed in earlier sections of this report, the long-term duration of operation, maintenance, and/or monitoring requirements for all of the remedial alternatives is very uncertain, due to several factors. Estimates of the total project duration for the various alternatives through final site closeout and removal from the National Priorities List, if attempts to make such estimates were made, would vary widely, but all such estimates would likely be in the range of multiple decades to a few centuries. These uncertainties would result in estimates of present value for the alternatives that would be of limited use as a comparative factor. In addition, as noted in USEPA's guidance (USEPA, 2000b), discounted present value costs tend to converge relatively rapidly to a constant value for total project durations in excess of 30 to 40 years. For these reasons, a period of 30 years was chosen as a common project duration to estimate a present value cost for each of the alternatives, to allow realistic relative comparisons between and among alternatives. After final design criteria have been developed for the selected alternatives, refinement of the cost estimates will likely be required.

The estimated costs for each remedial alternative include costs for monitoring the performance of the specific remedial action under each alternative, during both the short-term (construction and start-up) and long-term (operation and maintenance) phases. The monitoring costs are based on estimates of a monitoring program (sampling points, sampling frequency, and sample analyses) that would be reasonable and appropriate for each remedial alternative, to assist in making an overall comparative assessment of all the alternatives. However, the actual number and locations of monitoring points and the frequency of monitoring for the selected remedial alternatives would be determined during the remedial design phase, and the actual monitoring program may differ from the estimated monitoring program and costs included in this report.

The separate estimated cost items for each remedial alternative have also been organized under two main categories, consistent with USEPA guidance documents: capital costs, and operation and maintenance (O&M) costs (USEPA, 2000b)(USEPA, 2001). During the remedial design phase for the selected alternatives, further evaluation of the proper categorization of the cost elements (i.e., capital cost or O&M cost) may be appropriate.

8.1 No-Action Alternative

Evaluation of a No-Action alternative is required by CERCLA guidance to provide a baseline against which other alternatives can be compared. The No-Action alternative consists of no additional actions beyond those already implemented or required in the future at the site.

No Action is considered to be ineffective at achieving the remedial action objectives in a reasonable period of time. It is readily implementable, as it requires no additional systems or actions beyond what is already in place.

8.2 Building I-1-23 Source Area and Plume

8.2.1 Alternative A1 – Excavation (within 10 mg/kg VOC contour), Groundwater Extraction, and Phytoremediation

Effectiveness

Excavation - The effectiveness of excavating VOC-impacted Upper Clay soil at the Building I-1-23 source area, or of any other remediation technology that may be considered for this source area, can be evaluated based on the following key criteria:

- VOC mass expected to be removed compared with the total VOC mass potentially present in the source area
- Expected improvement in groundwater quality over time

With respect to the first of these criteria, soil excavation, alone, under Alternative A1 is expected to be only moderately effective at this VOC source area. Excavation of Upper Clay soil in Area 201 with identified VOC concentrations ≥ 10 mg/kg to a depth of 12 feet may be capable of removing up to approximately 15 percent of the total VOC mass present in the source area.

With respect to the second effectiveness criterion noted above, the VOC mass removal that could be accomplished by soil excavation, alone, under Alternative A1 is not expected to be very effective in improving groundwater quality downgradient of the source area over time. This was shown in the groundwater modeling simulations presented in Section 7.

As noted previously by USEPA, the accuracy of the VOC source area characterization, and the VOC source mass estimates prepared using the site data, is highly uncertain. There are no practical methods available to accurately determine how much VOC source mass could be removed by excavating Upper Clay soil to various lateral and vertical limits. If a large percentage of the NAPL and sorbed VOC mass was removed by excavation, this would have a pronounced effect on dissolved VOC levels downgradient of the source area over time. The estimates of the percentage of VOC source mass that could be removed by soil excavation under Alternative A1, and under any other alternatives that include excavation, may be somewhat conservative, i.e., the actual achievable mass removal effectiveness may be greater than the removal percentages used for the modeling projections and other estimates. However, several technical publications have described the observed effect that reductions in groundwater VOC concentrations in and near a source zone are relatively small until nearly all of the NAPL residuals have been removed (Lamarche, 1991) (Frind, 1999) (Imhoff, 1994) (Powers, 1992) (Pankow, 1996).

Phytoremediation - Phytoremediation, and the use of hybrid poplar trees in particular, has been shown to be effective at removing VOCs in shallow soil and groundwater (10 feet or less) and also at minimizing water infiltration through a soil cap or cover over landfills. Several sites in USEPA's Superfund Innovative Technology Evaluation (SITE) Program involve field demonstrations of phytoremediation (Schnoor, 1997). One of these sites involves the use of cottonwood trees to take up TCE from shallow groundwater (Betts, 1997). At a U.S. Army testing facility in Maryland, poplar trees are being used as hydraulic "pumps" to prevent the migration of contaminants to a nearby marsh, in a manner similar to the proposed use of poplars or cottonwoods in the West Swale. Phytoremediation has proved to be effective at removing TCE in the subsurface in climates similar to, and more harsh than, the southern Illinois climate.

Phytoremediation is a relatively recent technology that has been used in full-scale remedial actions only within the last decade, so its long-term effectiveness is still being assessed on many sites. The tree species that are typically used reach maturity, and thereby reach optimum remediation effectiveness, within about 3 years after planting. Because of the characteristics of the trees' root system, the technology's effectiveness in terms of VOC removal may extend at this site to approximately the top 10 feet of soil and the upper few feet of saturated clay. The reported life of a hybrid poplar is in the range of 30 years; therefore, long-term remediation effectiveness may require periodic planting of replacement trees or cuttings.

Planting of cottonwood trees across the West Swale is expected to provide some level of measurable improvement in groundwater quality through phytotransformation processes as the VOC-impacted shallow groundwater passes through the root zone of the trees. However, precise estimates of the quantity of VOCs that would be intercepted and degraded or removed by the trees planted in the West Swale under this alternative cannot be made, owing to limited published quantitative results of phytoremediation technology at full-scale sites and the influence of several site-specific factors. Preliminary estimates indicate that, although the trees are expected to have a beneficial effect on the concentrations of VOCs in the shallow groundwater and surface water, the percentage of VOC mass removed by the trees compared with the total VOC mass flux at the groundwater/surface water interface is relatively low. The planted trees, alone, are not likely to be capable of eliminating all detectable concentrations of VOCs in surface water within the West Swale and the shallow lake water, under current groundwater quality conditions. However, the trees would become increasingly effective over time as the VOC source remediation component of the remedy (soil excavation and groundwater extraction) gradually reduces the VOC concentrations in groundwater discharging to the West Swale and the shallow lake water.

Groundwater Extraction – The modeling results presented in Section 7 show that long-term operation of a single extraction well screened in the Upper Sand in the VOC source area should be effective in restoring groundwater quality to the target Cleanup Standards (≤ MCLs) over a large area from the lake to within a relatively short distance from the VOC source area. However, the modeling results also show that, unless all of the residual NAPL source material is removed, the VOC plume would rebound significantly within a short time after the extraction well stopped operation. Therefore, with respect to achieving and maintaining the full groundwater quality improvement benefit achievable by groundwater extraction, the extraction well would have to remain in operation until all residual NAPL and sorbed-phase VOC source material was removed via dissolved-phase extraction. The substantial uncertainties regarding the total mass of VOCs present and the nature of its distribution in the source area make estimation of the time frame required for pumping groundwater equally uncertain.

The modeling results (Section 7) also show that short-term (possibly less than 15 years) operation of an extraction well for the purpose of removing dissolved-phase VOC source mass could potentially provide substantial improvement in groundwater quality between the source area and the lake. However, the VOC concentrations in the plume would likely still remain well above the target Cleanup Standards for decades.

Implementability

The phytoremediation component of Alternative A1 is readily implementable at this site. It is expected that the establishment of a tree grove in the location shown on Figure 6-1 would not have an adverse effect on the current operations at the site. The area selected appears to be suitable for planting the trees and capable of supporting their continued growth.

Excavation of Upper Clay soil in Area 201 (see Figure 6-1) is expected to be implementable. Drawings showing existing buried utilities in the excavation areas obtained from General Dynamics Ordnance and Tactical Systems (GDOTS) and F&WS were reviewed, and no significant interferences with buried utilities were noted. An existing 8-inch sanitary sewer is present in the area, but this should not present a major problem, and relocation of the sewer is not expected to be required. The potential excavation areas are also in the same general locations as the excavations completed in 1996 for removal of the soil for the PCB remedial action. The documentation report for this previous work does not indicate that any buried utility interferences were encountered.

During the PCB soil excavation and building decontamination/demolition project in 1996, a substantial amount of coordination of the work with the building tenant (Primex Technologies at that time) was required to avoid interference with the manufacturing operations. The same level of coordination would be required with the current building tenant (GDOTS) to implement the work under Alternative A1. Building I-1-23 is currently unoccupied, but use of the building for manufacturing activities could resume at some time prior to, during, or after the remedial action construction activities. However, no work restrictions or access requirements of GDOTS that would prevent implementation of Alternative A1 are known, based on previous coordination with GDOTS during the predesign fieldwork performed in 2000.

Construction and operation of a relatively small groundwater extraction and treatment system for either short-term VOC source removal or long-term VOC source containment is physically possible. However, as demonstrated by the computer modeling simulations in Section 7, operation, maintenance, and periodic replacement of such a system may be needed for a very long time to hydraulically contain the VOC residuals that are likely to remain in the Building I-1-23 source area. Although the practicality of operating, maintaining, monitoring, and replacing such a system over long periods may be questionable, these measures would be implementable.

Cost

Supporting details for the Alternative A1 cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$830,000
Total OM&M* cost - Years 1-30	$4,352,000
Total present value for 30 years	$3,719,000

* Operation, maintenance, monitoring, and periodic costs

8.2.2 Alternative A2 – Excavation (within 1 mg/kg VOC contour), Groundwater Extraction, and Phytoremediation

Effectiveness

If the soil excavation component of Alternative A2 accomplishes the objective of removing nearly all of the NAPL and sorbed VOC source material from the Upper Clay, this alternative should be effective in both remediating the VOC source area and restoring the groundwater quality between Building I-1-23 and the lake, within a reasonable time period (estimated at less than 15 years). For the groundwater modeling simulations presented in Section 7, it was assumed that 97 percent of the total VOC mass in the Upper Clay would be removed by the excavation. To the degree that this level of mass removal is not accomplished, the long-term effectiveness of Alternative A2 in maintaining the groundwater quality improvements achieved from the relatively short groundwater extraction duration (estimated at 11 years) will begin to be similar to the overall effectiveness of Alternative A1. As the actual effectiveness of VOC mass removal from the Upper Clay drops farther below the target level of 97 percent, the groundwater extraction well will have to continue pumping from the Upper Sand unit at the source area for progressively longer time periods to achieve containment of the dissolved VOC plume that would continue to persist due to the increased mass of VOC residuals that would remain in the Upper Clay unit.

The short- and long-term effectiveness of the phytoremediation component of Alternative A2 would generally be the same as under Alternative A1.

Implementability

The installation, operation, and maintenance of a groundwater extraction and treatment system at this VOC source area, and the phytoremediation component of this alternative, are readily implementable. The soil excavation is also implementable, although the increased excavation depths to the top of the Upper Sand unit will create some difficulties due to the water-saturated sand heaving into the excavation when the Upper Clay overburden is entirely removed. The actual excavation depth that can be achieved would be determined in the field based on practical limitations of the excavation equipment and methods. The relatively large area and volume of soil excavation will also require close coordination of the work with GDOTS to avoid interference with their operations.

Cost

Supporting details for the Alternative A2 cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$2,747,000
Total OM&M* cost – Years 1-30	$2,941,000
Total present value for 30 years	$4,914,000

* Operation, maintenance, monitoring, and periodic costs

8.2.3 Alternative B – Excavation (within 10 mg/kg VOC contour), Permeable Reactive Barrier, and Phytoremediation

Effectiveness

The discussion included above under Alternative A1 regarding soil excavation and phytoremediation also applies to Alternative B, because these components of the remedial action would be the same under both alternatives.

If it is determined that a permeable reactive barrier (PRB) can be installed across the VOC plume in the Upper Sand unit immediately downgradient of the Building I-1-23 source area, the PRB should be capable of effectively destroying the VOCs that enter the reactive zone of the PRB with the flowing groundwater. This expectation is based on information and written proposals for the Building I-1-23 source area received from contractors/vendors of the PRB technology, on a review of information on the performance of full-scale PRBs installed at other sites, and on USEPA publications. In a 1998 publication (USEPA, 1998b), USEPA stated the following:

> *The USEPA recognizes this (PRB) technology as having the potential to effectively remediate subsurface contamination at many types of sites with significant cost savings compared to more traditional approaches (e.g., pump-and-treat)...From a federal perspective, one of the more significant advances for PRB technology occurred when a "chemical treatment wall" was identified in June 1995 as the preferred alternative in the Record of Decision (ROD) at a Superfund site (the Somersworth Municipal Landfill in Somersworth, New Hampshire).*

As presented in Section 6, USEPA – Region 3 also determined that a PRB would provide effective *in situ* treatment of chlorinated VOCs in groundwater at a

Superfund site in Virginia, as documented in an Explanation of Significant Differences issued in 1998 (USEPA, 1998a).

The design criteria for the PRB (hydraulic detention time within the reactive zone) can be selected so the constructed PRB is capable of destroying VOCs from the expected concentrations that would enter the PRB to "nondetect" concentrations as the water flows out of the PRB. Pilot-scale and full-scale PRB installations have demonstrated that this level of VOC treatment effectiveness is possible. Full-scale PRBs at several sites have proved to be reliable and effective over several years. Therefore, short-term effectiveness at the Building I-1-23 location is likely, provided the construction challenges for a PRB at the Building I-1-23 location can be successfully overcome. However, the USEPA has also reported that what appears to be only a minor compromise in the integrity of the PRB wall materials or placement during construction can allow contaminants to pass through a PRB untreated. The overall treatment performance of a PRB is highly dependent on the level of quality control and quality assurance that can be accomplished during construction of the PRB.

Calculations of the possible consumption rate of the reactive iron in the PRB using data on existing groundwater quality at the Building I-1-23 area indicate that a PRB installed at Building I-1-23, in accordance with a PRB contractor's preliminary design, should contain sufficient iron mass to provide VOC treatment for approximately 50 to 350 years. However, the oldest full-scale PRB was installed less than 20 years ago. The absence of long-term performance data for full-scale PRBs at other sites makes projections of the long-term reliability and effectiveness of a PRB at the Building I-1-23 area more difficult than comparable projections of short-term effectiveness.

As shown in the groundwater modeling simulations presented in Section 7, the use of a PRB after completing the soil excavation portion of the work should result in substantial improvement in groundwater quality over time. However, the modeling simulations show that effective performance of the PRB would be required for several decades, to prevent additional dissolved VOC mass originating from the VOC residuals remaining in the source area from re-establishing the VOC plume in the Upper Sand downgradient from the source area. Therefore, the effectiveness of the remedial action under Alternative B will be achieved only as long as the PRB continues to provide effective treatment of the VOCs. This remediation objective would require periodic efforts to maintain the hydraulic as well as the treatment performance of the

PRB using field techniques and equipment that are currently unproven, or possibly periodic complete removal and replacement of the PRB, which would be highly costly and would pose significant construction challenges. Therefore, the long-term effectiveness of a PRB for the Building I-1-23 source area is very uncertain.

Excavation of Upper Clay soil under this alternative would remove a portion of the total VOC mass likely to be present in the source area. However, excavation would have limited effectiveness in reducing the amount of time that a PRB would have to remain functional, to intercept and degrade dissolved VOCs migrating in groundwater that passes through the source zone, and would provide few other remediation benefits.

As with any selected alternative, the remedial action workplan prepared to implement Alternative B would specify contingency measures that would be implemented if the actual results of a PRB did not meet the performance expectations. For the Building I-1-23 source area, excavation of additional VOC source material within the Upper Clay soil could be a component of the specified contingency measures.

Implementability

The discussion included above under Alternative A1 regarding soil excavation and phytoremediation also applies to Alternative B, because these components of the remedial action would be the same under both alternatives.

Installation of a PRB at the Building I-1-23 area would likely present some design and particularly construction challenges, depending on the specific geologic conditions encountered at the location selected for the PRB. Installation of PRBs using trenching methods is typically limited to a depth of approximately 50 feet. Existing geologic data show that the Upper Sand unit near the northern end of Building I-1-23 extends to a depth of 42 feet bgs and probably deeper, since the thickness of the Upper Sand unit increases with distance from Building I-1-23 to the north. Construction difficulties for PRBs increase significantly as the trenching depth increases. Problems that have occurred with PRBs at other sites include difficulty in producing a uniform mixture of reactive iron and sand; difficulty in maintaining a uniform iron/sand mixture during placement in the trench; dewatering problems during trench construction; and other unexpected field problems. A high level of construction quality control is required. The specialized construction methods and equipment also require use of a contractor with previous PRB construction experience and proven competence. Even with a sound design, diligent construction quality assurance/quality control measures, and use of a qualified contractor, it is often difficult to accurately assess how effectively the completed PRB is intercepting and treating the dissolved VOCs over the full reactive surface area of the PRB. Short-circuiting of groundwater flow beneath or around the ends of PRBs, or through gaps in the PRB face resulting from construction problems, has been documented at PRB sites. Although challenges such as those noted above would likely be faced, it is expected that the potential difficulties could be addressed in the design and construction approach, and the trenching installation method is expected to be implementable. An alternative technology for placing the ZVI in the Upper Sand that does not have the depth limitations of the trenching method is also available. That technology is the proprietary Ferox® process offered by ARS Technologies, Inc. The Ferox® process uses pneumatic fracturing and pneumatic injection methods to place the ZVI in the reactive zone of the PRB. The type of installation method would be selected after further evaluation during the final design stage.

Drawings showing existing buried utilities in the general area of construction of a PRB were reviewed. It is likely that some existing utility lines would have to be permanently relocated to accommodate construction of a PRB. This may present difficulties that could prevent installation of a PRB, and coordination of the design and construction of the PRB with GDOTS would be required to avoid interference with manufacturing operations.

Cost

Supporting details for the Alternative B cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$2,276,000
Total OM&M* cost – Years 1-30	$3,559,000**
Total present value for 30 years	$4,415,000

* Operation, maintenance, monitoring, and periodic costs.

** Includes $1,900,000 for PRB replacement in year 20.

8.2.4 Alternative C – Multiphase Extraction with Pneumatic Fracturing, Groundwater Extraction, and Phytoremediation

Effectiveness

The discussion included above under Alternative A1 regarding the effectiveness of long-term and short-term groundwater extraction and treatment and phytoremediation also applies to Alternative C, because these components of the remedial action would generally be the same under both alternatives.

Operation of an MPE/SVE/groundwater dewatering system (horizontal wells) for up to 2 years is estimated to be capable of removing approximately 40 to 55 percent of the total VOC source mass present at the Building I-1-23 area. Therefore, with respect to the effectiveness criteria of VOC mass removed compared with the total VOC mass in the source area, use of an MPE/SVE/dewatering system would be moderately effective at this VOC source area.

With respect to the effectiveness criterion of the expected improvement in groundwater quality over time, the VOC mass removal that could be accomplished by an MPE/SVE/dewatering system alone would not be very effective in improving groundwater quality downgradient of the source area over time. This was shown in the groundwater modeling simulations presented in Section 7. Similar to the conditions under Alternative A1 described above, the use of a long-term groundwater extraction and treatment system after completing operation of the MPE/SVE/dewatering system would be required under Alternative C to achieve substantial improvement in groundwater quality over time.

Implementability

MPE is estimated to be implementable at this site. Conventional construction equipment would be used for installing the vertical wells, underground piping, and other equipment. Directional drilling equipment would be used to install the horizontal extraction wells. The stratigraphy at the location of the horizontal wells would need to be characterized to a greater extent prior to the installation of these wells to place them accurately at the bottom of the Upper Sand layer. This would likely be done using a direct-push sampling method (e.g., Geoprobe® rig), which would be less costly than a conventional drilling rig. The use of geophysical techniques to obtain soil stratigraphy data would also be evaluated. The mechanical extraction and treatment equipment is also readily available from a number of manufacturers. The liquid-ring vacuum pump requires a liquid to provide a seal and develop vacuum. This liquid is typically provided in one of three ways—by recirculating a portion of the extracted groundwater through the pump; by a separate pressurized water source (water utility or reservoir tank); or with oil, which requires an oil-sealed type of pump. At this site, either a pressurized water source or oil-sealed pumps would be used, because of potential operation and maintenance concerns with using recirculated groundwater.

Construction of all facilities associated with the MPE/SVE/groundwater dewatering system is expected to be implementable. The primary components of the system (MPE wells, SVE wells, horizontal groundwater extraction wells, groundwater and soil pore gas treatment equipment -- see Figures 6-4B and 6-4C) would be generally as described in the Preliminary Design Report (RMT, 2001d). The long-term groundwater extraction and treatment system that would be used following MPE/SVE system operation would be similar to the system as described under Alternative A1, and could be readily constructed. However, the uncertain and potentially lengthy time that a groundwater system may have to be operated and maintained to contain the effects of the VOC source material not removed by the MPE system may make implementation of a groundwater extraction/treatment system somewhat questionable from a practical standpoint.

The proximity of existing buried utilities to the area where the MPE wells will be installed in the Upper Clay and the presence of several existing monitoring wells may create some difficulties for pneumatic fracturing of the clay to enhance MPE effectiveness, owing to potential short-circuiting of the injected nitrogen gas through the soil fractures to the nearby utility line or well locations. Problems with ground surface heave during the pneumatic injection process and subsequent potential damage to nearby structures or equipment must also be considered. However, similar circumstances have been successfully addressed at several other sites with existing buried utilities, wells, and nearby structures where pneumatic fracturing was completed. As described in Section 5, pneumatic fracturing is a proven remediation enhancement technology that is intended for use in conditions such as the Building I-1-23 source area. With the use of an experienced contractor that specializes in pneumatic fracturing applications, and a conscientious design that anticipates and addresses potential site-specific problems, pneumatic fracturing is expected to be safely and effectively implementable under this alternative.

USEPA has determined (USEPA, 2004) that if Alternative C is selected for use at Building I-1-23, a pilot test using pneumatic fracturing in a well-defined, relatively small zone within the Upper Clay would be required before fracturing could be applied at full-scale in the entire Upper Clay treatment zone, to demonstrate that the technology will work and will not damage structures or mobilize DNAPL layers.

The liabilities associated with safety issues, potential damage to nearby buildings, buried utilities, and existing wells, and potential interference with GDOTS's production operations, would be the responsibility of the primary pneumatic fracturing vendor/contractor that would be selected for this work. The overall implementability of Alternative C would be dependent on the ability to secure appropriate contractual terms with the vendor, in which the vendor would agree to accept those liabilities, without unacceptable increases in overall cost.

Cost

Supporting details for the Alternative C cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$1,319,000
Total OM&M* cost – Years 1-30	$4,490,000
Total present value for 30 years	$4,352,000

* Operation, maintenance, monitoring, and periodic costs

Capital costs for this technology reflect the large number of wells, the feet of trenching required, and the mechanical equipment required for extraction and treatment.

Annual costs for the first 2 years (the period during which the MPE system is assumed to operate) are greater than the annual costs for the remainder of the 30-year estimating period, because of the frequency of site visits, and the influent and effluent water sampling and air sampling that would be required.

Costs for this alternative also include capital and annual costs for phytoremediation and compliance monitoring.

The total present value shown includes costs for operation, maintenance, and monitoring of the groundwater extraction and treatment system for 30 years.

8.2.5 Alternative D – Excavation (within 10 mg/kg VOC contour), Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits

Effectiveness

The discussion included above under Alternative A1 regarding the effectiveness of Upper Clay excavation to remove a portion of the VOC source mass also applies to Alternative D, because this component of the remedial action would be the same under both alternatives.

The effectiveness of the phytoremediation component of Alternative D would be enhanced compared with the conceptual design for phytoremediation under Alternatives A1, A2, B, and C. This enhanced level of effectiveness for the phytoremediation component of the remedy would be required to meet the applicability criteria for use of Alternate Concentration Limits. This would be accomplished by constructing an engineered wetland treatment zone in the portion of the lake embayment where the VOC plume originating at Building I-1-23 discharges into the West Swale and the shallow lake water. Published technical information for a similar remediation site (USGS, 1997) (USDOI, 2003) at which a natural wetland is providing substantial degradation of VOCs indicates that a constructed wetland at the terminal point of the Building I-1-23 plume should be effective in reducing VOCs to below or near detectable levels before the water enters the main lake body. Phreatophytic trees would also be planted in the West Swale near the lake, similar to the conceptual design in Alternative A1, and these trees should also contribute to the reduction of dissolved VOC concentrations in shallow groundwater as it emerges into the West Swale and wetland treatment zone.

Groundwater grab samples collected from temporary well points installed in several Geoprobe® borings in 1998 provided the chemistry data that were used to conclude that the Building I-1-23 plume discharges fully into a relatively narrow area in the West Swale and into the lake embayment. The phytoremediation component of Alternative D can be very effective if these previously observed conditions are representative of the long-term behavior of the groundwater/surface water interaction in this location. Groundwater samples would be collected during the predesign phase at various locations to verify that the VOC plume fully discharges into the lake embayment in the area in which the wetland treatment zone would be constructed.

Overall, Alternative D would provide only minimal improvement in groundwater quality from the Building I-1-23 source area to the lake, except the length of time the plume would persist may be slightly reduced because of the VOC mass removed by excavation. However, the phytoremediation component of Alternative D should be effective in both the short-term and long-term in preventing VOCs in shallow groundwater from impacting the main lake water body.

Implementability

The discussion included above under Alternative A1 regarding the implementability of Upper Clay excavation to remove the VOC source mass also applies to Alternative D, because this component of the remedial action would be the same under both alternatives.

The phytoremediation component of the alternative is also expected to be implementable. The physical characteristics of the existing lake embayment are conducive to the construction of a wetland treatment zone with relatively limited disturbance required in the existing areas adjacent to the lake embayment.

The phytoremediation component of Alternative D (tree plantings and wetland treatment zone) is expected to effectively eliminate the VOC impacts on surface water in Crab Orchard Lake. When these conditions have been achieved, all of the applicability criteria for use of Alternate Concentration Limits (ACLs) associated with the Building I-1-23 plume will be met. The use of groundwater ACLs has also been included in Decision Documents prepared by USEPA – Region 5 for several other CERCLA sites at which USEPA determined that the applicability criteria were met. Therefore, the component of Alternative D that provides for use of ACLs for groundwater quality is expected to be implementable and appropriate for the conditions at this site.

Cost

Supporting details for the Alternative D cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$1,074,000
Total OM&M* cost – Years 1-30	$1,988,000
Total present value for 30 years	$2,391,000

* Operation, maintenance, monitoring, and periodic costs

8.2.6 Alternative E – Phytoremediation Including Engineered Wetland and Alternate Concentration Limits

Effectiveness

The discussion included above under Alternative D regarding the effectiveness of phytoremediation (tree plantings in the West Swale and engineered wetland treatment zone in the lake embayment) to remove VOC impacts on surface water in Crab Orchard Lake also applies to Alternative E, because this component of the remedial action would be the same under both alternatives.

Because this alternative does not include any "active" measures for remediation of the VOC source area, it would not be effective in reducing the overall time required for the existing VOC source material to be removed by natural attenuation processes, or in improving the groundwater quality between the source area and the lake.

Implementability

The discussion included above under Alternative D regarding the implementability of phytoremediation and the use of groundwater ACLs also applies to Alternative E, because these components of the remedial action would be the same under both alternatives. All components of Alternative E are expected to be implementable.

Cost

Supporting details for the Alternative E cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$706,000
Total OM&M* cost – Years 1-30	$2,034,000
Total present value for 30 years	$2,046,000

* Operation, maintenance, monitoring, and periodic costs

8.2.7 Alternative F – Excavation (within 10 mg/kg VOC contour), *In Situ* Reductive Dechlorination, Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits

Effectiveness

The discussion included above under Alternative A1 regarding the implementability of Upper Clay excavation to remove a portion of the VOC source mass also applies to Alternative F, because this component of the remedial action would be the same under both alternatives.

Similarly, the discussion included above under Alternative D regarding the effectiveness of phytoremediation (tree plantings in the West Swale and an engineered wetland treatment zone in the lake embayment) to remove VOC impacts on surface water in Crab Orchard Lake also applies to Alternative F, because this component of the remedial action would be the same under both alternatives.

As reported for many other sites with significant VOC contamination of soil and groundwater, the stimulation of naturally occurring biological reductive dechlorination in soil containing VOC source material is capable of degrading substantial percentages of the VOC source mass (half to greater than 90 percent) within a relatively short time (a few years), when various site conditions are suitable for use of this technology. In the Building I-1-23 source area and associated plume, chemical indicators of reductive dechlorination already occurring in the groundwater have been observed. Based on results experienced at other sites, it is expected that enhancing the subsurface environment to allow the specific VOC-degrading microorganisms to thrive will be effective in reducing the total source mass. As with any *in situ* remediation technology, quantification of the VOC mass that would be degraded, or of the specific proportions of the mass degraded and the mass remaining, would be extremely difficult, at best, and more likely impossible.

However, on a comparative basis, *in situ* biological reductive dechlorination is expected to be moderately to highly effective in destroying VOC source mass.

Stimulation of the reductive dechlorination process would not be strictly limited to the immediate VOC source zone, as is the case for several other *in situ* physical/chemical remediation technologies. Biodegradation of the VOCs would likely continue in the groundwater and saturated soil to some distance downgradient of the source area, since some of the substrate solution injected into the source zone would be transported with the groundwater flow into the plume between the source area and the lake. The extent and effectiveness of this additional degradation of VOCs outside the source area would be influenced by the amount of substrate remaining in the groundwater as it moves from the source zone, which can be controlled to some degree by the concentration, type, injection method, injection locations, and frequency of the substrate solution injections into the Upper Sand. The substrate solution that would be placed (in bulk form) in the excavations in the Upper Clay would also provide some additional effectiveness in stimulating biodegradation of VOCs that would remain in the clay beneath and adjacent to the excavations.

At some sites where *in situ* reductive dechlorination has been used for VOC treatment, the dechlorination process has been found to be incomplete, resulting in the accumulation of breakdown products of TCE (1,2-DCE and vinyl chloride) in groundwater downgradient of the source/treatment area. This may have been caused by several factors, including inadequate electron donor substances, insufficient populations of appropriate microorganisms, or other bio-limiting chemical conditions. The groundwater chemistry data collected for the Building I-1-23 source area and plume indicate that reductive dechlorination is occurring, and the primary factor limiting the effectiveness of reductive dechlorination is likely to be insufficient electron donor substances. In addition, the data show that TCE breakdown products are not accumulating in the plume, which indicates that the conditions and microorganisms needed to complete the breakdown process for the TCE and PCE source mass are present.

Although the existing data indicate that conditions suitable for stimulating *in situ* reductive dechlorination appear promising, it is difficult to accurately estimate the overall VOC source destruction effectiveness that will be accomplished, due to factors such as uncertainty in the current VOC mass quantity and in the achievable rate and completeness of the biochemical breakdown process. A similar difficulty in estimating VOC source destruction/removal effectiveness is common to the technologies evaluated in the other remedial alternatives for the Building I-1-23 source area, other than excavation. To reflect this uncertainty for Alternative F, it was conservatively estimated in the modeling simulations presented in Section 7 that 50% of the original VOC source mass would be removed from both the Upper Clay and the Upper Sand units by reductive dechlorination.

USEPA has determined (USEPA, 2004) that if Alternative F is selected for use at Building I-1-23, a pilot test of approximately 6 to 12 months duration using reductive dechlorination in a well-defined, relatively small zone within the Upper Sand would be required before reductive dechlorination could be applied at full-scale in the entire source area, to demonstrate that the technology is capable of achieving the remedial objectives. In addition, as with any selected alternative, the remedial action workplan prepared to implement Alternative F would specify contingency measures that would be implemented if the actual results of enhanced reductive dechlorination did not meet the performance expectations. For the Building I-1-23 source area, excavation of additional VOC source material within the Upper Clay soil could be a component of the specified contingency measures.

The substrate solution would be applied only to the water-saturated portion of the Upper Clay (by bulk addition to the soil excavation), and to the full depth of the Upper Sand unit (by pressure injection). Therefore, the biodegradation process would not be effective in removing VOC source mass that may remain in the unsaturated portion of the Upper Clay following excavation. However, as noted previously, the soil excavation component of Alternative F would be expected to remove a significant percentage of the VOC source within this Upper Clay vadose zone.

Implementability

The discussions included above under Alternatives A1 and D regarding the applicability of the use of groundwater ACLs and the implementability of phytoremediation and excavation of Upper Clay also apply to Alternative F, because these components of the remedial action would be the same under Alternative F. Injection and distribution of substrate liquid into multiple points within the Upper Sand unit at the source area is expected to be implementable and efficient, due to the permeability of the sand. Bulk placement of substrate liquid into the excavations in the Upper Clay prior to and during backfilling would also be easily accomplished.

Cost

Supporting details for the Alternative F cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$1,410,000
Total OM&M* cost – Years 1-30	$2,154,000
Total present value for 30 years	$2,908,000

* Operation, maintenance, monitoring, and periodic costs

8.2.8 Alternative G – Electrical Resistive Heating (within 1 mg/kg VOC contour) and Phytoremediation

Effectiveness

To effectively conduct *in situ* thermal stripping of VOCs at the Building I-1-23 source area, it is necessary to uniformly distribute electrical current and, in turn, resistance and induced heat in the soil in proximity to the VOC source material. After reviewing source area characterization data for Building I-1-23 provided by RMT, two vendors/contractors of the proprietary ERH technology determined that ERH is expected to be capable of effectively increasing the subsurface temperature in the VOC source zone soil by use of multiple electrode arrays.

Because this is a relatively new, proprietary technology that is available from a limited number of vendors, the majority of the available information and performance data regarding ERH comes directly from the vendors. The reported performance data for sites where ERH has been used full-scale for VOCs show a relatively wide range of contaminant destruction/removal effectiveness, reflecting the variety of site-specific conditions and design, operation, and maintenance factors that influence the overall effectiveness of ERH at a given site. As with any *in situ* remediation technology, making an accurate quantitative estimate of the actual VOC destruction/removal effectiveness accomplished following full-scale use of ERH is very difficult. Using primarily before-and-after treatment soil sampling in the VOC source zones, the ERH vendors have reported total VOC source removal effectiveness of 60 to 70% to greater than 99%. Based on vendor claims and some independent data available from full-scale ERH sites, on a comparative basis, *in situ* ERH may be as or more effective in removing VOC source mass as other established or innovative technologies, other than physically excavating and removing the source. Based on available data for sites where ERH has been used at full-scale, reductions in VOC mass and concentrations of 90% or more can be achieved in the treatment zone where heating is sufficiently uniform and sustained at levels capable of vaporizing all soil moisture. For the modeling simulations of this alternative presented in Section 7, an overall VOC source mass removal efficiency of 90% was assumed. This estimated level of performance is believed to represent a reasonable balance between the lower removal efficiencies reported at some sites where ERH has been used at full scale, and vendor claims of potentially higher (> 99%) achievable removal efficiencies, without the benefit of existing demonstration or pilot-scale data for use of ERH at this site. Vendor estimates of treatment time to obtain this removal efficiency are approximately 1 year.

As with any selected alternative, the remedial action workplan prepared to implement Alternative G would specify contingency measures that would be implemented if the actual results of ERH did not meet the performance expectations. For the Building I-1-23 source area, excavation of VOC source material within the clay soil could be a component of the specified contingency measures.

Implementability

After reviewing information provided by RMT describing the conditions at Building I-1-23, an ERH vendor determined that use of ERH to remove VOCs under this alternative is expected to be implementable. However, engineering controls are likely to be required to protect existing buried utilities and prevent migration of VOC-laden steam and vapors from the treatment area through existing utility line corridors within the treatment zone. The ERH vendors also report that other potential safety concerns associated with use of ERH, such as steam venting from existing wells, exposure of remediation workers, site employees, or others to very hot water or steam, and electricity arcing or other electrocution hazards, have been fully addressed in their current designs.

General Dynamics Ordnance and Tactical Systems (GDOTS) currently leases most of the Area 9 buildings from U.S. Department of the Interior for production, storage, and warehousing operations associated with the manufacture of finished military ammunition of various calibers. Although Building I-1-23 is not currently leased by GDOTS and is unoccupied, GDOTS has indicated their preference to eventually lease Building I-1-23 and refurbish the building to house a new automated high-explosives load-line. GDOTS is currently in the startup phase of a new manual production line in Building I-1-58, which adjoins the southern end of Building I-1-23.

A meeting was held with representatives of GDOTS, F&WS, USEPA, IEPA, and RMT on 4 March 2004 at the GDOTS office at the Area 9 building complex. The purpose of the meeting was to present an overview of the types of equipment and operating conditions expected to be used to apply the ERH technology for remediation of the VOC source zones adjacent to Buildings I-1-23, I-1-2, and I-1-3, if ERH was the selected remedial alternative for any of these areas. At the conclusion of that meeting, the GDOTS representatives indicated the following:

- They do not believe there should be any major problems preventing consideration of ERH as a remedial alternative for the VOC source area adjacent to Building I-1-23.
- They would prefer selection of a different technology or alternative for this VOC source area if feasible.
- Their primary concerns regarding use of ERH adjacent to Building I-1-23 are:
    - Potential exposure of their employees working near the treatment zones, particularly inside the buildings, to VOC vapors that may not be captured by the ERH system and may migrate beneath and into the buildings.
    - Potential detrimental effects of stray voltage from the ERH system on the sensitive instrumentation and controls associated with their production operations in Building I-1-58 and other buildings. The GDOTS representatives stated that any adverse effects on the instrumentation or controls could result in potentially significant financial losses due to compromised quality control documentation or other physical effects on their products. The GDOTS representatives expressed a need to fully understand the actual and potential "electric field effects" of the high applied voltages used with ERH, to allow them to make their own assessment of potential adverse impacts on their operations or safety of their personnel.

Because ERH is a proprietary, patented technology, the ERH vendor would be responsible for the design, construction/installation, and operation/maintenance of the complete system. Therefore, the liabilities associated with safety issues and potential effects on GDOTS production operations would be the responsibility of the primary ERH vendor that would be selected for the work. The overall implementability of Alternative G would be dependent on the ability to secure appropriate contractual terms with the ERH vendor in which the vendor would agree to accept those liabilities, without unacceptable increases in overall cost. The technologies included in other alternatives for the Building I-1-23 area would also require some level of liability acceptance on the part of other technology vendors or contractors. However, the unique uncertainties associated with use of ERH at Building I-1-23 due to the relative newness of the technology and the concerns raised by GDOTS make the issue of liability acceptance by the vendor a key factor in determining the implementability of Alternative G.

Due to the extent of the subsurface electrode, drip-wetting, and vapor extraction systems required, the design and full-scale operational control of the ERH system are expected to be challenging. A high voltage electrical source (estimated 480 V, 807 kW with a power supply rating of 750 kW) would be required for this source area. This would require installing a new, potentially temporary, electrical supply line to the Building I-1-23 area from an undetermined location/distance. Indoor air monitoring in Buildings I-1-23 and I-1-58 would also be required at least during the "heating phase" of the ERH process, for comparison of the air quality with the OSHA criteria for occupational exposure.

If Alternative G was selected, a demonstration or pilot test of ERH in a smaller, well-defined zone within the overall source area would be required during the pre-design phase, prior to full-scale use of ERH over the entire source area. The pilot test would be needed to confirm design criteria for the full-scale system, to confirm achievable VOC removal effectiveness, and to demonstrate that full-scale installation and operation of the system would not result in any problems with safety, spreading of VOC contamination, adverse effects on the GDOTS production operations, etc. USEPA has determined that demonstration or pilot tests would be required for technologies included in other remedial alternatives that have not been attempted at this site (in-situ reductive dechlorination and pneumatic fracturing), and there are similar uncertainties regarding the feasibility and effectiveness of ERH technology. Because the VOC source zones at Building I-1-23 are located generally in a single, nearly contiguous area, full-scale application of ERH would encompass the overall source area as defined by the approximate 1 mg/kg total VOC contour.

Cost

Supporting details for the Alternative G cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$2,930,000
Total OM&M* cost – Years 1-30	$1,392,000
Total present value for 30 years	$3,837,000

* Operation, maintenance, monitoring, and periodic costs

8.3 Buildings I-1-2/I-1-3 Source Area and Plume

8.3.1 Alternative A – Limited Excavation (Building I-1-3 hot-spot) and Multiphase Extraction with Pneumatic Fracturing

Effectiveness

A "limited excavation" component of Alternative A would be effective in removing a significant hot spot of VOC source mass that was located in relatively shallow soil (depth limit of 6 feet) over a localized area adjacent to Building I-1-3. However, the limited hot spot excavation would obviously not be effective in addressing the large majority of the VOC source mass present at the Building I-1-3 area, which is present at greater depths in the saturated clay.

Operation of an MPE system enhanced by pneumatic fracturing for up to 2 years is estimated to be capable of removing approximately 15 to 20 percent of the total VOC source mass present at the Building I-1-2 area, and in the range of 40 percent of VOCs at the Building I-1-3 area. However, several hundred pounds, and possibly significantly more pounds, of VOCs would be likely to remain in the combined Buildings I-1-2/I-1-3 areas following MPE treatment. Therefore, with respect to the effectiveness criterion of VOC mass removed compared with the total VOC mass currently present in the source area, the use of an MPE system with pneumatic fracturing is expected to be marginally

(Building I-1-2 area) to moderately (Building I-1-3 area) effective at these VOC source areas.

With respect to the effectiveness criterion of the expected improvement in groundwater quality over time, the VOC mass removal that could be accomplished by an MPE system with pneumatic fracturing would not be effective in improving groundwater quality downgradient of the source areas over time. This was shown in the groundwater modeling simulations presented in Section 7. The improvement in groundwater quality that would result from Alternative A would be only slightly better than the quality that would result from reliance on natural attenuation processes alone.

Implementability

The "limited excavation" component of Alternative A to remove a shallow VOC hot spot adjacent to Building I-1-3 would be easy to implement.

Pneumatic fracturing of the clay soil followed by the installation and operation of an MPE well system at the Buildings I-1-2/I-1-3 source areas would be implementable. The geologic conditions and the physical setting at these areas are well suited for the use of this technology. The work would be done in an open area with few aboveground obstructions, and the buried utilities in the area are limited. The work areas on the eastern side of Buildings I-1-2/I-1-3 would also minimize the potential for interferences with GDOTS's operations. However, because of the extent of the MPE well system required, the design and full-scale operational control of the well system are expected to be challenging. A limitation of applying pneumatic fracturing within the clay in these VOC source areas is that an unfractured "buffer zone" of roughly 2 feet in depth should remain in the clay immediately above the sandstone bedrock, to prevent creating new fractures in the clay that could provide direct pathways for downward movement of NAPLs (if present) from the clay into the bedrock. The VOC removal efficiency of the MPE system in this unfractured layer within the clay would be much lower than the removal efficiency within the fractured clay. The significance of this limitation of pneumatic fracturing would depend on the VOC source mass that exists in the lower portion of the clay, which is not known.

The small unused "outbuildings" on the eastern side of Building I-1-3 (Figure 6-8) are scheduled to be demolished before the end of 2004, down to the concrete foundations This would facilitate access for application of the MPE system and the pneumatic fracturing enhancement over the full source area treatment zone (within the 10 mg/kg VOC contour), after further demolition and removal of the concrete foundations during the groundwater remedial action.

Cost

Supporting details for the Alternative A cost estimates are included in Appendix A. The estimates include the cost for installation and sampling of two monitoring wells that would be screened in the sandstone bedrock. The locations for these wells, which would be selected during the remedial design phase, would be downgradient of the Buildings I-1-2/I-1-3 source areas, along the groundwater flow path of the bedrock aquifer in the general vicinity of the Area 9 Buildings complex. The groundwater quality data obtained from sampling these new wells would be used to verify that the Lower Clay unit which is present in the source areas has restricted the impact of VOCs on the bedrock groundwater quality. The same costs for installation and sampling of the two bedrock monitoring wells are included in the estimates for all of the remedial alternatives for the Buildings I-1-2/I-1-3 source areas. A summary of the costs for Alternative A is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$1,935,000
Total OM&M* cost – Years 1-30	$1,828,000
Total present value for 30 years	$3,257,000

* Operation, maintenance, monitoring, and periodic costs

8.3.2 Alternative B – Permeable Reactive Barrier

Effectiveness

The comments regarding the general effectiveness of a PRB for *in situ* treatment of VOCs in groundwater included above for Building I-1-23/Alternative B are also applicable to the use of a PRB for the Buildings I-1-2/I-1-3 source area.

The use of a PRB to intercept and destroy VOCs would result in substantial improvement in groundwater quality over time throughout the plume downgradient of the PRB. This is shown in the groundwater modeling simulations presented in Section 7. The modeling simulations also show that effective performance of the PRB would likely be required for up to several centuries, to prevent additional dissolved VOC mass originating from the VOC residuals remaining in the source area from re-establishing the VOC plume downgradient from the source area. Therefore, the effectiveness of the remedial action under Alternative B will be achieved only as long as the PRB continues to provide effective treatment of the VOCs. This remediation objective would require periodic efforts to maintain the hydraulic as well as the treatment performance of the PRB using field techniques and equipment that are currently unproven, or periodic complete removal and replacement of the PRB, which would be highly costly and would pose significant construction challenges. Therefore, the long-term effectiveness of a PRB for the Buildings I-1-2/I-1-3 source area is uncertain.

Because this alternative does not include a component for remediation of VOC sources, the VOCs remaining in the source areas would remain in their present conditions. Although the PRB would be relatively effective in destroying the dissolved VOC mass in the plume downgradient of the source area at least during the functional lifetime of the original PRB (estimated to be approximately 20 years for cost estimating), the PRB would be ineffective in reducing the overall time required for all of the VOC source mass to be removed by natural attenuation processes.

As with any selected alternative, the remedial action workplan prepared to implement Alternative B would specify contingency measures that would be implemented if the actual results of a PRB did not meet the performance expectations. For the Buildings I-1-2/I-1-3 source area, excavation of additional VOC source material within the clay soil could be a component of the specified contingency measures.

Implementability

Installation of a PRB across the width of the VOC plume to the west of the source area is expected to be constructible. The trenching depth (average of 27.5 to 35 feet) would be within the depth range achievable using conventional equipment. The thickness of the Upper Sand at the PRB location (7.5 feet average) would make placement of the ZVI and sand mixture easier to accomplish, compared with the difficulties expected with installing a PRB at the Building I-1-23 area. However, the same general difficulties associated with PRB construction as described above for Building I-1-23/Alternative B are also applicable to the use of a PRB for the Buildings I-1-2/I-1-3 source area. Drawings showing existing buried utilities in the general area of construction of a PRB were reviewed. It is likely that some existing utility lines would have to be permanently relocated to accommodate construction of a PRB. This is not expected to present difficulties that would prevent installation of a PRB, although coordination of the design and construction of the PRB with GDOTS would be required to prevent interference with manufacturing operations.

Cost

Supporting details for the Alternative B cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$1,783,000
Total OM&M* cost – Years 1-30	$5,277,000**
Total present value for 30 years	$4,692,000

* Operation, maintenance, monitoring, and periodic costs.

** Includes PRB replacement in year 20.

8.3.3 Alternative C – Alternate Concentration Limits

Effectiveness

There is no "active" remediation component of Alternative C. Therefore, this alternative provides no more effectiveness than the No Action alternative.

Implementability

As described in Section 6, the ACL applicability criteria are met for the plume from the Buildings I-1-2/I-1-3 source area. USEPA has included the use of ACLs as a component of the selected remedial action at several other sites. Therefore, the use of ACLs for groundwater quality is expected to be implementable and appropriate for the conditions associated with the Buildings I-1-2/I-1-3 source area and plume.

Cost

Supporting details for the Alternative C cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$77,000
Total OM&M* cost – Years 1-30	$1,745,000
Total present value for 30 years	$1,237,000

* Operation, maintenance, monitoring, and periodic costs

8.3.4 Alternative D – Excavation (within 10 mg/kg VOC contour) and Alternate Concentration Limits

Effectiveness

Although this alternative includes removal of significantly more VOC mass by excavation than under Alternative A, the VOC mass expected to be removed under this alternative compared with the total VOC mass present in the source areas at Buildings I-1-2/I-1-3 would be minimal. There would also be little, if any, expected improvement in groundwater quality over time resulting from the soil excavation, although the overall time required for the VOC source area to completely attenuate by natural processes would be slightly reduced.

Implementability

Soil excavation to remove VOCs as defined under this alternative is expected to be implementable. Only a few buried utilities in the excavation areas may require temporary interruption or relocation.

As noted above for Alternative C, the use of groundwater ACLs is expected to be implementable and appropriate for the conditions associated with the Buildings I-1-2/I-1-3 source area and plume.

Cost

Supporting details for the Alternative D cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$902,000
Total OM&M* cost – Years 1-30	$1,745,000
Total present value for 30 years	$2,062,000

* Operation, maintenance, monitoring, and periodic costs

8.3.5 Alternative E – Excavation (within 10 mg/kg VOC contour), *In Situ* Reductive Dechlorination with Pneumatic Fracturing, and Alternate Concentration Limits

Effectiveness

To effectively stimulate *in situ* biological degradation of VOCs at the Buildings I-1-2/I-1-3 area, it is necessary to effectively distribute a substrate liquid in the clay soil in proximity to the VOC residual mass. The use of pneumatic fracturing of the clay prior to substrate injection is expected to be capable of substantially enhancing the ability to saturate the source zone soil with substrate solution.

As with any *in situ* remediation technology, making a quantitative estimate of the VOC destruction effectiveness of the reductive dechlorination component of this alternative is very difficult, at best, and likely impractical. However, as noted above for Building I-1-23/Alternative F, on a comparative basis, *in situ* biological reductive dechlorination is expected to be moderately to highly effective in destroying VOC source mass.

As described in Section 6, a type of bio-substrate would be selected that is a long-lasting electron-donor source for maintaining active biodegradation of the VOCs. Single injection "events" of similar substrates at other sites are reported to have resulted in substantial biodegradation rates of VOCs for up to 2 to 3 years after the injection. With the relatively low groundwater flowrates in the Buildings I-1-2/I-1-3 source area, and the large unit-volume amount of substrate liquid that is expected to be injected with the pneumatic fracturing enhancement and also placed in bulk form into the soil excavations, a single injection event at the source area should stimulate active biodegradation of VOC source mass for up to a few years.

The groundwater chemistry data collected for the Buildings I-1-2/I-1-3 source areas and plume indicate that reductive dechlorination is occurring, and the primary factor limiting the effectiveness of reductive dechlorination is likely to be insufficient electron donor substances. In addition, the data show that TCE breakdown products are not accumulating in the plume, which indicates that the conditions and microorganisms needed to complete the breakdown process for the TCE and PCE source mass are present. For the modeling simulations presented in Section 7, it was conservatively estimated that 50% of the original

VOC source mass would be removed from the Upper Clay and the Lower Clay units by reductive dechlorination.

Documented experience from other sites where full-scale pneumatic fracturing has been used shows that the enlarged soil apertures induced by pneumatic fracturing are expected to remain open for several months or longer, thereby allowing additional substrate injection events to be performed, if necessary, without the need to repeat the pneumatic fracturing enhancement.

Although pneumatic fracturing and substrate injection are expected to be implementable at the Buildings I-1-2/I-1-3 source area, USEPA has determined (USEPA, 2004) that prior to the design and construction phases, these technologies must initially be applied to a demonstration or pilot test zone at one of the source zones, rather than committing to full-scale application of the fracturing/injection process throughout the entire source area. This would allow the actual feasibility and effectiveness of the equipment and methods to be monitored and assessed during a demonstration period (estimated duration of 6 to 12 months), and the knowledge gained would be applied during subsequent use of the fracturing/injection processes at the remainder of the VOC source area. The monitoring program developed during the remedial design phase would include relatively frequent and comprehensive monitoring of groundwater parameters during the initial demonstration or pilot test period, after the initial placement of substrate into the source zone soil, to confirm that the expected performance results were being obtained. As with any selected alternative, the remedial action workplan for Alternative E may specify contingency measures that could be implemented if the actual results of enhanced reductive dechlorination did not meet the performance expectations.

The comments regarding the general effectiveness of soil excavation included above under Alternative D also apply to the excavation component of Alternative E, because this component of the remedial action would be the same under both alternatives.

Implementability

The conceptual design for applying pneumatic fracturing of the clay, prior to injection of the bio-substrate liquid, is the same conceptual design as would be used for pneumatic fracturing prior to the use of an MPE system, as described above under Alternative A. Based on a site-specific quotation from, and discussions with, a company that specializes in pneumatic fracturing, the physical conditions at Buildings I-1-2/I-1-3 are expected to yield effective pneumatic fracturing results.

At several other sites, substrate liquid is reported to have been successfully injected through boreholes or wells directly into relatively tight soil types, with positive biodegradation results. Although no documented cases could be found where pneumatic fracturing has been used to enhance the effectiveness of bio-substrate injection, the injection of numerous types of fluids into various types of soil for remediation purposes without enhancement by pneumatic fracturing is well-proven and documented. Therefore, it is expected that the significant increase in soil permeability created by pneumatic fracturing will make injection of substrate liquid into the soil at Buildings I-1-2/I-1-3 readily implementable. The dilation of the existing natural and secondary porosity in the clay caused by fracturing should allow a significant amount of substrate liquid, on a unit-volume basis, to be injected into the soil throughout the area and depth of the primary VOC source zones, without displacing significant quantities of groundwater or VOC residuals.

Cost

Supporting details for the Alternative E cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$1,753,000
Total OM&M* cost – Years 1-30	$1,861,000
Total present value for 30 years	$3,084,000

* Operation, maintenance, monitoring, and periodic costs

8.3.6 Alternative F – Electrical Resistive Heating (within 10 mg/kg VOC contour) and Groundwater Monitoring

Effectiveness

Several of the comments included above for Building I-1-23, Alternative F, apply to the effectiveness criterion for this Alternative G for the Buildings I-1-2/I-1-3 source areas. For the modeling simulations of this alternative presented in Section 7, an overall VOC source mass removal efficiency of 90% was assumed, within the targeted ERH treatment zone defined by the approximate 10 mg/kg total VOC contour at both of the source areas. As discussed above, this is believed to be a reasonable estimated performance level for this technology, given the current uncertainties regarding full-scale use of ERH over these relatively large source areas. In addition, as with use of MPE technology for these source areas (Alternative A), an untreated "buffer zone" is likely to be required in the Lower Clay immediately above the sandstone bedrock, to minimize the potential for downward movement of VOCs from the clay into the bedrock during application of ERH.

Implementability

After reviewing information provided by RMT describing the conditions at Buildings I-1-2/I-1-3, an ERH vendor determined that use of ERH to remove VOCs under this alternative is expected to be implementable. However, engineering controls are likely to be required to protect existing buried utilities and prevent migration of VOC-laden steam and vapors from the treatment area through existing utility line corridors or other subsurface pathways within or near the treatment zones. The ERH vendors also report that other potential safety concerns associated with use of ERH, such as steam venting from existing wells, exposure of remediation workers, site employees, or others to very hot water or steam, and electricity arcing or other electrocution hazards, have been fully addressed in their current designs.

GDOTS currently leases Buildings I-1-2 and I-1-3 from the U.S. Department of the Interior. The buildings are currently used for storage and warehousing of "energetics" (explosives) and primers used in production of military ammunition of various calibers that occurs in other Area 9 buildings. Building I-1-1, which adjoins Building I-1-2 to the south, is also currently leased by GDOTS and used for warehousing of finished military ammunition.

As noted above, a meeting was held with representatives of GDOTS, F&WS, USEPA, IEPA, and RMT on 4 March 2004 at the GDOTS office at the Area 9 building complex. The purpose of the meeting was to present an overview of the types of equipment and operating conditions expected to be used to apply the ERH technology for remediation of the VOC source zones adjacent to Buildings I-1-23, I-1-2, and I-1-3, if ERH was the selected remedial alternative for any of these areas. At the conclusion of that meeting, the GDOTS representatives indicated the following:

- They do not believe there should be any insurmountable problems preventing consideration of ERH as a remedial alternative for the VOC source areas adjacent to Buildings I-1-2 and I-1-3.

- They would prefer selection of a different technology or alternative for these VOC source areas if feasible.
- Their primary concerns regarding use of ERH adjacent to Buildings I-1-2 and I-1-3 are:
  - Potential exposure of their employees working near the treatment zones, particularly inside the buildings, to VOC vapors that may not be captured by the ERH system and may migrate beneath and into the buildings.
  - Potential detrimental effects of stray voltage from the ERH system on the sensitive instrumentation and controls associated with their production operations in various buildings within the Area 9 complex. The GDOTS representatives stated that any adverse effects on the instrumentation or controls could result in potentially significant financial losses due to compromised quality control documentation or other physical effects on their products. The GDOTS representatives expressed a need to fully understand the actual and potential "electric field effects" of the high applied voltages used with ERH, to allow them to make their own assessment of potential adverse impacts on their operations or safety of their personnel.
  - Safety hazards associated with the presence of "energetics" stored inside the buildings. GDOTS indicated they would prefer to temporarily relocate these stored materials away from the eastern building walls, particularly in Building I-1-2, where the explosives are currently stored within a few feet from the exterior building wall and within roughly 10 feet of the potential locations of the high-voltage ERH electrodes. However, GDOTS noted that the feasibility of moving these materials would require further evaluation by their production and safety management personnel, and would require advance planning and coordination to avoid undesirable impacts on their production operations.

As discussed in Subsection 8.2.8 (Alternative G, Building I-1-23 area), the liabilities associated with safety issues and potential effects on GDOTS production operations would be the responsibility of the primary ERH vendor that would be selected for the work. The overall implementability of Alternative F would be dependent on the ability to secure appropriate contractual terms with the ERH vendor in which the vendor would agree to accept those liabilities, without unacceptable increases in overall cost. The technologies included in other alternatives for the Building I-1-2/I-1-3 areas would also require some level of liability acceptance on the part of other technology vendors or contractors. However, the unique uncertainties associated with use of ERH at Buildings I-1-2/I-1-3 due to the relative newness of the technology and the concerns raised by GDOTS make the issue of liability acceptance by the vendor a key factor in determining the implementability of Alternative F.

GDOTS also indicated that the small unused "outbuildings" on the eastern side of Building I-1-3 (Figure 6-11) are scheduled to be demolished before the end of 2004, down to the concrete foundations This would facilitate access for application of ERH over the full source area treatment zone (within the 10 mg/kg VOC contour), after further demolition and removal of the concrete foundations during the groundwater remedial action.

As described for Alternative G (use of ERH) at the Building I-1-23 area, a demonstration or pilot test using ERH in a smaller, well-defined zone within the overall source area would be required during the pre-design phase, prior to full-scale use of ERH over the entire source area. The pilot test would be needed to confirm design criteria for the full-scale system, to confirm achievable VOC removal effectiveness, and to demonstrate that full-scale installation and operation of the system would not result in any problems with safety, spreading of VOC contamination, adverse effects on the GDOTS production operations, etc. The pilot test would lengthen the overall time required for active ERH treatment at the Buildings I-1-2/I-1-3 areas, from approximately one year (if both areas were treated concurrently) to up to 2 years or more through completion of the treatment and demobilization/site restoration stages of the combined Buildings I-1-2/I-1-3 source area.

Due to the extent of the subsurface electrode, drip-wetting, and vapor extraction systems required, the design and full-scale operational control of the ERH system are expected to be challenging. A high voltage electrical source (estimated 12.4 or 13.8 kV, 2,535 kW with a power supply rating of 2,500 kW) would be required for these source areas (not including the Building I-1-23 area). This would require installing a new, potentially temporary, electrical supply line to the Buildings I-1-2/I-1-3 area from an undetermined location/distance. Indoor air monitoring in Buildings I-1-2, I-1-3, and possibly adjacent buildings would also be required at least during the "heating phase" of the ERH process, for comparison of the air quality with the OSHA criteria for occupational exposure.

A limitation of using ERH within the clay in these VOC source areas is that an untreated "buffer zone" of roughly 2 feet in depth should remain in the Lower Clay immediately above the sandstone bedrock, to minimize the potential to create direct pathways for downward movement of NAPLs (if present) from the clay into the bedrock, particularly during the initial heating period of the soil, as the viscosity and other NAPL properties are altered before the soil temperatures reach the vapor point of the VOCs. The VOC removal efficiency of the ERH systems in this buffer zone would be much lower than the removal efficiency within the fully heated treatment zone. The significance of this limitation of ERH would depend on the VOC source mass that exists in the lower portion of the clay, which is not known.

Cost

Supporting details for the Alternative F cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$3,030,000
Total OM&M* cost – Years 1-30	$1,384,000
Total present value for 30 years	$3,930,000

* Operation, maintenance, monitoring, and periodic costs

8.4 Area 9 Repository Source Area and Plume

8.4.1 Alternative A – Phytoremediation and Monitored Natural Attenuation

Effectiveness

As described in Section 6, the existing natural attenuation processes occurring beneath and adjacent to the Repository are effective in containing and degrading VOCs in the soil and groundwater that flows through the VOC source zones beneath the Repository, and in degrading the VOCs in the plumes that originate in the vicinity of Building I-1-36A and on the south side of the Repository. The VOC plumes that originate from these three areas (beneath the Repository, near Building I-1-36A, and on the south side of the Repository) all merge on the southern and eastern sides of the Repository, and then flow to the east where the merged plumes emerge as surface water in the East Swale, which flows into Crab Orchard Lake. Detailed information describing the nature and extent of the VOC plume associated with the Repository is included in the Preliminary Design Report – Revision 0 (RMT, 2001d), pages 5-4 to 5-6.

The physical conditions between the Repository and the East Swale into which the groundwater plume discharges are very conducive to use of phytoremediation in this area, as included in this alternative. The plantings of trees and prairie grasses in this area are expected to effectively intercept and remove the low concentrations of dissolved VOCs that may occasionally be present where the shallow groundwater discharges into the drainage swale.

Implementability

The phytoremediation and MNA components of this alternative are readily implementable. The preliminary design for the phytoremediation component of this alternative is shown on Figure 6-10.

Cost

Supporting details for the Alternative A cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$199,000
Total OM&M* cost – Years 1-30	$1,655,000
Total present value for 30 years	$1,322,000

* Operation, maintenance, monitoring, and periodic costs

8.4.2 Alternative B – Phytoremediation and Alternate Concentration Limits

Effectiveness

The discussion included above under Alternative A regarding the effectiveness of phytoremediation also applies to Alternative B, because this component of the remedial action would be the same under both alternatives.

Implementability

The phytoremediation component of Alternative B (tree and prairie grass plantings) is expected to effectively eliminate the low-concentration, intermittent VOC impacts that have been observed in surface water in the East and Center Swales. When these conditions have been achieved, all of the applicability criteria for the use of Alternate Concentration Limits (ACLs) associated with the Repository plume will be met. The use of groundwater ACLs has been included in Decision Documents prepared by USEPA – Region 5 for several other CERCLA sites where USEPA determined that the applicability criteria were met. Therefore, the component of Alternative B that provides for use of ACLs for groundwater quality (in lieu of use of MNA under Alternative A) is expected to be implementable and appropriate for the conditions at this site.

Cost

Supporting details for the Alternative B cost estimates are included in Appendix A. A summary of the costs is as follows (all costs in 2004 dollars):

DESCRIPTION	COST
Capital cost	$175,000
Total OM&M* cost – Years 1-30	$1,534,000
Total present value for 30 years	$1,210,000

* Operation, maintenance, monitoring, and periodic costs

Section 9
Comparative Analysis of Alternatives

9.1 Introduction

This section presents an evaluation of the relative performance of each alternative. The purpose of this comparative analysis is to identify the key advantages and disadvantages of each alternative relative to the other alternatives, so that the key tradeoffs can be identified and balanced by the decision-makers. The alternatives are discussed relative to one another, and with respect to each of nine specific criteria.

Overall protection of human health and the environment (Criterion 1) and compliance with Applicable or Relevant and Appropriate Requirements (ARARs) (Criterion 2) will generally serve as threshold determinations in that they must be met by any alternative in order for it to be eligible for selection. The next five criteria, long-term effectiveness and permanence (Criterion 3); reduction of toxicity, mobility, and volume through treatment (Criterion 4); short-term effectiveness (Criterion 5); implementability (Criterion 6); and cost (Criterion 7) represent "balancing" criteria that will be discussed with regard to tradeoffs among the alternatives. State acceptance (Criterion 8) and community acceptance (Criterion 9) are typically evaluated following comment on an RI/FS report and Proposed Plan, and are addressed when a final decision is being made regarding the selected remedial action and a Record of Decision (ROD) or other form of Decision Document is being prepared. For this feasibility study and selection-of-remedy process for Sites 32/33, the state and community acceptance criteria will be addressed after USEPA (the lead agency) has made a preliminary selection of preferred remedial alternatives.

Generally, alternatives are discussed from highest to lowest rankings with respect to each criterion.

9.2 Overall Protection of Human Health and the Environment

9.2.1 General Comments

The findings of the risk evaluation performed as part of the remedial investigation for the PCBOU (O'Brien & Gere, 1988) were that "...the groundwater exposure pathway is incomplete at the Area 9 Landfill...," and that "...the groundwater exposure pathway is incomplete because there are no exposed users of groundwater at the Area 9 Building Complex."

The Record of Decision (ROD) for the PCB Areas Operable Unit (effective date August 1, 1990) states (Section IX): "The Selected Remedy also addresses the threat from surface water and groundwater by removing the material that could contaminate the water." The ROD further states (Section X): "The Selected Remedy…is protective of human health and the environment for the four study sites comprising the PCB Areas Operable Unit."

Concentrations of VOCs well above the Cleanup Standards (MCLs and MCLGs) had been identified in groundwater at the site in the original Remedial Investigation Report (O'Brien & Gere, 1988). However, as stated in the ROD (Section VI), "Although contaminants were found in other media (groundwater and surface water) at the study sites comprising this operable unit, the risk assessment does not indicate that these contaminants currently pose a threat to human health and/or the environment," primarily because there was at that time, and continues to be, no use of site groundwater as a drinking water supply.

Although the ROD, in a discussion of Site 33, Area 9 Building Complex, reported that TCE groundwater contamination was detected in one well at 906 µg/L, the ROD did not require groundwater remediation per se. The ROD - Scope of Work, Section III. B. states "If, at any time following completion of the remedy, groundwater at a remediated study site exceeds any of the stated cleanup standards, the need for additional remedial work, as contemplated by Section VII of the Decree, shall be evaluated." As USEPA noted in its ROD Responsiveness Summary for the PCB Areas, Response #69, at paragraph c.,

> *In the preamble to the revised NCP, U.S. EPA's approach to groundwater remediation is discussed. The preamble states 'The goal of EPA's Superfund approach is to return usable ground waters to their beneficial uses within a time frame that is reasonable given the particular circumstances at the site.' The RI Report indicated that there was groundwater contamination associated with the PCB Areas operable unit, but did not document risks from groundwater. U.S. EPA believes that the removal of sources of contamination will control any potential groundwater problems. However, if monitoring activities during and after remediation indicate that there is potential risk from the groundwater, additional remediation activities will be considered.*
>
> *Since a remedy other than source control was not selected for groundwater, the 10^{-6} excess cancer risk target level discussed in the Proposed Plan and selected*

> *in this ROD will not necessarily be a cleanup level but will trigger a review of conditions at the sites.*

The response continues to state that if the standards specified in the ROD are exceeded, the groundwater situation will be evaluated to determine if further remedial action is necessary. Response #69 concludes with the statement that the risk calculations for groundwater will reflect realistic and site-specific exposure scenarios.

During the PCB remedial action at Sites 32/33, three PCB source areas (former Area 9 Landfill, Building I-1-23, Building I-1-2) that were suspected of potentially contributing to VOC contamination of groundwater and surface water were further characterized. During that additional sampling, groundwater contamination by volatile organic compounds was detected.

The ROD – Scope of Work, Section III. B., Cleanup Standards, requires groundwater monitoring before, during, and after soil remediation. The monitoring results are to be evaluated to determine if they exceed any excess human health risk or any standard, i.e., whether the contaminants in groundwater exceed a cumulative, excess lifetime cancer risk greater than 1×10^{-6} or exceed any Maximum Contaminant Level (MCL) for drinking water. USEPA has determined (Fulghum, 1999) that, since MCLs are known to be exceeded in groundwater at the site, it is not necessary to perform a risk assessment to determine the cumulative, lifetime cancer risk prior to selection of the remedial action for groundwater.

Prior to the remedial action for PCBs in 1996, a Supplemental Investigation was performed to determine the presence, nature, and concentrations of contaminants (other than cadmium, lead, and PCBs) that would remain in the untreated soil and sediment that met the criteria as "backfill" material. The results of that Supplemental Investigation formed the basis of a Final Effective Risk Assessment (FERA) (IT Corp., 1995) completed in 1995. The FERA demonstrated that compliance with the soil and surface water remediation goals was expected to be achieved after completion of the work defined in the remedial design documents. However, the FERA was completed prior to F&WS's request that soil and sediment with PCB levels < 25 mg/kg from the various PCBOU remediation sites be consolidated in an Area 9 "Repository" instead of being left in place or used as backfill per the plan described in the ROD. USEPA has determined that the FERA must eventually be revised to account for the consolidation of the excavated PCB soil and sediment at the Area 9 Repository, and to address the presence of VOC contamination. USEPA has also stated that because "groundwater contamination exceeds MCLs, the Consent Decree, the ROD, and the Scope of Work allow USEPA to determine the need for additional work without first conducting a risk assessment. Also, the FERA is intended to assess post-remediation conditions to assure *[sic]* that cleanup goals are met. Therefore, the appropriate time to revise the 1995 FERA is after source removal is complete" (Fulghum, 1999).

In accordance with the original ROD and subsequent determinations by USEPA, a demonstration that the final site conditions, including VOC levels that may remain in various media at the site, meet the protectiveness levels specified in the Cleanup Standards will be prepared after completion of the remedial action for groundwater that will be selected by USEPA based on the results of this Focused FS Report – Rev. 3.

9.2.2 Building I-1-23 Source Area and Plume

All of the alternatives, except Alternative E, provide removal of a portion of the VOC mass present in the source area. This increases the general level of protectiveness, primarily by reducing the potential for contact (dermal or inhalation) with VOCs during potential future construction-related excavations in the area. All of the alternatives, except Alternative E, also enhance protection of human health and the environment by providing removal and/or *in situ* destruction of VOCs in groundwater and soil at the source area, and long-term improvement in groundwater quality downgradient of the VOC source area. The use of an "enhanced" design for the phytoremediation component of Alternatives D, E, and F (engineered wetland in the lake embayment) also provides a greater and more rapid degree of protectiveness than Alternatives A, B, C, and G by removing the current VOC impacts on shallow lake water caused by discharge of the VOC plume.

A quantitative assessment of the projected increased protectiveness provided by all alternatives would be difficult to make, and as noted above, is not necessary to allow a groundwater remedial action to be selected by USEPA.

9.2.3 Buildings I-1-2/I-1-3 Source Area and Plume

All of the alternatives, except Alternative C, provide removal and/or *in situ* destruction of VOCs, thereby increasing the current level of protectiveness of human health and the environment. Alternatives A, D, E, and F would improve long-term protectiveness primarily by reducing the potential for contact (dermal or inhalation) with VOCs during potential future construction-related excavations in the VOC source area by removing a portion of the existing VOC source mass. Alternatives B and C do not provide this potential improvement. However, if such future below-ground construction never occurs, this slight benefit of Alternatives A, D, E, and F would not be realized.

Alternatives A, D, E, and F would provide a somewhat greater long-term incremental improvement in overall protectiveness than Alternatives B and C through removal of a greater amount of VOC source mass, with a resulting reduction in the time required for full restoration of groundwater quality by natural attenuation processes following the remedial construction phase.

9.2.4 Area 9 Repository Source Area and Plume

The VOCs at this source area are present in native, undisturbed soil beneath approximately 20 feet of fill materials that comprise the Repository. The Repository effectively functions as a clay cover that precludes potential future human exposures to the VOC source material because of the impracticality of potential future construction activities within the VOC-impacted soil. Alternatives A and B both enhance overall protectiveness by long-term improvement in groundwater quality in the limited VOC plume area outside of the Repository footprint, through phytoremediation and natural attenuation.

9.3 Compliance with ARARs

The remedial alternatives developed for groundwater at Sites 32/33 must be consistent with the ARARs specified in the ROD for the PCBOU. The ARARs that would be pertinent to one or more of the remedial alternatives for groundwater at Sites 32/33 are identified in the following direct excerpt from the ROD (pages 40 to 45):

1. <u>*Surface Water Discharge*</u>

   Clean Water Act

   - *If pond or stream water from Site 17 or stream or ditch water from Area 9 (Sites 32 and 33) must be discharged to a surface water body during site preparation, the discharge shall meet the effluent standards and prohibitions and water quality standards established under Sections 301, 302, 303, 307, 318, and 405 of the Clean Water Act (40 CFR 122.41 and 122.44).*

2. <u>*Excavation of Soil and Sediment*</u>

   Resource Conservation and Recovery Act, Subtitle C

   - *Excavated material which is RCRA hazardous will be handled and stored in accordance with the substantive technical standards applicable to generators of hazardous waste and for owners and operators of hazardous waste storage facilities (40 CFR 262.34; and 264, Subparts B, C, I, J, and L).*

- *Excavated material which is RCRA hazardous will be handled and stored in accordance with the land disposal restrictions (40 CFR 268).*
- *The excavation activities, when completed, shall meet the closure performance standards for clean closure (40 CFR 264, Subpart G) for the specific hazardous waste constituents.*
- *The excavation and storage activities must also meet any more stringent State of Illinois equivalent provisions (35 IAC Part 724 design requirements).*

Toxic Substances Control Act

- *Excavated material which contains PCBs at concentrations greater than 50 parts per million will be handled and stored in accordance with the requirements of 40 CFR 761.65.*

Clean Air Act

- *During excavation the national ambient air quality standards (NAAQS) for particulate matter and lead shall not be exceeded (40 CFR 50.6 and 50.12).*

3. *Incineration of Soil and Sediment*

[not pertinent to groundwater remedial action]

4. *Vitrification*

[not pertinent to groundwater remedial action]

5. *Stabilization/Fixation*

[not pertinent to groundwater remedial action]

6. *Disposal or Decontamination of Equipment*

Resource Conservation and Recovery Act, Subtitle C

- *During remediation and closure all equipment, structures, and soils that are used on/with RCRA hazardous materials must be properly decontaminated or disposed of (40 CFR 264.114).*
- *Decontamination of equipment, structures, and soils that are used on/with RCRA hazardous materials must meet any more stringent regulatory decontamination or disposal standards of the State of Illinois (35 IAC Part 724).*

Toxic Substances Control Act

- *During remediation and closure all equipment, structures, and soils that are used on/with TSCA regulated PCB-contaminated soil and sediment must be properly decontaminated (40 CFR 761.79).*

7. <u>*Industrial Landfill or Caps*</u>

[not pertinent to groundwater remedial action]

8. <u>*Backfill Excavation*</u>

- *During backfilling activities the NAAQS for particulate matter shall not be exceeded (40 CFR 50.6).*

9. <u>*Monitoring and Maintenance*</u>

Resource Conservation and Recovery Act, Subtitle C

- *Groundwater monitoring for the remediated study sites shall be in accordance with the groundwater monitoring requirements of RCRA (40 CFR 264, Subpart F).*

Solid Waste Disposal Act as amended by RCRA Subtitle D

- *Groundwater and leachate monitoring for the on-site landfill shall be in accordance with the RCRA Subtitle D, solid waste landfill requirements (40 CFR 241.204).*
- *Groundwater and leachate monitoring for the on-site landfill will meet any more stringent technical regulations of the State of Illinois (35 IAC Part 807).*

10. <u>*Personnel Protection*</u>

Occupational Safety and Health Act (OSHA)

- *During all remedial activities the requirements of the Occupational Safety and Health Act for the training and safety of workers will be observed (29 CFR 1910.120 and 1926, Subparts C, D, E, and P).*

11. <u>*Remediation Goals*</u>

Crab Orchard Enabling Legislation (16 U.S.C. 666f and g)

National Wildlife Refuge Administration Act (16 U.S.C. 668dd)

Eagle Protection Act of 1940 (16 U.S.C. 668a)

Migratory Bird Treaty Act of 1918 (16 U.S.C. 703-711), as amended

- *The chemical specific remediation goals which have been established for the study sites comprising the PCB Areas, and any other that will be established for this operable unit, will be consistent with the statutory requirements cited above.*

For implementation of the Selected Remedy, U.S. EPA, DOI, and IEPA have agreed to consider a number of procedures as guidance. These include, but are not limited to: U.S. EPA's Risk Assessment Guidance for Superfund; U.S. EPA's Superfund Remedial Design and Remedial Action Guidance; U.S. EPA's RCRA Technical Enforcement Guidance Document; U.S. EPA's proposed MCL for PCBs; any proposed revisions to U.S. EPA's design standards for RCRA Subtitle D landfills, which are available before remedial design; the State of Illinois Waste Management Facilities Design Criteria; and State of Illinois Monitoring Well Construction and Installation Criteria.

In addition to the ARARs specified in the ROD as cited above, IEPA has identified the chemical-specific and action-specific standards and regulations listed below that may be pertinent for consideration during evaluation of the remedial alternatives and selection of a preferred alternative for groundwater:

Chemical-specific State Standards and Regulations

- *35 IAC Part 620 - Groundwater Quality, Subpart D, Section 620.410, Class I -* Groundwater Standards [refer to Tables 6-5 through 6-8 in the Groundwater Investigation Report (RMT, 2000) for a listing of these numerical standards]
- *35 IAC Part 302, Subpart B - General Use Water Quality Standards, specifically Part 302.208* - Numeric Standards for Chemical Constituents, and Part 302.1210 - Other Toxic Substances (refer to Table 6-12 in the Groundwater Investigation Report for a listing of these numerical standards, as excerpted from the referenced regulations and as calculated for Crab Orchard Lake by IEPA Bureau of Water)

Potential Action-specific State Regulations

- *35 IAC Subtitle B - Air Pollution, Part 201* - Substantive permitting requirements under Parts 201.141, .143, .152-.165, .207-.210, .261-.265, .282-.283, .310-.312 for construction or modification of an emission source.
- *35 IAC Part 304, Subpart A - General Effluent Standards, specifically Parts 304.102 and 304.105-.141* - For discharges to waters of the state.
- *35 IAC Part 305 - Monitoring and Reporting, specifically Parts 305.102 -.103* - For discharges to waters of the state.
- *35 IAC Part 306, Subpart A* - Systems Reliability, specifically Part 306.102

- *35 IAC Part 309, Subpart A - NPDES Permits* - Substantive requirements pertinent to construction and operation of contaminated groundwater treatment or pretreatment works and to point source discharges to waters of the state on all CERCLA sites.
- *35 IAC Part 704 - UIC Permit Program; 35 IAC Part 730 - Underground Injection Control Operating Requirements* - Substantive permitting requirements for underground injection of hazardous liquids (Class IV UIC well) or non-hazardous fluid (Class V UIC well). Injection of contaminated fluid into underground sources of drinking water in excess of any primary drinking water regulations is prohibited. 35 IAC Part 704.124(c) exempts Class IV wells (hazardous) from this prohibition on RCRA and CERCLA sites; however, no exemption exists for Class V wells.
- *35 IAC Part 722 - Standards Applicable to Generators of Hazardous Waste* - If solid waste (defined per 35 IAC Part 721.102) is generated, the generator must determine if that waste is a hazardous waste.
- *35 IAC Subtitle G - Waste Disposal, specifically Parts 724 and 728* - If hazardous waste is present on a site, pertinent requirements of hazardous waste treatment, storage, and disposal under 35 IAC Subtitle G (Waste Disposal) must be followed.
- *35 IAC Part 808 - Special Waste Classifications* - Generators of a waste must classify the waste. A special waste (defined per Section 3.45 of Illinois Environmental Protection Act) determination is required under 35 IAC Part 808.12. Management of special waste must be in accordance with 35 IAC Subtitle G (Waste Disposal), including 35 IAC Part 809 (Special Waste Hauling) and 35 IAC Part 810 (Solid Waste Disposal).

Since the naturally occurring discharge of groundwater to surface water (drainage swales, marshes, and the lake) is the source of VOCs that have been observed in surface water at the site, the destruction, removal, or containment of VOC source material remaining in soil at the identified source areas, as provided with several of the alternatives, is expected to result in some reduction in VOC concentrations observed in surface water over time. The amount and rate of reduction in surface water VOC concentrations at the groundwater/surface water interface for the remedial alternatives are expected to be proportionately comparable to the reductions in groundwater VOC concentrations over time as projected by the computer model simulations discussed in Section 7. Several of the alternatives include phytoremediation to provide either a "polishing" or "enhanced" level of treatment of shallow groundwater to remove VOCs before the groundwater discharges to surface water drainage features or to the lake. These measures are expected to assist in achieving consistent compliance with surface water quality standards more rapidly than the remedial alternatives that do not include a phytoremediation component.

As determined from the modeling simulations discussed in Section 7, the time required to attain the target Cleanup Standards for groundwater over all or even portions of Sites 32/33 will be lengthy for any of the remedial alternatives. However, significant improvements in groundwater quality would be expected to occur over much shorter time periods.

This criterion is not considered to be a significant impediment or discriminating factor in the comparative analysis of the alternatives.

In addition to the ROD-specified ARARs and the IEPA standards and regulations listed above, the remedial alternatives selected for the groundwater VOC source areas must address the Cleanup Standards for groundwater. Those Cleanup Standards, excerpted directly from the Consent Decree Scope of Work, are as follows:

> *Before soil remediation begins, the groundwater at the study sites comprising the PCB Areas Operable Unit will be monitored to establish current concentrations of site-related contaminants. Groundwater at the remediated study sites, and groundwater and leachate at the containment unit will then be monitored during and after remediation of the sites. The monitoring results will be evaluated to see if any of the following levels of contaminants above naturally occurring background levels has* [have] *been exceeded in groundwater:*
>
> 1. *any MCL or non-zero MCLG for carcinogens*
> 2. *a cumulative, excess life-time cancer risk greater than 1.0 x* 10^{-6}*; or*
> 3. *any MCL, non-zero MCLG, or a hazard index of 1.0, for noncarcinogens.*
>
> *If, at any time following completion of the remedy, groundwater at a remediated study site exceeds any of the stated cleanup standards, the need for additional remedial work, as contemplated by Section VII of the Decree shall be evaluated. The risk assessment shall follow procedures established in the "Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual" (RAGS) (EPA/540/1-89/02) or any amendments thereof. All of the assumptions used in the risk assessment calculations shall be subject to the review and approval by U.S. EPA prior to their use.*

The groundwater modeling simulations included in Section 7 demonstrate that, even by applying the best available treatment technologies in various combinations, the time required to achieve the groundwater Cleanup Standards throughout the aquifer at Sites 32/33 is expected to be lengthy using any of the remedial alternatives. This same limitation of available technologies was recognized during the previous selection of multiphase extraction (MPE) for remediation of the VOC source areas, as described in the ESD (USEPA, 2000a). As stated in the ESD: "...U.S. EPA recognizes that restrictions upon groundwater use must be imposed and that it will be several decades before the TCE contamination is reduced to levels that meet the cleanup standards specified in the ROD. In fact, it may be technically impossible to achieve MCLs throughout the aquifer given the nature of the contaminants and the media in which they are present." The ESD also described an action plan whereby after the "active" portion of the remedial action using the MPE systems, "...U.S. EPA may seek a technical impracticality *[sic]* (TI) waiver, pursuant to CERCLA or seek an alternate groundwater standard pursuant to State of Illinois Groundwater Standards (35 IAC Part 620)....If the selected remedy is discontinued due to technical impracticality *[sic]* waiver, pursuant to CERCLA or if an alternative groundwater standard is sought pursuant to State of Illinois Groundwater Standards (35 IAC Part 620), an institutional control to prohibit use of this aquifer for drinking water purposes will be implemented until such time as the aquifer is restored to its beneficial use." As noted above, the same technical limitations in achieving the groundwater Cleanup Standards described in the ESD would occur with use of any of the remedial alternatives evaluated in this document. Therefore, consideration of a TI waiver, or alternative groundwater standards under 35 IAC Part 620, or Alternate Concentration Limits under CERCLA, for all or portions of Sites 32/33 may be appropriate at some time.

9.3.1 Building I-1-23 VOC Source Area

The remedial alternatives developed for this VOC source area present a wide range of capabilities for achieving the ARARs and Cleanup Standards for groundwater quality everywhere within the VOC source area and plume, over widely varying time periods. Given sufficient time, groundwater quality may eventually be restored to the Cleanup Standards under all of the remedial alternatives, with Alternative E requiring the longest time. Comparison of the alternatives with respect to the ARARs compliance criterion must therefore be considered primarily with respect to the estimated time frame required for each alternative to achieve the groundwater Cleanup Standards.

Alternatives A1, A2, and C are projected to provide comparable rates and levels of removal of the VOC plume. However, Alternatives A1 and C would maintain the groundwater quality improvements only with long-term groundwater extraction at the source area. Long-term groundwater extraction would not be necessary under Alternative A2. In addition, the groundwater quality within the overall source area would be restored more rapidly under Alternative A2 than for any of the other alternatives.

Alternatives F and G would provide comparable rates and levels of improvement in groundwater quality. Because Alternatives B and E do not include a source area remediation component, the groundwater quality in and somewhat downgradient of the source area would be the same as under no-action conditions, although a large portion of the downgradient plume would be gradually restored under Alternative B. The time required to achieve the Cleanup Standards under Alternative D would be lengthy; only Alternative E would require a longer time period.

Alternatives A1, A2, and C are expected to be capable of reducing the VOC concentrations in groundwater discharging into the lake so that the surface water quality will meet the Illinois general use water quality standards within a relatively short time (possibly less than 2 decades), and of maintaining compliance with the surface water quality standards over time. However, compliance with the surface water standards could be maintained under Alternatives A1 and C only if long-term groundwater extraction (for source containment) is provided. The short-term pumping option under Alternative A1 (for source removal) may be capable of eventually reducing the VOC plume concentrations sufficiently to allow the surface water VOC concentrations to continuously meet the water quality standards, but the time to achieve this is difficult to estimate and would be considerably longer than the time required if long-term groundwater extraction is used. The engineered wetland included in Alternatives D, E, and F will eliminate the surface water quality impacts due to the VOC plume as soon as the wetland vegetation is established. The rate and level of reduction in surface water quality impacts under Alternatives B and G would be comparable, requiring a few decades to eliminate VOC concentrations in the shallow groundwater near the discharge zone at the lake.

Other than the factor of the time required to achieve the groundwater and surface water standards, all of the alternatives are expected to be capable of complying with the ARARs specified in the ROD, and with the additional standards and regulations identified by IEPA.

9.3.2 Buildings I-1-2/I-1-3 Source Area

All of the alternatives are expected to be capable of complying with the ARARs specified in the ROD, and with the additional standards and regulations identified by IEPA as listed above, except for the factor of the time required to meet the groundwater quality standards. None of the alternatives developed for this VOC source area are expected to achieve the ARARs and Cleanup Standards for groundwater quality everywhere within the VOC source area and plume for many decades.

9.3.3 Area 9 Repository VOC Source Area

Alternatives A and B are both expected to be capable of complying with the ARARs specified in the ROD, and with the additional standards and regulations identified by IEPA as listed above, except for the factor of the time required to meet the groundwater quality standards. Compliance with the surface water quality standards will be enhanced by the phytoremediation that is included as a component of both alternatives.

9.4 Long-term Effectiveness and Permanence

The assessment of alternatives against this criterion evaluates the comparative long-term effectiveness of the alternatives in improving the current level of protection of human health and the environment.

The ESD (USEPA, 2000a) stated that the effectiveness of the MPE systems at the separate VOC source areas was to be evaluated based on the following factors:

- A comparison of the total mass of contaminants removed against time of operation, or
- A comparison of the reduction in contaminant levels (i.e., VOC concentrations in extracted soil pore gas and groundwater) against time of operation.

The evaluation criteria listed above were developed specifically for the primary technology selected in the ESD to be applied at each source area (MPE), based on the site characterization data available at that time. These two criteria were intended primarily to assess the effectiveness of MPE system operation only by monitoring changes in cumulative VOC mass removal and VOC concentrations over time. When the rate of the changes reached an "asymptotic" level, the MPE systems would be considered to have reached the limits of their remediation effectiveness.

Since the time of the ESD, a substantial amount of additional information has been obtained regarding the extent and mass of VOCs present at the separate VOC source areas, and the expected effect of various degrees and types of source area remediation on the amount and rate of groundwater quality improvement over time. This information allows the following additional criteria to be used for evaluating the comparative effectiveness of the remedial alternatives presented in this document:

- The estimated total VOC mass expected to be removed and/or destroyed, as a percentage of the estimated total VOC mass in the source area, and
- The expected improvement in groundwater quality over time.

9.4.1 Building I-1-23 VOC Source Area

The option of using long-term extraction of contaminated groundwater at the VOC source area following excavation of some VOC source mass from the Upper Clay, as provided in Alternative A1, or following use of MPE as provided in Alternative C, would result in a marked improvement in groundwater quality, particularly downgradient of the capture zone of the pumping well(s). However, operation of the extraction well(s) pumping from the Upper Sand unit in the VOC source area would be required for a long time before the NAPL mass remaining in the Upper Clay would be expected to be removed. As shown by the modeling simulations, shutdown of the extraction well(s) before all NAPL mass is removed would result in a rebound of the plume concentrations between the source area and the lake. USEPA has determined that a groundwater restoration timeframe of 100 years or longer would be considered reasonable for the PCBOU, because the upper aquifer is not expected to be used for drinking water purposes in the near term, and an alternative source of drinking water is available. Therefore, although Alternatives A1 and C may provide long-term effectiveness with respect to groundwater remediation, the remediation benefits would not be permanent until all NAPL mass had been removed from the Upper Clay by natural processes, which may require over 200 years under Alternative C, and over 300 years under Alternative A1.

The substantial additional volume of Upper Clay soil that would be excavated under Alternative A2 would be expected to remove a sufficient amount of the NAPL and sorbed VOC mass from the Upper Clay that the groundwater extraction component of this alternative should provide considerably more long-term effectiveness and permanence of groundwater restoration than under any of the other alternatives. The estimated total groundwater extraction duration required under Alternative A2 (less than 15 years) would also be significantly shorter than the groundwater extraction duration under Alternative A1 (over 300 years) or Alternative C (over 200 years), to achieve comparable levels of groundwater restoration permanence.

Alternatives C, F, and G provide more aggressive efforts to remove or destroy VOC source mass than the other alternatives, and therefore provide somewhat greater long-term effectiveness. The results of the VOC mass removal or destruction would also be permanent under these alternatives. Similar to Alternative A1, Alternative C would provide long-term effectiveness and permanence with respect to groundwater quality improvement only with long-term groundwater extraction, until all NAPL and sorbed VOC mass in the Upper Clay remaining after the MPE treatment phase was removed by natural processes. The modeling simulations show that Alternatives F and G should provide comparable long-term effectiveness for groundwater quality remediation.

Alternatives B and D provide comparable long-term effectiveness because they both include the same source area remediation component (excavation within the 10 mg/kg VOC contour). However, the permeable reactive barrier (PRB) under Alternative B provides somewhat more effectiveness than Alternative D with respect to improvement in groundwater quality between the source area and the lake. Both alternatives would also be effective in preventing VOC impacts on the shallow lake water owing to the VOC plume entering the surface water, although the phytoremediation and engineered wetland under Alternative D would achieve these results more quickly than the PRB under Alternative B.

Alternative E provides the least long-term effectiveness of any alternative for this source area. The "enhanced" phytoremediation component (engineered wetland) of the alternative should, however, provide long-term elimination of VOC impacts on the shallow lake water.

9.4.2 Buildings I-1-2/I-1-3 Source Area

Alternatives A, E, and F provide more aggressive efforts to remove or destroy the VOC source mass than the other alternatives, and therefore provide somewhat greater long-term effectiveness. The VOC mass removal or destruction, and the general improvement in groundwater quality, would also be permanent under these alternatives. The modeling simulations show that Alternatives E and F should provide comparable improvements in groundwater quality over time, and those improvements would be more rapid and significant than the long-term effectiveness of Alternative A in restoring groundwater quality.

Over time, the permeable reactive barrier (PRB) included in Alternative B should provide continuous *in situ* destruction of VOCs, and therefore the cumulative VOC mass destroyed should continuously increase, provided the PRB can be maintained to provide long-term (multiple decades or a few centuries) treatment effectiveness. However, Alternative B provides no direct removal or destruction of VOCs at the source areas, and therefore provides minimal increased protectiveness and long-term effectiveness.

The VOC source removal provided by the soil excavation in Alternatives D and E would result in moderate long-term improvement in protectiveness, by reducing potential exposures of workers to VOCs in soil and groundwater during possible future trenching or construction activities in the source area.

The only difference between Alternative C and the No Action alternative is that groundwater monitoring would be performed under Alternative C. This alternative provides no improvement in long-term protectiveness over existing conditions.

9.4.3 Area 9 Repository VOC Source Area

Alternatives A and B are both expected to supplement the existing effective natural attenuation processes by providing additional treatment of shallow groundwater in low-lying areas at the Center and East Swales that receive the discharge of the merged groundwater plumes on the eastern side of the Repository. These alternatives will use and enhance the long-term effectiveness of the existing natural attenuation processes at this VOC source area. Alternatives A and B are equivalent with respect to this evaluation criteria.

9.5 Reduction of Toxicity, Mobility, and Volume Through Treatment

9.5.1 Building I-1-23 VOC Source Area

With the use of long-term groundwater extraction and treatment in Alternatives A1 and C, Alternatives A1, A2, and C provide greater reduction in mobility of VOCs than the other alternatives, by focusing the groundwater extraction within the main source area. Groundwater extraction under these three alternatives would also provide capture and removal of dissolved VOCs over a broader area than the *in situ* groundwater treatment zone provided by the permeable reactive barrier (PRB) in Alternative B, thereby providing greater reduction in both volume and mobility of VOCs over time than the PRB. The short-term groundwater extraction option (for source removal) under Alternative A1 would also provide significant reduction of the VOC source mass, but would not reduce VOC mobility after the extraction well(s) stopped operation, due to the expected rebound of the VOC plume.

Alternative A2 is expected to provide removal or destruction of more of the VOC source mass in a shorter time than the other alternatives. The long-term groundwater extraction component of Alternative C would be effective in reducing the mobility of VOCs remaining after completing the source area remediation. Alternatives B, D, F, and G would do little to reduce the mobility of the VOC source mass that would remain after completing the "active" phase of the source area remediation.

Reduction of the toxicity of the VOCs would be generally proportional to the removal or destruction of VOC mass provided by the alternatives. Because Alternatives A2, C, F, and G are expected to remove or destroy more VOCs than the other alternatives, they would also provide greater reduction of VOC toxicity. However, under both Alternatives B and F, there is a potential that if the PRB (Alternative B) or the *in situ* biodegradation (Alternative F) does not provide complete destruction of the VOCs, breakdown products such as vinyl chloride that have higher toxicity than the parent compounds may be present in the groundwater at some locations. This would not be expected to be a major concern, however, because the phytoremediation component of both alternatives should prevent potential VOC breakdown products from impacting the shallow surface water at the groundwater discharge area.

Control of the mobility and toxicity of the VOCs removed in the groundwater treatment system under Alternatives A1, A2, and C would depend on the method and care used in managing the spent activated carbon from the treatment systems.

9.5.2 Buildings I-1-2/I-1-3 Source Area

Alternatives A, E, and F would provide removal or destruction of more of the VOC source mass in a shorter time than the other alternatives. However, the mass removal under Alternatives A and F ends when the MPE or ERH system is shut down. The VOC mass destruction via *in situ* biodegradation under Alternative E is expected to continue in the main source areas as well as in the groundwater to some distance downgradient of the source areas for a few years after the final bio-substrate injection event.

The permeable reactive barrier (PRB) under Alternative B would provide continuous *in situ* destruction of dissolved VOCs during the functional life of the PRB, which is uncertain. Over the time that it remains effective, the PRB is expected to be capable of destroying a quantity of VOC mass that may be comparable to the mass that would be removed or destroyed using an MPE system (Alternative A), *in situ* biodegradation (Alternative E), or ERH (Alternative F). The PRB also reduces the mobility of VOCs in groundwater more effectively than the other alternatives.

Alternative D provides only limited reduction of VOC volume and no reduction of VOC mobility. The only difference between Alternative C and the No Action alternative is that groundwater monitoring would be performed under Alternative C; this alternative provides no reduction in VOC volume, toxicity, or mobility.

Reduction of the toxicity of the VOCs would be generally proportional to the removal or destruction of VOC mass provided by the alternatives. Because Alternatives A, E, and F are expected to remove or destroy more VOCs than the other alternatives, they would also provide greater reduction of VOC toxicity. However, under both Alternatives B and E, there is a potential that if the PRB (Alternative B) or the *in situ* biodegradation (Alternative E) does not provide complete destruction of the VOCs, breakdown products such as vinyl chloride that have higher toxicity than the parent compounds may be present in the groundwater at some locations. This is not expected to be a major concern, however, because the VOCs that may reach the groundwater/surface water discharge areas would rapidly dissipate from the shallow surface water pool areas on the western side of Highway 148 by volatilization and aerobic biodegradation.

9.5.3 Area 9 Repository VOC Source Area

The existing natural attenuation processes that are a component of Alternatives A and B are currently providing a high degree of reduction in volume, mobility, and toxicity of VOCs from this source area. The phytoremediation component of Alternatives A and B will provide further reduction of volume, mobility, and toxicity through phytotransformation of the VOCs by the trees and prairie grasses.

9.6 Short-term Effectiveness

The site is located in a moderately secured, largely unpopulated area. Comments regarding protection of the community under this criterion will be limited to workers at the GDOTS plant in Area 9 and temporary visitors to the site, such as F&WS personnel.

9.6.1 Building I-1-23 VOC Source Area

The alternatives that include source area soil excavation and off-site disposal as a component of the remedial action (Alternatives A1, A2, B, D, and F) would present a higher level of potential exposure of construction workers to VOCs during implementation of the alternative than the alternatives that do not include soil excavation (Alternatives C, E, and G). There would also be a slightly increased risk of exposure of the general public to VOCs during transport of the soil for disposal. These potential exposures would be greatest under Alternative A2, because of the substantially larger volume of soil that would be excavated and disposed.

Alternatives C and G would have a lower potential for adverse exposures to hazardous substances during the construction phase than the alternatives that include soil excavation, because of the smaller volume of contaminated soil and water that would be produced. However, the potential exposures to steam, hot water, hot soil vapor, condensate containing concentrated VOCs, and electrical hazards during operation of the ERH system (Alternative G) would result in greater potential short-term exposures to remediation workers and possibly to GDOTS employees or site visitors from hazardous substances or conditions than any of the other alternatives. Alternative B would have recurring potential for adverse exposures during replacement of the PRB, which has been assumed to be required every 20 years. Alternative E would have only limited potential adverse exposures in the construction phase, and potential exposures during the post-construction phase would occur only during the regular groundwater monitoring activities that would be common to all of the alternatives.

Alternatives A1, A2, and C would provide somewhat more rapid short-term improvement in groundwater quality downgradient of the VOC source area than the other alternatives, due to the groundwater extraction component of the alternatives. The effectiveness of the hydraulic control or VOC source removal provided by the groundwater extraction well(s) under Alternatives A1, A2, and C can be easily adjusted by changing the flowrate produced by the well. This feature provides more flexibility and predictability for optimizing the short- and long-term effectiveness of the remedial action under Alternatives A1, A2, and C than with the remediation components provided by the other alternatives.

All of the alternatives, except Alternative E, involve the use of heavy equipment (drill rigs, dozers, excavators, etc.) in the source area, which will create noise, combustion exhaust, and physical hazards from operation of the equipment. All of these alternatives present some degree of hazard related to inhalation or ingestion of VOCs while excavating or drilling.

All of the alternatives include some form of phytoremediation as a component of the work. Therefore, the very limited potential exposures during the construction phase for phytoremediation and during long-term monitoring are the same for each alternative. The vegetation provided for phytoremediation would not reach its peak groundwater remediation effectiveness until roughly 3 years after planting, although this factor is also common to each of the alternatives.

9.6.2 Buildings I-1-2/I-1-3 Source Area

Alternatives D, E, and F would present a higher level of potential exposure of workers to VOCs during implementation than under the other alternatives. This would be due to the volume of VOC-impacted soil that would be excavated and transported for off-site disposal, and the potential exposures to the steam, hot water, hot soil vapor, condensate containing concentrated VOCs, and electrical hazards that would be present during operation of the ERH system (Alternative F). There would also be a slightly increased risk of exposure of the general public to VOCs during transport of the soil for disposal. After the construction and operational phase of each alternative is completed, all of the alternatives (except Alternative B) would have limited to no potential adverse short-term or long-term exposures, except during the regular monitoring activities that would be required with all of the alternatives. Alternative B would have recurring potential for adverse exposures during replacement of the PRB, which has been assumed to be required every 20 years.

All of the alternatives, except Alternative C, involve the use of heavy equipment (drill rigs, dozers, excavators, etc.) in the source area, which will create noise, combustion exhaust, and physical hazards from operation of heavy equipment. All of the alternatives present some degree of hazard related to inhalation or ingestion of VOCs while excavating or drilling.

As shown in the groundwater modeling simulations, Alternatives E and F are expected to provide significantly greater and more rapid groundwater quality improvement than the other alternatives.

9.6.3 Area 9 Repository VOC Source Area

Alternatives A and B both present a very low short- or long-term risk to the community, workers, and the environment during implementation. The existing natural attenuation conditions are effectively controlling the VOC source area impacts. Therefore, the time required for the vegetation planted for phytoremediation to reach maturity will not impair the short-term effectiveness.

9.7 Implementability

9.7.1 Building I-1-23 VOC Source Area

Of the remedial alternatives that provide the more effective VOC source area treatment (A2, C, F, and G), Alternative F (excavation and *in situ* reductive dechlorination) would be the easiest to implement. It would require no special equipment or difficult installation methods, and bulk chemicals (nutrient solution, sodium sulfite, etc.) are available from a number of vendors who will deliver to the site.

The soil excavation component under several of the alternatives is expected to be implementable, despite the presence of several existing underground utilities. The successful completion of the PCB soil excavations in 1996 provides some indication that the existing utilities can be successfully avoided. However, Alternative B would have considerable uncertainty regarding the constructibility of the PRB at this location, owing to the depth and thickness of the Upper Sand unit. The extent of these construction challenges would not be known until additional pilot soil borings were completed during pre-design fieldwork. Existing buried utilities in the location of the PRB would also be an impediment to construction. The PRB is a patented technology available from a limited number of contractors with patent implementation rights, and a site use license and fee are required. Alternative B may also have less reliability than Alternatives A1, A2, C, F, and G with regard to long-term remediation results, owing to the relatively recent development of PRB technology and the lack of demonstrated long-term PRB performance at other sites. Pneumatic fracturing of the clay under Alternative C, certain types and methods of bio-substrate addition as included under Alternative F, and the use of ERH technology under Alternative G are also patented technologies offered by a limited number of vendors with patent implementation rights. The ability to secure appropriate contractual terms with the specialty vendors/contractors that would provide the ERH (Alternative G) and pneumatic fracturing (Alternative C) technologies, to address the liabilities associated with safety and health issues, potential damage to nearby buildings, utilities, etc., and potential interference with GDOTS's production operations, is a key factor in determining the implementability of the alternatives that use these technologies.

It is expected that the design and construction of the physical systems and equipment required under Alternative B can be completed. However, in comparison to most of the other alternatives, successful implementation of a PRB would likely be more challenging, requiring specialized expertise and strict quality control during construction.

The use of pneumatic fracturing in the Upper Clay under Alternative C may present challenges owing to existing buried utility lines and the need to fracture the clay at shallow depths, but methods to address these site features are available. Alternative C would also require operation of several treatment systems (MPE, SVE, and high-flow groundwater extraction/treatment) for approximately 2 years following the construction phase, followed by the installation and operation of long-term, low-flow groundwater extraction/treatment equipment.

The number, complexity, and size of equipment components, including controls and monitoring systems, required for Alternative G (ERH) would be greater than for any of the other alternatives. A greater amount of on-site and off-site labor than the other alternatives would also be required during the field implementation phase, which is expected to require up to approximately two years, including a demonstration/pilot test period. Periodic monitoring of indoor air quality inside Buildings I-1-23, I-1-58, and possibly other buildings would also be required with Alternative G, which would not be necessary for the other alternatives. Confirmation of the distance required to install an adequate electrical power supply to the treatment area, and an evaluation of the final design details for the ERH system by GDOTS to confirm that there would be no interference with their operations, are two of the key factors that would have to be resolved to establish the overall implementability of Alternative G.

Following initial construction, Alternatives D, E, and F would have no systems requiring continuous operation or maintenance. Alternatives A1, A2, and C would require periodic operator attention for the small-scale groundwater extraction/treatment system. Alternatives C and G would require more frequent access to, and activity in, the area adjacent to Building I-1-23 during their respective operating periods than any of the other alternatives. This would present added implementation difficulty only if the use of Building I-1-23 for manufacturing or storage resumes.

A demonstration or pilot test period would be required prior to full-scale use of both in-situ reductive dechlorination (Alternative F) or ERH (Alternative G), which would lengthen the overall implementation schedule for each alternative by several months. A demonstration or pilot test would also be required prior to full-scale use of pneumatic fracturing under Alternative C, although this testing would not be expected to cause significant implementation delays.

Phytoremediation for the VOC plume beneath the West Swale near the lake is expected to be readily implementable. Although it is also expected to be constructible, the engineered wetland treatment zone under Alternatives D, E, and F would present more design challenges than the proposed use of eastern cottonwood trees, alone, under the other alternatives, although the engineered wetland can be implemented. The Crab Orchard Refuge Manager with F&WS has indicated that the use of the shallow bay of the lake where the VOC plume from Building I-1-23 discharges into the lake to create a new wetland treatment zone is acceptable. No other permits or authorizations are expected to be necessary to implement this component of the remedial alternatives.

9.7.2 Buildings I-1-2/I-1-3 Source Area

Of the three alternatives that provide significant VOC source mass removal or destruction (Alternatives A, E, and F), Alternative E (excavation and *in situ* reductive dechlorination) would be much easier to implement than Alternative A (MPE) or Alternative F (ERH) at this source area, with fewer potential problems. However, the MPE system with pneumatic fracturing of the clay and ERH are also expected to be implementable.

The same comments above for several of the Building I-1-23 alternatives regarding the existence of a limited number of vendors/contractors and the patent rights for implementation of PRBs, pneumatic fracturing, and ERH also apply to Alternatives A, B, E, and F for the Buildings I-1-2/I-1-3 area. The same questions regarding long-term performance and reliability of a PRB (Alternative B) would also apply.

Alternative B would likely require a high level of coordination of the construction work with GDOTS because of the expected need to relocate existing utilities for construction of the PRB, and the location of the construction work along the main plant access road. The construction work under Alternatives A, D, E, and F would be located on the eastern side of the plant buildings in an area that is not currently used for manufacturing activities, and thus would require a lower level of coordination with GDOTS during the construction phase.

The number, complexity, and size of equipment components, including controls and monitoring systems, required for Alternative F (ERH) would be greater than for any of the other alternatives. This would require a greater amount of on-site and off-site labor than the other alternatives during the field implementation phase, which is expected to require up to approximately two years, including a demonstration/pilot test period. Periodic monitoring of indoor air quality inside Buildings I-1-2, I-1-3, I-1-1, and possibly other buildings would also be required with Alternative F, which would not be necessary for the other alternatives. Confirmation of the distance required to install an adequate electrical power supply to the treatment area, and an evaluation of the final design details for the ERH system by GDOTS to confirm that there would be no interference with their operations, are two of the key factors that would have to be resolved to establish the overall implementability of Alternative F.

9.7.3 Area 9 Repository VOC Source Area

The phytoremediation component of Alternatives A and B is readily implementable.

9.8 Cost

A summary of the estimated costs for each remedial alternative is included in Table 9-1. Detailed backup for the estimates is included in Appendix A.

9.9 State Acceptance

The state (support agency) acceptance criterion evaluates the technical and administrative issues and concerns the state may have regarding each of the alternatives. This criterion will be addressed by USEPA in the final Decision Document prepared for the groundwater remedy.

9.10 Community Acceptance

The community acceptance criterion evaluates issues and concerns the public may have regarding each of the alternatives. This criterion will be addressed by USEPA following public notice and participation procedures to be determined by USEPA.

Section 10
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Table 2-1
Maximum Contaminant Level Concentrations for Volatile Organic Compounds Detected in Groundwater at Sites 32/33

PARAMETER	MCL(1) (µg/L)	ILLINOIS CLASS I GW STDS.(2) (µg/L)
1,1,2,2-Tetrachloroethane	NE	NS
1,1,2-Trichloroethane	5	5
1,1-Dichloroethane	NE	NS
1,1-Dichloroethene	7	7
1,2,4-Trichlorobenzene	70	70
1,2-Dichlorobenzene	600	600
1,2-Dichloroethane	5	5
1,2-Dichloroethene, total	70	170
1,3-Dichlorobenzene	NE	NS
1,4-Dichlorobenzene	75	75
2-Butanone	NE	NS
4-Methyl-2-pentanone	NE	NS
Acetone	NE	NS
Benzene	5	5(3)
Bromodichloromethane	80(3)	NS
Carbon disulfide	NE	NS
Carbon tetrachloride	5	5
Chlorobenzene	100	NS
Chloroform	80(3)	NS
Chloromethane	NE	NS
cis-1,2-Dichloroethene	70	70
Ethane	NE	NS
Ethylbenzene	700	NS(4)
Methane	NE	NS
Methylene chloride	5	NS
Tetrachloroethene	5	5
Toluene	1,000	1,000(4)
trans-1,2-Dichloroethene	100	100
Trichloroethene	5	5
Vinyl chloride	2	2
Xylene, M + P	NE	NS
Xylenes, total	10,000	10,000(4)

Notes:

(1) MCL = Federal Primary Drinking Water Standards - Maximum Contaminant Levels.

(2) Illinois Class I Groundwater Standards. 35 IAC Part 620 - Groundwater Quality, Subpart D, Section 620.410.

(3) Total for combined trihalomethanes (THM) cannot exceed 80 µg/L. THMs include bromodichloromethane and chloroform.

(4) Standard for sum of benzene, ethylbenzene, toluene, and xylene (BTEX) is 11,705 µg/L.

NE = not established.
NS = no standard.

Table 5-1
Definition of Matrix Treatment Technologies(1)

TECHNOLOGY	DESCRIPTION
Soil, Sediment, and Sludge Technologies	
***In Situ* Biological Treatment**	
Bioventing	Oxygen is delivered to contaminated unsaturated soil by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.
Enhanced biodegradation	The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soil to enhance *in situ* biological degradation of organic contaminants. Nutrients, oxygen, or other amendments may be used to enhance biodegradation and contaminant desorption from subsurface materials.
Landfarming	Contaminated soil is periodically turned over or tilled into the soil to aerate the waste.
Natural attenuation	Natural subsurface processes, such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials, allowed to reduce contaminant concentrations to acceptable levels.
Phytoremediation	Phytoremediation is a set of processes that uses plants to clean contamination in soil, groundwater, surface water, sediment, and air.
***In Situ* Physical/Chemical Treatment**	
Electrokinetic separation	The Electrokinetic Remediation (ER) process removes metals and organic contaminants from low-permeability soil, mud, sludge, and marine dredging. ER uses electrochemical and electrokinetic processes to desorb, and then remove, metals and polar organics. This *in situ* soil processing technology is primarily a separation and removal technique for extracting contaminants from soil.
Fracturing	Pressurized air is injected beneath the surface to develop cracks in low-permeability and overconsolidated sediment, opening new passageways that increase the effectiveness of many *in situ* processes and enhance extraction efficiencies.
Soil flushing	Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the groundwater to raise the water table into the contaminated soil zone. Contaminants are leached into the groundwater, which is then extracted and treated.

(1) From Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, Federal Remediation Technologies Roundtable, Web site: www.frtr.gov.

Table 5-1 (Continued)
Definition of Matrix Treatment Technologies[1]

TECHNOLOGY	DESCRIPTION
Soil vapor extraction	Vacuum is applied through extraction wells to create a pressure/concentration gradient that induces gas-phase volatiles to diffuse through soil to extraction wells. The process includes a system for handling off-gases. This technology also is known as *in situ* soil venting, *in situ* volatilization, enhanced volatilization, or soil vacuum extraction.
Solidification/Stabilization	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).
***In Situ* Thermal Treatment**	
Thermal treatment	Steam/Hot air injection or electromagnetic/fiber optic/radio frequency/electrical conduction heating is used to increase the mobility of volatiles and facilitate extraction. The process includes a system for handling off-gases.
***Ex Situ* Biological Treatment**	
Biopiles	Excavated soil is mixed with soil amendments and placed in aboveground enclosures. Processes include prepared treatment beds, biotreatment cells, soil piles, and composting.
Composting	Contaminated soil is excavated and mixed with bulking agents and organic amendments such as wood chips, and animal and vegetative wastes, which are added to enhance the porosity and organic content of the mixture to be decomposed.
Genetically engineered organisms	Genetically engineered organisms refer to microorganisms that have undergone external processes by which their basic set of genes has been altered.
Landfarming	Contaminated soil is applied onto the soil surface and periodically turned over or tilled into the soil to aerate the waste.
Slurry phase biological treatment	An aqueous slurry is created by combining soil or sludge with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the soil contaminants. Upon completion of the process, the slurry is dewatered and the treated soil is disposed.

(1) From Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, Federal Remediation Technologies Roundtable, Web site: www.frtr.gov.

Table 5-1 (Continued)
Definition of Matrix Treatment Technologies[1]

TECHNOLOGY	DESCRIPTION
Ex Situ **Physical/Chemical Treatment**	
Chemical extraction	Waste contaminated soil and extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.
Chemical reduction/oxidation	Reduction/Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.
Dehalogenation	Reagents are added to soil contaminated with halogenated organics. The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.
Separation	Separation techniques concentrate contaminated solids through physical and chemical means. These processes seek to detach contaminants from their medium (i.e., the soil, sand, and/or binding material that contains them).
Soil washing	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.
Soil vapor extraction	A vacuum is applied to a network of aboveground piping to encourage volatilization of organics from the excavated media. The process includes a system for handling off-gases.
Solar detoxification	Solar detoxification is a process that destroys contaminants by using the ultraviolet energy in sunlight.
Solidification/Stabilization	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).
Ex Situ **Thermal Treatment**	
Hot gas decontamination	The process involves raising the temperature of the contaminated equipment or material for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants.
Incineration	High temperatures, 871-1,204 °C (1,600- 2,200 °F), are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.

[1] From Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, Federal Remediation Technologies Roundtable, Web site: www.frtr.gov.

Table 5-1 (Continued)
Definition of Matrix Treatment Technologies(1)

TECHNOLOGY	DESCRIPTION
Open burn/Open detonation	In open burn operations, explosives or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as flame, heat, or a detonatable wave (that does not result in a detonation). In open detonation operations, detonatable explosives and munitions are destroyed by a detonation, which is initiated by the detonation of a disposal charge.
Pyrolysis	Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.
Thermal desorption	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.
Containment	
Landfill cap	Landfill caps are used for contaminant source control.
Water harvesting vegetative cover	Water harvesting vegetative cover is a land cover that, through engineered vegetative design, enhances evaporation, plant transpiration, and moisture removal from the soil.
Other Treatment Technologies	
Excavation, retrieval, and off-site disposal	Contaminated material is removed and transported to permitted off-site treatment and disposal facilities. Pretreatment may be required.
Ground Water, Surface Water, and Leachate Technologies	
***In Situ* Biological Treatment**	
Co-metabolic treatment	Injection of a dilute solution of liquids and/or gases (e.g., toluene, methane or oxygen) into the contaminated groundwater zone to enhance the rate of methanotrophic biological degradation of organic contaminants.
Enhanced biodegradation	The rate of biodegradation of organic contaminants by microbes is enhanced by increasing the concentration of electron acceptors in groundwater. Oxygen is the main electron acceptor for aerobic biodegradation. Nitrate can serve as an alternative electron acceptor under anaerobic conditions.
Natural attenuation	Natural subsurface processes, such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials, are allowed to reduce contaminant concentrations to acceptable levels.

(1) From Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, Federal Remediation Technologies Roundtable, Web site: www.frtr.gov.

Table 5-1 (Continued)
Definition of Matrix Treatment Technologies[1]

TECHNOLOGY	DESCRIPTION
Phytoremediation of organics	Phytoremediation is a set of processes that uses plants to clean contamination, particularly organic substances, in groundwater and surface water.
In Situ Physical/Chemical Treatment	
Aeration	Aeration is the process by which the area of contact between water and air is increased, either by natural methods or by mechanical devices.
Air sparging	Air is injected into saturated matrices to remove contaminants through volatilization.
Bioslurping	Bioslurping combines the two remedial approaches of bioventing and vacuum-enhanced free-product recovery. Bioventing stimulates the aerobic bioremediation of hydrocarbon-contaminated soil. Vacuum-enhanced free-product recovery extracts LNAPLs from the capillary fringe and the water table.
Directional wells	Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling.
Dual-phase extraction	A high-vacuum system is applied to simultaneously remove various combinations of contaminated groundwater, separate-phase petroleum product, and hydrocarbon vapor from the subsurface.
Fluid/Vapor extraction	A high-vacuum system is applied to simultaneously remove liquid and gas from low-permeability or heterogeneous formations.
Hot water or steam flushing/stripping	Steam is forced into an aquifer through injection wells to vaporize volatile and semivolatile contaminants. Vaporized components rise to the unsaturated zone, where they are removed by vacuum extraction and then treated.
Hydrofracturing	Injection of pressurized water through wells cracks low-permeability and overconsolidated sediment. Cracks are filled with porous media that serve as avenues for bioremediation or to improve pumping efficiency.
In-well air stripping	Air is injected into a double-screened well, lifting the water in the well and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. Once in the well, some of the VOCs in the contaminated groundwater are transferred from the dissolved phase to the vapor phase by air bubbles. The contaminated air rises in the well to the water surface, where vapors are drawn off and treated by a soil vapor extraction system.

(1) From Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, Federal Remediation Technologies Roundtable, Web site: www.frtr.gov.

Table 5-1 (Continued)
Definition of Matrix Treatment Technologies[1]

TECHNOLOGY	DESCRIPTION
Passive/Reactive treatment walls	These barriers allow the passage of water while prohibiting the movement of contaminants by employing such agents as chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and others.
Ex Situ Biological Treatment	
Bioreactors	Contaminants in extracted groundwater are put into contact with microorganisms in attached or suspended growth biological reactors. In suspended systems, such as activated sludge, contaminated groundwater is circulated in an aeration basin. In attached systems, such as rotating biological contactors and trickling filters, microorganisms are established on an inert support matrix.
Constructed wetlands	The constructed wetlands-based treatment technology uses natural geochemical and biological processes inherent in an artificial wetland ecosystem to accumulate and remove metals and other contaminants from influent waters.
Ex Situ Physical/Chemical Treatment	
Adsorption/Absorption	In liquid adsorption, solutes concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase.
Air stripping	Volatile organics are partitioned from groundwater by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.
Granulated activated carbon (GAC)/Liquid-phase carbon adsorption	Groundwater is pumped through a series of canisters or columns containing activated carbon to which dissolved organic contaminants adsorb. Periodic replacement or regeneration of saturated carbon is required.
Ion exchange	Ion exchange removes ions from the aqueous phase by exchange with innocuous ions on the exchange medium.
Precipitation/ Coagulation/Flocculation	This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. The process usually uses pH adjustment, the addition of a chemical precipitant, and flocculation.
Separation	Separation techniques concentrate contaminated wastewater through physical and chemical means.
Sprinkler irrigation	Wastewater is distributed over the top of the filter bed through which wastewater is trickled. The organic contaminants in wastewater are degraded by the microorganisms attached to the filter medium.

[1] From Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, Federal Remediation Technologies Roundtable, Web site: www.frtr.gov.

Table 5-1 (Continued)
Definition of Matrix Treatment Technologies[1]

TECHNOLOGY	DESCRIPTION
Ultraviolet oxidation	Ultraviolet (UV) radiation, ozone, and/or hydrogen peroxide are used to destroy organic contaminants as water flows into a treatment tank. An ozone destruction unit is used to treat off-gases from the treatment tank.
Containment	
Deep well injection	Deep well injection is a liquid waste disposal technology. This alternative uses injection wells to place treated or untreated liquid waste into underground reservoirs, where it will not cause environmental harm.
Groundwater pumping	Groundwater pumping is a component of many pump-and-treat processes, which are some of the most commonly used groundwater remediation technologies at contaminated sites.
Slurry walls	These subsurface barriers consist of vertically excavated trenches filled with slurry. The slurry, usually a mixture of bentonite and water, hydraulically shores the trench to prevent collapse and retards groundwater flow.
Air Emissions/Off-Gas Treatment Technologies	
Air Emissions/Off-Gas Treatment	
Biofiltration	Vapor-phase organic contaminants are pumped through a soil bed and sorb to the soil surface, where they are degraded by microorganisms in the soil.
High-energy corona	The HEC process uses high-voltage electricity to destroy VOCs at room temperature.
Membrane separation	This organic vapor/air separation technology involves the preferential transport of organic vapors through a nonporous gas separation membrane (a diffusion process analogous to putting hot oil on a piece of waxed paper).
Oxidation	Organic contaminants are destroyed in a high-temperature 1,000°C (1,832°F) combustor. Trace organics in contaminated air streams are destroyed at lower temperatures, 450°C (842°F), than conventional combustion by passing the mixture through a catalyst.
Vapor-phase carbon adsorption	Off-gases are pumped through a series of canisters or columns containing activated carbon to which organic contaminants adsorb. Periodic replacement or regeneration of saturated carbon is required.

(1) From Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, Federal Remediation Technologies Roundtable, Web site: www.frtr.gov.

Table 5-2
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
No Action	None	None	No Action carried through as a "baseline" for comparative evaluation of potential responses	Does not measure effectiveness of naturally occurring contaminant attenuation because monitoring not included	Not applicable	No cost	Yes (only as comparative baseline)
Limited action	On-site access restrictions	Fencing	Fencing at East and West Swales to minimize potential human and wildlife contact with surface water in the plume discharge zone	Not effective ■ Generally provides no additional long-term effectiveness compared to existing conditions	Implementable in several areas at site	Low	No However, temporary fencing likely appropriate as a component of remedial construction in some areas
		Security	Manned security service or camera surveillance	Not effective ■ No additional effectiveness compared to existing conditions	Implementable	Medium	No Not necessary based on potential hazards or risk to environment
	Institutional controls	Property management	Groundwater and land use restrictions	Potentially effective ■ Groundwater use already controlled on property owned by federal government ■ Potentially effective in mitigating potential future human health exposures	Implementable	Low	Yes
		Property acquisition	Purchase of property	Potentially effective ■ No groundwater impacts off of existing site/property	Moderately implementable ■ Feasibility based on legal issues uncertain ■ May not be acceptable to regulatory agencies or to F&WS	No cost (property already owned by federal government)	No Property already owned by federal government
	Monitoring	Monitored Natural Attenuation	Long-term monitoring of groundwater quality improvements by natural attenuation processes, under USEPA-approved workplans and guidelines	Potentially effective ■ Effective approach for confirming expected continuation of natural attenuation of VOC plume associated with Repository source area ■ Groundwater ingestion exposure not a completed pathway	Implementable	Medium	Yes

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Containment	Vertical barriers	Slurry walls	Soil-bentonite or cement-bentonite slurry placed in trench around perimeter of contaminant source areas, keyed into confining base layer	Not effective ■ Could prevent migration of groundwater plume originating from leaching of VOC source material into groundwater at some site source areas, if wall can be keyed into Lower Clay unit at I-1-23 area ■ Not effective for source beneath Repository or at I-1-2/I-1-3 ■ Not effective in destroying VOC source material	Not implementable ■ Construction requires specialized equipment, owing to depth requirement for wall ■ Additional hydraulic control within containment area and *ex situ* groundwater treatment likely required ■ Proximity of buildings to VOC source areas makes construction impractical	High	No Not considered as a stand-alone technology; may be considered as limited component of a broader Area I-1-23 remedial alternative, if warranted
		Sheet piling	Steel sheet piling or HDPE interlocking barrier sheets installed around perimeter of contaminant source areas, keyed into confining base layer	Not effective ■ Can prevent migration of groundwater plume originating from leaching of VOC source material into groundwater at some site source areas, if piling can be keyed into Lower Clay unit at I-1-23 area ■ Not effective for source beneath Repository ■ Not effective in destroying VOC source material	Not implementable ■ Construction impractical because of proximity of buildings to VOC source areas and other physical difficulties such as piling depth ■ Additional hydraulic control within containment area and *ex situ* groundwater treatment would likely be required	High	No
		Injected screens	Similar to sheet piling, except piles are removed and grout injected into void space	Not effective ■ Can prevent migration of groundwater plume originating from leaching of VOC source material into groundwater at some site source areas, if grout screen can be keyed into Lower Clay unit at I-1-23 area ■ Not effective for source beneath Repository ■ Not effective in destroying VOC source material	Not implementable ■ Construction impractical because of proximity of buildings to VOC source areas and other physical difficulties such as piling depth ■ Additional hydraulic control within containment area and *ex situ* groundwater treatment would likely be required	High	No

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Containment (continued)	Vertical barriers (continued)	Grout curtains	Closely-spaced holes drilled around perimeter of contaminant source areas, to confining base layer; grout injected into boreholes to provide overlapping grout zones	Not effective ■ Can prevent migration of groundwater plume originating from leaching of VOC source material into groundwater at some site source areas, if grout curtain can be keyed into Lower Clay unit at I-1-23 area ■ Not effective for source beneath Repository ■ Not effective in destroying VOC source material	Not implementable ■ Construction impractical because of proximity of buildings to VOC source areas and other physical difficulties such as grouting depth ■ Additional hydraulic control within containment area and *ex situ* groundwater treatment likely required	High	No
	Hydraulic containment	Interceptor trenches	Perforated pipe laid in trench installed across groundwater flow path, with pump in sump	Potentially effective ■ Could intercept plumes in Upper Sand, to remove dissolved VOC mass via groundwater extraction, if constructible	Moderately implementable ■ Construction impractical owing to physical difficulties of trenching depths, interference from proximity of buildings to VOC source areas, and buried utilities ■ Would require groundwater treatment and disposal	High	No
		Extraction wells	Vertical or horizontal wells used to extract water and encompass target containment area with a capture zone	Effective ■ Can effectively capture and contain target aquifer areas ■ Effectiveness requires constant operation ■ Can intercept plumes in Upper Sand and remove VOC mass via groundwater extraction ■ Not effective for pumping from Upper Clay	Implementable ■ Would require groundwater treatment and disposal ■ Long-term O&M required for groundwater treatment ■ Need to adequately pump to obtain desired capture, but not at too high of a rate to cause nontargeted plume redirection	Medium/High	Yes
	Surface covers	Low-permeability cap	Placement of a low-permeability surface cap, such as pavement, compacted clay, and/or geomembranes to limit infiltration	Potentially effective ■ Can decrease infiltration volume through source areas ■ Effectively mitigates potential human contact	Implementable ■ Requires surface access and regular maintenance ■ Standard technology	Low/Medium	Yes

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Removal	Extraction	Vertical extraction wells	Vertical extraction well(s) to remove contaminated groundwater using various types of equipment and methods	Potentially effective ■ Could remove dissolved VOC mass via groundwater extraction from Upper Sand unit at source areas and prevent further migration of VOC source mass into plume	Implementable ■ Difficult to route electrical conduit and pump discharge pipes to wells constructed through Repository waste since trenching into waste material not desirable ■ Could be used at I-1-23, but not at I-1-2/I-1-3 ■ Would require groundwater treatment and disposal	Medium/High	Yes
		Horizontal extraction wells	Well(s) drilled and installed horizontally into Upper Sand at Building I-1-23 source area	Potentially effective ■ Could remove dissolved VOC mass via groundwater extraction at source area and prevent further migration of VOC source mass into plume ■ Provides additional benefit of dewatering Upper Clay for application of other technologies	Implementable ■ Would require further characterization of Upper Sand geology at I-1-23 source area ■ Would require groundwater treatment and disposal	Medium/High	Yes
		Multiphase extraction (MPE)	High-vacuum pump removes combination of contaminated groundwater and soil vapors from vertical wells within soil at VOC source areas	Potentially effective ■ Capable of removing groundwater with dissolved VOCs, NAPL, and soil vapors from low-permeability or heterogeneous formations ■ Predesign pilot study yielded moderately low recoveries and limited area of influence without technology enhancement ■ Could increase effectiveness with pneumatic fracturing of clay soil at all source areas	Implementable ■ Difficult to route pump discharge pipes to wells constructed through Repository waste since trenching into waste material not desirable ■ Potentially high operation and maintenance labor requirement, but only short-term operation (2 years +/-) required ■ Would require groundwater treatment and disposal	Medium/High	Yes

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Removal (continued)	Extraction (continued)	Dual-phase extraction	Submersible pump used in vertical well(s) within the source areas to create groundwater cone of depression; VOCs then removed from enlarged vadose zone via a vacuum pump connected to the same well(s)	Potentially effective ■ Capable of removing liquid and gas (soil vapors) from moderately permeable heterogeneous formations ■ Effectiveness limited based on results of 1998 pilot testing at the site ■ Low aquifer permeability severely limits vapor recovery at source area in the clay ■ Some increased effectiveness possible with pneumatic fracturing ■ No significant advantage over MPE; submersible pumps in wells screened in clay unit not effective in dewatering clay	Implementable ■ Difficult to route pump discharge pipes to wells constructed through Repository waste since trenching into waste material not desirable ■ Potentially high operation and maintenance labor requirement, but only short-term operation (2 years +/-) required ■ Would require groundwater treatment and disposal	Medium/High	No
	Excavation	Excavation and disposal	Conventional heavy excavation equipment used to excavate contaminated soil; soil disposed at an appropriate off-site facility; objective of excavation to remove source area mass to minimize further leaching of VOCs to groundwater	Potentially effective ■ Complete removal of VOC mass, but only within excavated soil ■ Large percentage of total VOC mass in source areas present in soil that cannot be excavated ■ Any VOC source remaining in soil after excavation is a continuing long-term source of groundwater impacts	Implementable ■ May need to use sheeting/shoring for deep excavations ■ Not feasible for VOC sources beneath Repository because of presence of PCB-impacted soil and depth of Repository waste material ■ Disposal costs may vary greatly depending on soil waste classification after excavation ■ Excavation feasibility limited in areas near existing structures ■ Could not access soil beneath buildings	High	Yes

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Treatment	*In situ* treatment	Air sparging	Injection of compressed air below water table within plume through series of wells to volatilize VOCs and stimulate biodegradation; recovery of VOCs in soil pore gas via soil vapor extraction (SVE) system	Not effective ■ Pilot-scale field tests at Sites 32/33 showed air sparging to be ineffective and possibly detrimental to groundwater cleanup because of stratified geology ■ Potential to cause increased groundwater contaminant concentrations if rate of VOC volatilization and vertical movement to atmosphere or soil vapor collection point is insufficient ■ May precipitate dissolved ferrous iron over time, causing plugging of saturated soil pores and restricted effectiveness of VOC volatilization and removal owing to reduced soil permeability for air movement	Moderately implementable ■ Likely to have lateral migration of VOC vapors beyond functional limits of vapor collection system, as effective recovery would be difficult ■ Density of vapor collection wells excessive	Medium	No

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Treatment (continued)	*In situ* treatment (continued)	Steam sparging	Similar to air sparging except steam injected instead of air to enhance VOC volatilization and possibly stimulate biodegradation	Not effective ■ Pilot-scale field tests at Sites 32/33 showed sparging to be ineffective and possibly detrimental to groundwater cleanup because of stratified geology ■ Potential to cause increased groundwater contaminant concentrations if rate of VOC volatilization and vertical movement to atmosphere or soil vapor collection point is insufficient	Moderately implementable ■ Potential operating problems similar to air sparging ■ Significant amount of operation and maintenance attention required ■ Transient steam and VOC vapors near and beneath site occupied buildings containing explosives and military ordnance may be safety and exposure concerns ■ Significant energy requirement possible ■ Safety hazards for remediation personnel ■ Can damage or destroy subsurface structures/items, such as conduit and PVC monitoring wells ■ Potential for exacerbating contamination through uncontrolled migration ■ Unknown effect on possible subsurface PCBs remaining in VOC source areas	High	No
		Permeable treatment walls/zones	Trench, pit, or injected zone installed across groundwater plume flow path in Upper Sand and possibly Upper Clay, filled with permeable material mixture (e.g., zero-valent iron) to "passively" treat water flowing through the zone	Potentially effective ■ Would provide relatively high VOC destruction effectiveness via chemical redox reactions ■ Technology still in relatively early stages of full-scale application ■ Does not directly destroy VOC mass at source ■ Reactive media could be consumed or plugged over time, reducing effectiveness ■ Long-term effectiveness will decrease, but rate and degree of decrease difficult to predict ■ Effectiveness is highly dependent on proper construction and QA/QC	Implementable ■ Potential construction difficulties owing to trenching depths required ■ Potential long-term maintenance or replacement of entire reactive zone required ■ Typically installed downgradient of source area(s) ■ Requires thorough QA/QC program to ensure proper construction to avoid potential problems, such as uneven distribution of treatment media, "holes" in the wall, zones of reduced permeability, and groundwater flow bypass	High	Yes

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Treatment (continued)	*In situ* treatment (continued)	Thermally enhanced recovery	Uses electrical resistance, radio frequency microwave, or hot air thermal process to volatilize VOCs from soil, which are then removed by a vapor extraction system	Potentially effective ■ Limited full-scale experience for VOC removal at NPL sites ■ Requires field test to determine effectiveness prior to full-scale use ■ Shown to be effective in low-permeability soil for removing VOCs at some sites ■ Effectiveness is dependent on ability to deliver and evenly distribute electrical current or other heat-producing energy throughout the target zone ■ Technologies are in early stages of full-scale application ■ Subsurface utilities and structures could limit effectiveness ■ Typically not as effective for granular (sand/gravel) media ■ Potentially limited effectiveness of required vapor recovery system leading to excessive number of vapor recovery wells or migration of contaminants beyond treatment zone ■ Difficult to assess and quantify final effectiveness	Moderately implementable ■ Must be used with vapor extraction and treatment systems ■ Subsurface utilities, existing monitoring wells, and nearby structures could be damaged or limit implementability ■ Transient steam and VOC vapors near and beneath occupied buildings containing explosives and military ordnance may be safety and exposure concerns ■ Use of high-voltage electricity presents safety concerns for remediation workers and GDOTS personnel, and potential interference with GDOTS production operations ■ High energy requirement ■ Likely to be difficult to control and collect steam/vapors ■ Licensed, proprietary technology offered by limited number of vendors ■ Potential unforeseen problems owing to new technology application ■ Liability acceptance by technology vendor/contractor is necessary	High	Yes

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Treatment (continued)	*In situ* treatment (continued)	Electro-osmotic recovery	Uses electro-osmosis in treatment zones located directly in contaminated soil areas; induced electrical current acts as a liquid "pump" to flush contaminants from the soil to a treatment or collection zone	Potentially effective ■ Can be effective in low-permeability soil for removing VOCs ■ Technology in early stages of full-scale application ■ Subsurface utilities and structures could limit effectiveness ■ Typically not as effective for granular (sand/gravel) media ■ Very limited full-scale use on VOC sites ■ Effective only for water-saturated soil; no effect in vadose zone	Moderately implementable ■ Difficult or impractical construction ■ Must be used with extraction technologies ■ Subsurface utilities and nearby structures could limit implementability ■ Licensed, proprietary technology with a limited number of vendors ■ Potential unforeseen problems owing to new technology application	High	No
		Chemical oxidation	Series of injection wells or infiltration trenches to introduce oxidizing chemical solutions into groundwater to react with and degrade organic contaminants	Not effective ■ Requires field test to determine effectiveness and design criteria ■ Minimal effectiveness likely owing to low permeability of Upper Clay at VOC source areas and highly localized reaction zone in subsurface	Moderate implementability ■ Significant engineering and process control problems ■ May precipitate dissolved ferrous iron and other metal ions, causing plugging of saturated soil pores and restricted effectiveness of organics degradation and chemical distribution ■ Site-specific heterogeneous subsurface not conducive to achieve precision of controlled injections needed for this technology	High	No

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Treatment (continued)	*In situ* treatment (continued)	Co-metabolic biological treatment	A primary substrate solution is injected into a contaminated groundwater area; in the process of oxidizing the substrate, the microbial population degrades the contaminants	Not effective ■ Bench-scale and/or field pilot-scale tests, and characterization of existing microorganism populations, required to determine ability to influence degradation ■ Co-metabolic degradation is primarily an aerobic process; soil conditions in source areas at this site are predominantly anaerobic ■ Technology still under development ■ Minimal effectiveness likely owing to low permeability of clay units at VOC source areas, without enhancements to increase bulk permeability of the soil	Moderate implementability ■ Potentially difficult to generate and maintain aerobic conditions throughout impacted Upper Clay that are sufficient for active co-metabolic biodegradation ■ Would require significant alteration of existing anaerobic conditions in source areas ■ Difficult to adequately deliver substrate into the geologically heterogeneous subsurface, without enhancements to increase bulk permeability of the soil	Medium	No

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Treatment (continued)	*In situ* treatment (continued)	Enhanced bioremediation	Providing nutrients, electron acceptors, and/or electron donor (food source) materials to impacted groundwater/soil to accelerate the natural biodegradation process; nutrient solutions delivered to soil via pressure injection or gravity infiltration	Potentially effective ■ Newer technology, but well-documented effectiveness for VOCs and NAPL in groundwater and saturated soil ■ Pilot-scale test to confirm effectiveness prior to full-scale application may be warranted ■ Effectiveness is dependent on ability to deliver and evenly distribute substrate/nutrients within target zone ■ Reduced rate of VOC destruction in Upper Clay expected due to low soil permeability, without physical enhancement to increase permeability ■ Possible increase in daughter breakdown products (DCE, VC) in portions of VOC plume during implementation ■ Would need to ensure completion of dechlorination process ■ Expected to be effective for VOC destruction in Upper Sand ■ Destroys target VOCs via reductive dechlorination with ultimate products being carbon dioxide and water ■ Difficult to assess and quantify final effectiveness	Moderate implementability ■ Potential limitation due to low rate of delivery and poor distribution of substrate/nutrient solution into low-permeability clay in source areas without enhancements to increase soil permeability ■ Potential for transient migration of contaminants ■ Some difficulty in delivering and evenly distributing nutrients and electron acceptors/donors in a heterogeneous subsurface ■ May require several substrate injection events to obtain complete dechlorination ■ Numerous electron donors/products commercially available; however, some are licensed, proprietary products ■ Pilot test over several months prior to full-scale use may be warranted	Medium	Yes

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Treatment (continued)	*In situ* treatment (continued)	*In situ* recirculation wells	Various designs providing below-grade air stripping, vacuum vapor extraction, and/or biological treatment, some within patented well design	Not effective ■ New technology with little documented results ■ Would require field test to determine effectiveness and design criteria ■ Likely not effective for low-permeability soil (Upper Clay), but may be effective in higher permeability Upper Sand unit ■ Balanced flow between upper and lower zones likely difficult to accomplish owing to soil heterogeneity	Moderate implementability ■ Uncertain operation and maintenance requirements ■ Potential unforeseen problems owing to new technology ■ Licensed, proprietary technology with a limited number of vendors ■ Site-specific heterogeneous subsurface not conducive to controlled injection or circulation cell development	Medium/High	No
		Fracturing-pneumatic or hydraulic	Enhancement technology used for increasing effectiveness of primary recovery technologies (or distribution/injection technologies); uses pressurized air (pneumatic), nitrogen, or water (hydraulic) to physically fracture targeted media and increase size of recovery pathways	Potentially effective ■ Shown to be effective at numerous full-scale sites as a removal technology enhancement ■ Would increase recovery system and/or distribution system effectiveness ■ May require pilot-scale test to demonstrate effectiveness ■ Potential for induced fractures to close if treatment/removal technology is not initiated within a relatively short time (several weeks) after fracturing, thereby losing effectiveness	Implementable ■ Engineering controls would be required adjacent to, or within, "sensitive" buildings, structures, or utilities to prevent short-circuiting of fracturing fluid or damage to facilities ■ Care must be taken to ensure that mobilization of contaminants, including NAPL, does not occur beyond the influence of the recovery/remediation system ■ Typically requires implementation of a primary technology and only acts as an enhancement, not a stand-alone treatment technology ■ Licensed, proprietary technology with a limited number of vendors	Medium	Yes (As a supplemental component to other technologies)

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Treatment (continued)	*In situ* treatment (continued)	Phytoremediation	Use of various plant species to remediate soil, groundwater, and/or surface water	Potentially effective ■ Recent technology with limited long-term performance data, but well-documented effectiveness for VOCs in groundwater in appropriate settings ■ Can be effective in areas with groundwater table ≤15 feet bgs ■ Removal of VOCs can occur through phytotransformation, rhizosphere bioremediation, and phytovolatilization ■ Typical effectiveness increases somewhat as vegetation matures ■ Limited treatment effectiveness during plant dormant season	Implementable ■ Can be used in areas of shallow surface water contamination or groundwater table depth ■ Relatively simple design and installation ■ Could be used in combination with other treatment technologies	Low	Yes
		Monitored Natural Attenuation	Use of existing naturally occurring contaminant attenuation and degradation mechanisms	Potentially effective ■ Natural attenuation processes expected to be effective at reducing contaminant concentrations in Repository area VOC plume over time ■ Effectiveness can be directly monitored and observed	Implementable ■ Site investigation data indicate natural degradation of VOCs in Repository area plume is already occurring	Low	Yes

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Treatment (continued)	At-grade (*ex situ*) treatment	Air stripping	Packed-column or shallow-tray air stripping unit or cascade aeration at point of discharge	Potentially effective ■ Effective for VOC constituents of concern in groundwater ■ Proven effectiveness at full-scale CERCLA sites	Implementable ■ Must be used in combination with groundwater extraction option ■ Requires periodic on-site labor for operation and maintenance	Medium	Yes
		Activated carbon	Activated carbon in removable canisters or fixed-mounted vessels for gas-phase or liquid-phase treatment of VOCs	Potentially effective ■ Effective for detected VOCs, except vinyl chloride ■ Proven effectiveness at full-scale CERCLA sites	Implementable ■ Must be used in combination with groundwater extraction option ■ Would require disposal or regeneration of spent carbon	Medium	Yes
		Thermal destruction	Thermal or catalytic oxidizer for destruction of VOCs in gas phase Requires process operation to transfer VOCs from water phase to gas phase	Potentially effective ■ Effective for all VOCs in site groundwater ■ Not practical for low VOC concentrations in groundwater	Implementable ■ Supplemental fuel source required ■ Must be used in combination with groundwater extraction or soil vapor extraction option ■ High supplemental fuel source consumption for low contaminant concentrations	Medium/High	No
		Aerobic biological	Various process options for aerobic biological treatment of groundwater	Potentially effective ■ May not produce treated water quality required for discharge without supplemental polishing treatment ■ Requires bench-scale and/or pilot-scale testing to determine effectiveness and design criteria	Implementable ■ Treatment process more susceptible to upsets and requires more operation and maintenance attention and operator skill than physical-chemical process equipment ■ May require supplemental organic substrate for metabolism of microorganisms responsible for VOC degradation ■ Post-biological treatment polishing step likely required ■ Must be used in combination with groundwater extraction option ■ Likely not as cost-effective as other *ex situ* technologies that would yield equivalent or better performance	Medium/High	No

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
Treatment (continued)	At-grade (*ex situ*) treatment (continued)	Anaerobic biological	Various process options for anaerobic biological treatment of groundwater	Not effective ■ Would not produce treated water quality required for discharge without supplemental polishing treatment ■ Requires bench-scale and/or pilot-scale testing to determine effectiveness and design criteria	Implementable ■ Treatment process more susceptible to upsets and requires more operation and maintenance attention and operator skill than physical-chemical process equipment ■ Must be used in combination with groundwater extraction option ■ Post-biological treatment polishing step likely required ■ Organic contaminant concentrations much too low for effective use of anaerobic treatment ■ Anaerobic conditions may be impractical to maintain ■ Likely not as cost-effective as other *ex situ* technologies that would yield equivalent or better performance	Medium/High	No
		Chemical oxidation	Addition of oxidizing chemicals to groundwater, sometimes with ultraviolet light, to oxidize organics	Potentially effective ■ Some concurrent oxidation and precipitation of metals likely to occur ■ Bench-scale and/or pilot-scale testing required to confirm effectiveness and design criteria	Implementable ■ Must be used in combination with groundwater extraction option ■ Likely not as cost-effective as other *ex situ* technologies that would yield equivalent or better performance	Medium/High	No
Off-site disposal	Treated or untreated groundwater	Discharge to POTW	Untreated groundwater with VOCs or treated groundwater discharged to Site 33 sanitary sewer system, or trucked from site to POTW	Potentially effective ■ POTW expected to be effective in treating groundwater contaminants, but confirmation required	Moderate implementability ■ Dependent on willingness of POTW to accept contaminated or treated groundwater over a several-year period, and special requirements or limitations may be imposed ■ Upcoming connection of all Refuge wastewater flow to a local POTW's sewer system makes this approach potentially implementable in the near future	Low/Medium	Yes

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
On-site disposal	Treated groundwater	Injection wells	Series of wells for injecting treated water into sandstone aquifer for recharge	Potentially effective ■ Provides conservation of groundwater resource	Implementable ■ Achievable injection flowrate expected to be adequate for extracted groundwater flowrate ■ May be subject to state statutory prohibition; if not, may still require variance and will require state permit ■ Requires high level of treatment for VOC removal and to provide stable water chemistry with low nonfilterable solids level ■ High level of maintenance required compared with other disposal options	Medium/High	Yes
		Infiltration basin or trenches/drainfield	Gravity discharge of water to perforated pipe laid in trench system or drainfield with permeable backfill, or to earth basin, for gravity infiltration into groundwater	Not effective ■ Not as effective as injection wells, but potentially viable in combination with other disposal technologies ■ No additional effectiveness compared to discharge to on-site surface drainage channels ■ Provides conservation of groundwater resource ■ Low-permeability Upper Clay unit would significantly hinder infiltration	Moderately implementable ■ Uncertain ability to achieve required infiltration rate owing to local site hydrogeologic and hydrologic conditions ■ May have seasonal limitations ■ Impractical due to high water table ■ Requires high level of treatment for VOC removal and to provide stable water chemistry with low nonfilterable solids level	Low/Medium	No

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
On-site disposal (continued)	Treated groundwater (continued)	Discharge to surface water	Discharge to existing drainage channels on-site (with ultimate discharge into lake or other local surface water)	Potentially effective ■ Takes advantage of existing site drainage patterns ■ Treatment methods available to meet limits required in surface water discharge permit	Implementable ■ Implementable design, construction, operation, and maintenance ■ Requires discharge permit ■ Would require high level of treatment for VOC removal	Low/Medium	Yes
		Non-potable service water	Pumps and piping provided to distribute treated groundwater to existing use points at site production facilities	Potentially effective ■ Provides effective use of groundwater resource ■ Potential service water supply for on-site production operations and general maintenance	Not implementable ■ Impractical as sole disposal method owing to variable water flowrate demand ■ Current production operations at Area 9 buildings not believed to require continuous service water supply ■ Would require high level of treatment for VOC removal	Low	No
		Irrigation	Pumps and piping provided to distribute treated groundwater to selected site areas for irrigation	Potentially effective ■ Provides effective use of groundwater resource ■ Could provide irrigation for trees or plants used as part of phytoremediation approach for groundwater treatment or irrigation for crops grown adjacent to the site	Moderately implementable ■ Expected to be constructible, although significant length of buried force main required ■ High level of treatment may not be required ■ Does not provide means for disposal of treated groundwater during non-growing season	Medium	Yes
	Untreated groundwater	Non-potable service water	Pumps and piping provided to distribute untreated groundwater to existing use points at site production facilities	Not effective ■ Provides use of groundwater resource ■ Potential service water supply for on-site production operations and general maintenance ■ Potential for exposure of on-site workers to groundwater contaminants ■ Does not remove VOCs from extracted groundwater	Not implementable ■ Impractical as sole disposal method owing to variable water flowrate demand ■ Current production operations at Area 9 buildings not believed to require continuous service water supply	Low	No

Table 5-2 (Continued)
Identification and Screening of Remedial Technologies

GENERAL RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COMPARATIVE COST	ACCEPTABLE FOR FURTHER CONSIDERATION?
On-site disposal (continued)	Treated groundwater (continued)	Discharge to surface water	Extracted groundwater pumped directly to point-source discharge into lake at new outfall or into on-site surface water drainage system	Not effective ■ Not effective for removal of VOCs from groundwater ■ Relies on dilution and volatilization in surface water to reduce VOC concentrations ■ Not expected to meet limits required in surface water discharge permit	Not implementable ■ Requires discharge permit ■ Would not likely be implementable (regulatorily acceptable) without treatment ■ Could result in unacceptable VOC concentrations in lake or other surface water	Low	No
		Irrigation	Pumps and piping provided to distribute untreated groundwater to selected site areas for irrigation	Not effective ■ Provides use of groundwater resource ■ Potential for exposure of on-site workers and wildlife to groundwater contaminants ■ Does not remove VOCs from extracted groundwater	Not implementable ■ Expected to be constructible, although significant length of buried force main required ■ Not likely to be implementable (regulatorily acceptable) without some level of groundwater treatment	Medium	No

Table 6-1
List of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 3

Building I-1-23 Source Area and Plume

ALTERNATIVE	PRIMARY COMPONENTS	GENERAL APPROACH
A1	■ Excavation of Upper Clay within 10 mg/kg VOC contour, to 12 feet maximum depth (Area 201) ■ Source area groundwater extraction and treatment for Upper Sand after excavation ■ Phytoremediation at West Swale ■ Institutional Controls to prevent future potable supply well(s)	Partial source area remediation followed by long-term hydraulic containment/control or short-term hydraulic source removal
A2	■ Excavation of Upper Clay within 1 mg/kg VOC contour, to approximate depths of 17 feet (Area 201), 15 feet (Area 208), and 24 feet (Area 212) ■ Source area groundwater extraction and treatment for Upper Sand after excavation ■ Phytoremediation at West Swale ■ Institutional Controls to prevent future potable supply well(s)	Partial source area remediation followed by short-term hydraulic source removal
B	■ Excavation of Upper Clay within 10 mg/kg VOC contour, to 12 feet maximum depth (Area 201) ■ PRB across plume width in Upper Sand near source area ■ Phytoremediation at West Swale ■ Institutional Controls to prevent future potable supply well(s)	Partial source area remediation followed by long-term source containment/control and *in situ* passive treatment
C	■ MPE with pneumatic fracturing in Upper Clay ■ MPE/SVE/horizontal dewatering wells in Upper Sand ■ Phytoremediation at West Swale ■ Source area groundwater extraction and treatment for Upper Sand after MPE ■ Institutional Controls to prevent future potable supply well(s)	Source area remediation followed by long-term hydraulic containment/control

Table 6-1 (Continued)
List of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2

Building I-1-23 Source Area and Plume

ALTERNATIVE	PRIMARY COMPONENTS	GENERAL APPROACH
D	■ Excavation of Upper Clay within 10 mg/kg VOC contour, to 12 feet maximum depth (Area 201) ■ Phytoremediation at West Swale and engineered wetland in lake embayment ■ Establishment of ACLs for shallow groundwater quality at groundwater/surface water interface area ■ Institutional Controls to prevent future potable supply well(s)	Partial source area remediation, remediation of surface water impacts, and ACLs
E	■ Phytoremediation at West Swale and engineered wetland in lake embayment ■ Establishment of ACLs for shallow groundwater quality at groundwater/surface water interface area ■ Institutional Controls to prevent future potable supply well(s)	Remediation of surface water impacts and ACLs
F	■ Excavation of Upper Clay within 10 mg/kg VOC contour, to 12 feet maximum depth ■ *In situ* reductive dechlorination at VOC source area ■ Phytoremediation at West Swale and engineered wetland in lake embayment ■ Establishment of ACLs for shallow groundwater quality at groundwater/surface water interface area ■ Institutional Controls to prevent future potable supply well(s)	Partial source area remediation, remediation of surface water impacts, and ACLs
G	■ Electrical resistive heating within 1 mg/kg VOC contour, in Upper Clay and Upper Sand ■ Phytoremediation in West Swale ■ Institutional Controls to prevent future potable supply well(s)	Source area remediation

Table 6-1 (Continued)
List of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2

Buildings I-1-2/I-1-3 Source Area and Plume

ALTERNATIVE	PRIMARY COMPONENTS	GENERAL APPROACH
A	■ Limited excavation (Building I-1-3 hot-spot) ■ MPE with pneumatic fracturing in Upper and Lower Clay ■ Institutional Controls to prevent future potable supply well(s)	Source area remediation
B	■ PRB in Upper Sand across plume width west of source area ■ Institutional Controls to prevent future potable supply well(s)	Long-term source area containment/control and *in situ* passive treatment
C	■ Establishment of ACLs for shallow groundwater quality at groundwater/surface water interface areas ■ Institutional Controls to prevent future potable supply well(s)	ACLs
D	■ Excavation of Upper Clay within 10 mg/kg VOC contour, to 10 feet maximum depth ■ Establishment of ACLs for shallow groundwater quality at groundwater/surface water interface area ■ Institutional Controls to prevent future potable supply well(s)	Partial source area remediation and ACLs
E	■ Excavation of Upper Clay within 10 mg/kg VOC contour, to 10 feet maximum depth ■ *In situ* reductive dechlorination with pneumatic fracturing at VOC source areas ■ Establishment of ACLs for shallow groundwater quality at groundwater/surface water interface areas ■ Institutional Controls to prevent future potable supply well(s)	Source area remediation and ACLs
F	■ Electrical resistive heating within 10 mg/kg VOC contour ■ Institutional Controls to prevent future potable supply well(s)	Source area remediation

Table 6-1 (Continued)
List of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2

Area 9 Repository Source Area and Plume

ALTERNATIVE	PRIMARY COMPONENTS	GENERAL APPROACH
A	■ Phytoremediation at East and Center Swales ■ Monitored Natural Attenuation for VOC plume ■ Institutional Controls to prevent future potable supply well(s)	MNA and phytoremediation of groundwater discharge to surface water
B	■ Phytoremediation at East and Center Swales ■ Establishment of ACLs for shallow groundwater quality at groundwater/surface water interface area along the swales ■ Institutional Controls to prevent future potable supply well(s)	ACLs and phytoremediation of groundwater discharge to surface water

Table 6-2
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Building I-1-23
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
A1	■ Excavate VOC-impacted soil from Upper Clay in "Area 201" adjacent to the building within the previously defined concentration contour of 10 mg/kg total VOCs (maximum depth approximately 12 feet). ■ Dispose excavated soil at a licensed off-site disposal facility; assume that half of waste soil volume would be managed as non-hazardous waste, and half as "characteristically" hazardous waste. ■ Install an extraction well system in the Upper Sand at the source area. Pump groundwater: (1) at the minimum rate needed for long-term containment of contaminated groundwater in the source area (approximately 10 gpm), or (2) at the optimum rate for short-term removal of VOC source mass. Treat extracted groundwater on-site, and discharge to Crab Orchard Lake. ■ Plant phreatophytic trees across the West Swale near the lake, for phytoremediation of shallow groundwater. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water, and to prevent future interference with the long-term or short-term groundwater extraction measures.	■ Soil excavation is intended to remove a practical volume of VOC source material from shallow soil, to supplement the VOC mass removal accomplished with the PCB soil removal in 1996. ■ Excavated soil would be characterized to confirm appropriate on-site management and off-site disposal methods. ■ The phytoremediation would provide polishing treatment to remove some of the dissolved VOCs remaining in shallow groundwater before it discharges into the West Swale and shallow lake water. The phytoremediation would not be designed to provide a specific "treated" water quality for groundwater or surface water. ■ The purpose of the extraction well system depends on the optional remediation objective selected for this component of the alternative. For the long-term hydraulic containment option, the purpose is hydraulic containment of the remaining dissolved VOC source material, which will allow concentrations in the downgradient plume (beyond the capture zone of the extraction well) to be substantially reduced over time. For the short-term hydraulic source removal option, the purpose is to remove dissolved VOC source mass from the Upper Sand unit (and indirectly from the Upper Clay unit) until the incremental VOC mass removal rate compared with the cumulative mass removed since the start of pumping is less than a predetermined percentage of the cumulative mass removed, indicating that further pumping would produce minimal additional mass removal benefit.

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Building I-1-23
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
A2	■ Excavate VOC-impacted soil within the previously defined concentration contour of 1 mg/kg total VOCs from the Upper Clay in "Area 201" (depth approximately 17 feet), in "Area 208" (depth approximately 15 feet), and in "Area 212" (depth approximately 24 feet or to the practical depth limit as determined in the field). ■ Dispose excavated soil at a licensed off-site disposal facility; assume that 50% of waste soil would be managed as non-hazardous waste, and 50% would be managed as "characteristically" hazardous waste. ■ Install an extraction well system in the Upper Sand at the source area. Pump groundwater at the optimum rate for short-term removal of VOC source mass. Treat extracted groundwater on-site, and discharge to Crab Orchard Lake. ■ Plant phreatophytic trees across the West Swale near the lake, for phytoremediation of shallow groundwater. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water, and to prevent future interference with the long-term or short-term groundwater extraction measures.	■ The large soil excavation volume is intended to remove a substantial volume of VOC source material from the Upper Clay, to supplement the VOC mass removal accomplished with the PCB soil removal in 1996. ■ Excavated soil would be characterized to confirm appropriate on-site management and off-site disposal methods. ■ The phytoremediation would provide polishing treatment to remove some of the dissolved VOCs remaining in shallow groundwater before it discharges into the West Swale and shallow lake water. The phytoremediation would not be designed to provide a specific "treated" water quality for groundwater or surface water. ■ Operating duration of the extraction well system is estimated to be 10 to 15 years.

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Building I-1-23
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
B	■ Excavate VOC-impacted soil from the Upper Clay in "Area 201" adjacent to the building within the previously defined concentration contour of 10 mg/kg total VOCs (maximum depth approximately 12 feet). ■ Dispose excavated soil at a licensed off-site disposal facility; assume that 50% of waste soil would be managed as non-hazardous waste, and 50% would be managed as "characteristically" hazardous waste. ■ Install a permeable reactive barrier across the full plume width through the full depth of the Upper Sand, just downgradient of VOC source area. ■ Plant phreatophytic tree species across the West Swale near the lake, for phytoremediation of shallow groundwater. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water, and to prevent future interference with the long-term source containment/treatment measures.	■ This alternative is similar to Alternative A1, except a PRB is used to treat groundwater *in situ* and provide VOC source containment, rather than using a groundwater extraction and treatment system in the source area. ■ Soil excavation is included to remove a practical volume of VOC source material from shallow soil, to supplement the VOC mass removal accomplished with the PCB soil removal in 1996. ■ Excavated soil would be characterized to confirm appropriate on-site management and off-site disposal methods. ■ The phytoremediation would provide polishing treatment to remove some of the dissolved VOCs remaining in shallow groundwater before it discharges into the West Swale and shallow lake water. The phytoremediation would not be designed to provide a specific "treated" water quality for groundwater or surface water.

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Building I-1-23
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
C	■ Install an MPE well system in both the Upper Clay and the Upper Sand at the VOC source area. Pneumatic fracturing of the Upper Clay, and horizontal dewatering wells and SVE wells in the Upper Sand, in addition to MPE wells, are included. Provide on-site treatment for extracted groundwater and soil vapor, with treated water discharged to Crab Orchard Lake. Operate the system for up to 2 years, at which time performance will be assessed and decisions made regarding continuation of operations. ■ Plant phreatophytic tree species across the West Swale near the lake, for phytoremediation of shallow groundwater. ■ Install an extraction well in the Upper Sand at the source area. Pump groundwater at the minimum rate needed to contain contaminated groundwater in the source area (approximately 10 gpm) and treat on-site. Discharge treated water to Crab Orchard Lake. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water, and to prevent future interference with the long-term groundwater extraction measures.	■ Excavation of Upper Clay soil is not included, because the VOC source material will be treated *in situ* using MPE with pneumatic fracturing. ■ The phytoremediation would provide polishing treatment to remove some of the dissolved VOCs remaining in shallow groundwater before it discharges into the West Swale and shallow lake water. The phytoremediation would not be designed to provide a specific "treated" water quality for groundwater or surface water. ■ The purpose of the extraction well system is long-term hydraulic containment of the remaining dissolved VOC source material, which will allow concentrations in the downgradient plume to be substantially reduced over time.

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Building I-1-23
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
D	■ Excavate VOC-impacted soil from the Upper Clay in "Area 201" adjacent to the building within the previously defined concentration contour of 10 mg/kg total VOCs (maximum depth approximately 12 feet). ■ Dispose excavated soil at a licensed off-site disposal facility; assume that 50% of waste soil would be managed as non-hazardous waste, and 50% would be managed as "characteristically" hazardous waste. ■ Plant phreatophytic trees across the West Swale near the lake, and construct an engineered wetland treatment zone in the lake embayment, for phytoremediation of shallow groundwater and possibly surface water. ■ Establish Alternate Concentration Limits for shallow groundwater quality, with the point of compliance established at the interface zone where the groundwater plume discharges into surface water. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	■ This alternative includes "enhanced" phytoremediation consisting of a constructed wetland treatment zone, designed to intercept VOC-impacted groundwater where it discharges into the West Swale and lake embayment, and to provide a specific level of treatment effectiveness for shallow groundwater and surface water to eliminate VOC impacts on the lake water.

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Building I-1-23
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
E	■ Plant phreatophytic trees across the West Swale near the lake, and construct an engineered wetland treatment zone in the lake embayment, for phytoremediation of shallow groundwater and possibly surface water. ■ Establish Alternate Concentration Limits for shallow groundwater quality, with the point of compliance established at the interface zone where the groundwater plume discharges into surface water. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	■ This alternative is the same as Alternative D, without soil excavation in the source area.

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Building I-1-23
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
F	■ Excavate VOC-impacted soil from the Upper Clay in "Area 201" adjacent to the building within the previously defined concentration contour of 10 mg/kg total VOCs (maximum depth approximately 12 feet). ■ Dispose excavated soil at a licensed off-site disposal facility; assume that 50 percent of waste soil would be managed as non-hazardous waste, and 50 percent would be managed as "characteristically" hazardous waste. ■ Place a bio-substrate into the subsurface to stimulate *in situ* biological reductive dechlorination of VOCs in the Upper Sand and the Upper Clay units. ■ Plant phreatophytic trees across the West Swale near the lake, and construct an engineered wetland treatment zone in the lake embayment, for phytoremediation of shallow groundwater and possibly surface water. ■ Establish Alternate Concentration Limits for shallow groundwater quality, with the point of compliance established at the interface zone, where the groundwater plume discharges into surface water. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	■ A substrate material to promote growth of naturally occurring bacteria would be pressure-injected in liquid form into the Upper Sand unit. Additional substrate liquid would be placed in bulk quantities into the soil excavations in the Upper Clay unit prior to backfilling. The enhanced bacterial growth will substantially increase the effectiveness of the reductive dechlorination process for degradation of VOCs, which is already occurring in the source area.

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Building I-1-23
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
G	■ Perform electrical resistive heating (ERH) within the previously defined concentration contour of 1 mg/kg total VOCs. ■ Plant phreatophytic trees across the West Swale near the lake. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	■ The ERH would "boil off" the NAPL and dissolved and sorbed VOCs within the effective treatment zone. The vapors would be captured by vapor extraction wells. Vapors and condensate would be treated. ■ The phytoremediation would provide polishing treatment to remove some of the dissolved VOCs remaining in shallow groundwater before it discharges into the West Swale and shallow lake water. The phytoremediation would not be designed to provide a specific "treated" water quality for groundwater or surface water.

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Buildings I-1-2/I-1-3
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
A	■ Excavate a shallow VOC source hot spot previously located near Building I-1-3. ■ Dispose excavated soil at a licensed off-site disposal facility; assume that 50 percent of waste soil would be managed as non-hazardous waste, and 50 percent would be managed as "characteristically" hazardous. ■ Install an MPE well system in the Upper and Lower Clay at the VOC source areas, preceded by pneumatic fracturing of the clay. Provide on-site treatment for extracted groundwater and soil vapor, with treated water discharge to the East Swale. Operate the system for up to 2 years, and then assess performance and make decisions regarding continuation of operations. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	■ The hot spot excavation is included because pneumatic fracturing of the clay for use of MPE would not be effective at the shallow depth of this VOC source material ($\leq$ 6 feet). ■ Excavated soil would be characterized to confirm appropriate on-site management and off-site disposal methods.
B	■ Install a permeable reactive barrier in Upper Sand across the full width of the VOC plume extending west from the source areas. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Buildings I-1-2/I-1-3
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
C	■ Establish Alternate Concentration Limits for shallow groundwater quality, with the point of compliance established at the interface zone where the groundwater plume discharges into surface water. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	■ This alternative does not include VOC source remediation.
D	■ Excavate VOC-impacted soil from the Upper Clay adjacent to the buildings within the previously defined concentration contour of 10 mg/kg total VOCs (maximum depth of 10 feet). ■ Dispose excavated soil at a licensed off-site disposal facility; assume that 50 percent of waste soil would be managed as non-hazardous waste, and 50 percent would be managed as "characteristically" hazardous. ■ Establish Alternate Concentration Limits for shallow groundwater quality, with the point of compliance established at the interface zone where the groundwater plume discharges into surface water. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	■ Soil excavation is included to remove a practical volume of VOC source material from shallow soil, to supplement the VOC mass removal accomplished with the PCB soil removal in 1996. ■ Excavated soil would be characterized to confirm appropriate on-site management and off-site disposal methods.

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Buildings I-1-2/I-1-3
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
E	▪ Excavate VOC-impacted soil from the Upper Clay adjacent to the buildings within the previously defined concentration contour of 10 mg/kg total VOCs (maximum depth of 10 feet). ▪ Dispose excavated soil at a licensed off-site disposal facility; assume that 50 percent waste soil would be managed as non-hazardous waste, and 50 percent would be managed as "characteristically" hazardous waste. ▪ Place a bio-substrate into the subsurface to stimulate *in situ* biological reductive dechlorination of VOCs in the Upper Clay and the Lower Clay units. ▪ Establish Alternate Concentration Limits for shallow groundwater quality, with the point of compliance established at the interface zone, where the groundwater plume discharges into surface water. ▪ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	▪ Soil excavation is included to remove a practical volume of VOC source material from shallow soil, to supplement the VOC mass removal accomplished with the PCB soil removal in 1996. ▪ Excavated soil would be characterized to confirm appropriate on-site management and off-site disposal methods. ▪ Pneumatic fracturing would be applied within the previously identified VOC source zones in the clay. A substrate material to promote growth of naturally occurring bacteria would then be pressure-injected in liquid form into the fractured clay. Additional substrate liquid would be placed in bulk quantities into the soil excavations in the clay prior to backfilling. The enhanced bacterial growth will substantially increase the effectiveness of the reductive dechlorination process for degradation of VOCs, which is already occurring in the source area.
F	▪ Perform electrical resistive heating (ERH) within the previously defined concentration contour of 10 mg/kg total VOCs. ▪ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	▪ The ERH would "boil off" the NAPL and dissolved and sorbed VOCs within the effective treatment zone. The vapors would be captured by vapor extraction wells. Vapors and condensate would be treated.

Table 6-2 (Continued)
Summary of Remedial Alternatives for Groundwater
Focused Feasibility Study - Revision 2
PCB Operable Unit - Sites 32/33

Area 9 Repository
VOC Source Area and Associated Groundwater Plume

ALTERNATIVE	PRIMARY COMPONENTS	COMMENTS
A	■ Plant phreatophytic trees and a constructed prairie along the East and Center Swales, for phytoremediation of the shallow groundwater plume where it discharges into the swales. ■ Use Monitored Natural Attenuation to address the contaminated groundwater zone from beneath the Repository to the East and Center Swales. ■ Use Institutional Controls to prevent future use of contaminated aquifer for drinking water.	■ The phytoremediation would provide polishing treatment to remove some of the dissolved VOCs remaining in shallow groundwater before it discharges into the East and Center Swales.
B	■ Plant phreatophytic trees and a constructed prairie along the East and Center Swales, for phytoremediation of the shallow groundwater plume where it discharges into the swales. ■ Establish Alternate Concentration Limits for shallow groundwater quality, with the point of compliance established near the groundwater/surface water interface in the area where the Repository plume discharges into the East and Center Swales. ■ Use institutional controls to prevent future use of the contaminated aquifer for drinking water.	■ The phytoremediation under this alternative would be the same as for Alternative A.

Table 9-1
Crab Orchard National Wildlife Refuge
PCB Operable Unit - Sites 32/33
Area I-1-23 Cost Estimate Summary

Alternative	Description	Total Capital Cost ($)	Total Cost ($)	Total Present Value ($)
A1	Soil Excavation to 10 mg/kg, Long-Term Groundwater Extraction and Treatment, and Phytoremediation	830,000	5,182,000	3,719,000
	Soil Excavation to 10 mg/kg, 11 Years of Groundwater Extraction and Treatment, and Phytoremediation	830,000	3,757,000	2,984,000
A2	Soil Excavation to 1 mg/kg, 11 Years of Groundwater Extraction and Treatment, and Phytoremediation	2,747,000	5,688,000	4,914,000
B	Soil Excavation to 10 mg/kg, Permeable Reactive Barrier, and Phytoremediation	2,276,000	5,836,000	4,415,000
C	Multi-phase Extraction with Pneumatic Fracturing followed by Groundwater Extraction and Treatment and Phytoremediation	1,319,000	5,809,000	4,352,000
D	Soil Excavation to 10 mg/kg, Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits	1,074,000	3,062,000	2,391,000
E	Phytoremediation Including Engineered Wetland and Alternate Concentration Limits	706,000	2,740,000	2,046,000
F	Soil Excavation to 10 mg/kg, In-Situ Reductive Dechlorination, Phytoremediation Including Engineered Wetland, and ACLs	1,410,000	3,564,000	2,908,000
G	In-situ Electrical Resistive Heating (ERH) to 1 mg/kg and Phytoremediation	2,930,000	4,322,000	3,837,000

Note:
Total present value is for a 30-year period and annual discount rate of 3.2 percent.
Total cost is total realized dollars (sum of capital, operation, maintenance, and monitoring costs) over the common 30-year estimating period for all alternatives, not adjusted for inflation or discounting rates.

Table 9-1 (Continued)
Crab Orchard National Wildlife Refuge
PCB Operable Unit - Sites 32/33
Area I-1-2/I-1-3 Cost Estimate Summary

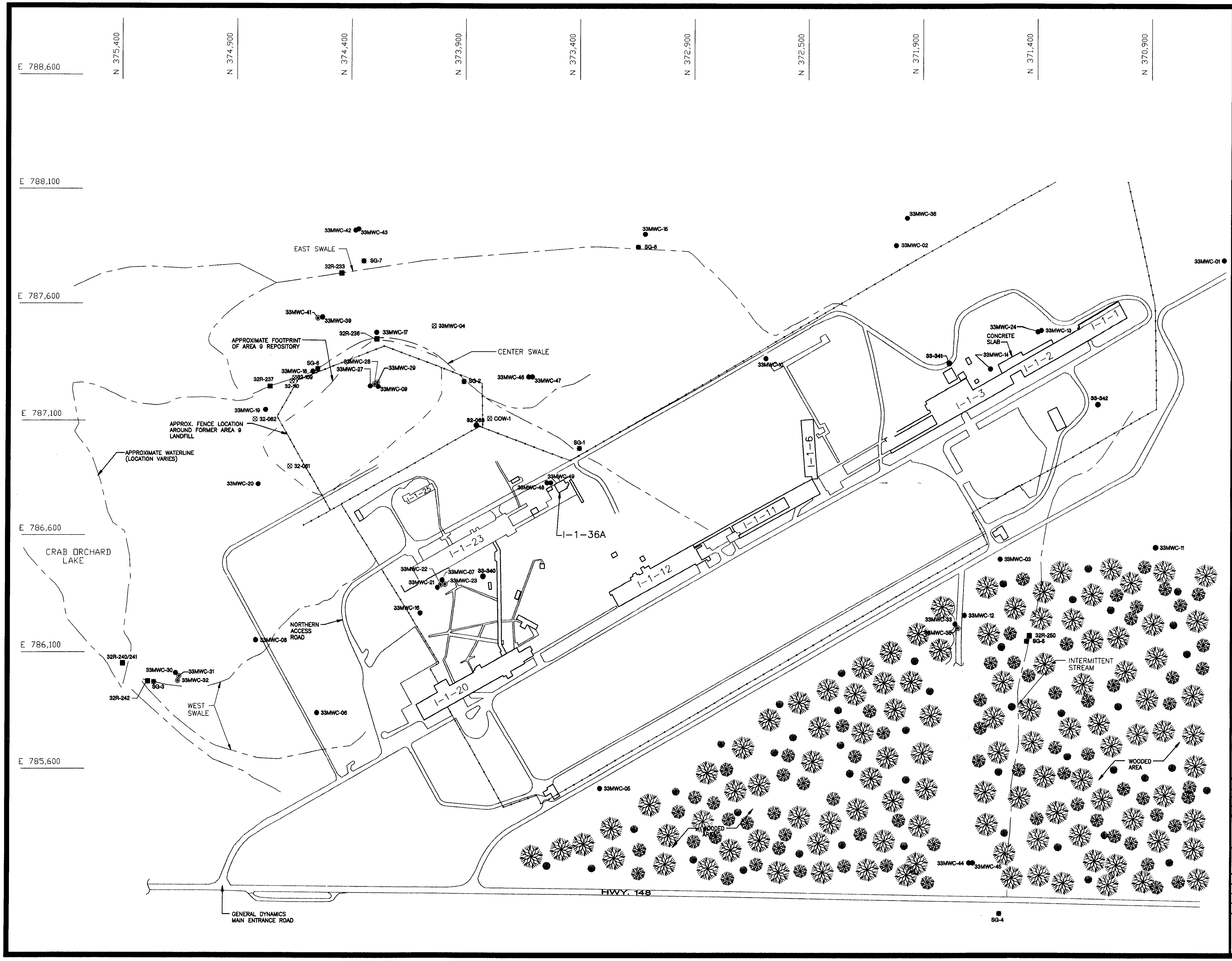
Alternative	Description	Total Capital Cost ($)	Total Cost ($)	Total Present Value ($)
A	Limited Excavation (I-1-3 hotspot) and Multi-phase Extraction with Pneumatic Fracturing	1,935,000	3,763,600	3,257,000
B	Permeable Reactive Barrier	1,783,000	7,059,500	4,692,000
C	Alternate Concentration Limits	77,000	1,821,700	1,237,000
D	Soil Excavation to 10 mg/kg and Alternate Concentration Limits	902,000	2,647,430	2,062,000
E	Soil Excavation to 10 mg/kg, In-situ Reductive Dechlorination with Pneumatic Fracturing, and ACLs	1,753,000	3,613,600	3,084,000
F	In-situ Electrical Resistive Heating (ERH) in 10 mg/kg Source Area	3,030,000	4,414,600	3,930,000

Note:
Total present value is for a 30-year period with an annual discount rate of 3.2 percent.
Total cost is total realized dollars (sum of capital, operation, maintenance, and monitoring costs) over the common 30-year estimating period for all alternatives, not adjusted for inflation or discounting rates.

Table 9-1 (Continued)
Crab Orchard National Wildlife Refuge
PCB Operable Unit - Sites 32/33
Repository Cost Estimate Summary

Alternative	Description	Total Capital Cost ($)	Total Cost ($)	Total Present Value ($)
A	Phytoremediation and Monitored Natural Attenuation	199,400	1,854,800	1,322,400
B	Phytoremediation and Alternate Concentration Limits	174,800	1,708,300	1,210,300

Note:
Total present value is for a 30-year period with an annual discount rate of 3.2 percent.
Total cost is total realized dollars (sum of capital, operation, maintenance, and monitoring costs) over the common 30-year estimating period for all alternatives, not adjusted for inflation or discounting rates.

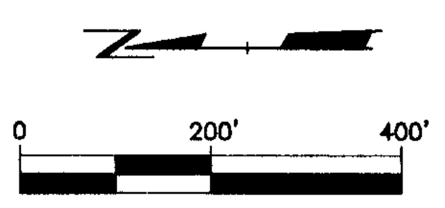


LEGEND

● 33MWC-30	SHALLOW MONITORING WELL
◉ 33MWC-22	PIEZOMETER
● SG-4	STAFF GAUGE
■ 32R-242	SURFACE WATER SAMPLING LOCATION
⊠ 32-061	MONITORING WELL, ABANDONED (APPROXIMATE LOCATION)
——— — ———	APPROXIMATE CENTERLINE OF SURFACE DRAINAGE CHANNEL/SWALE
—+—+—+—	FENCE
——— · ———	APPROXIMATE FOOTPRINT OF AREA 9 REPOSITORY

NOTES

1. SOURCE: BASE MAP FROM "1998 TCE INVESTIGATION, WORKPLAN AND PILOT STUDY FOR THE PCB OPERABLE UNIT AT THE CRAB ORCHARD NATIONAL WILDLIFE REFUGE SUPERFUND SITE, MARION, ILLINOIS" REV. 1, MAY 1998, PREPARED BY FLUOR DANIEL GTI.



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PROJECT:

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE:

SITE PLAN

DRAWN BY: SIEWERTD	SCALE:	PROJ. NO. 04781.12
CHECKED BY: BSS	1"=200'	FILE NO. 47811226.DWG
APPROVED BY: TEG	DATE PRINTED:	**FIGURE 1-1**
DATE: AUGUST 2004		

RMT.

744 Heartland Trail
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P.O. Box 8923 53708-8923
Phone: 608-831-4444
Fax: 608-831-3334

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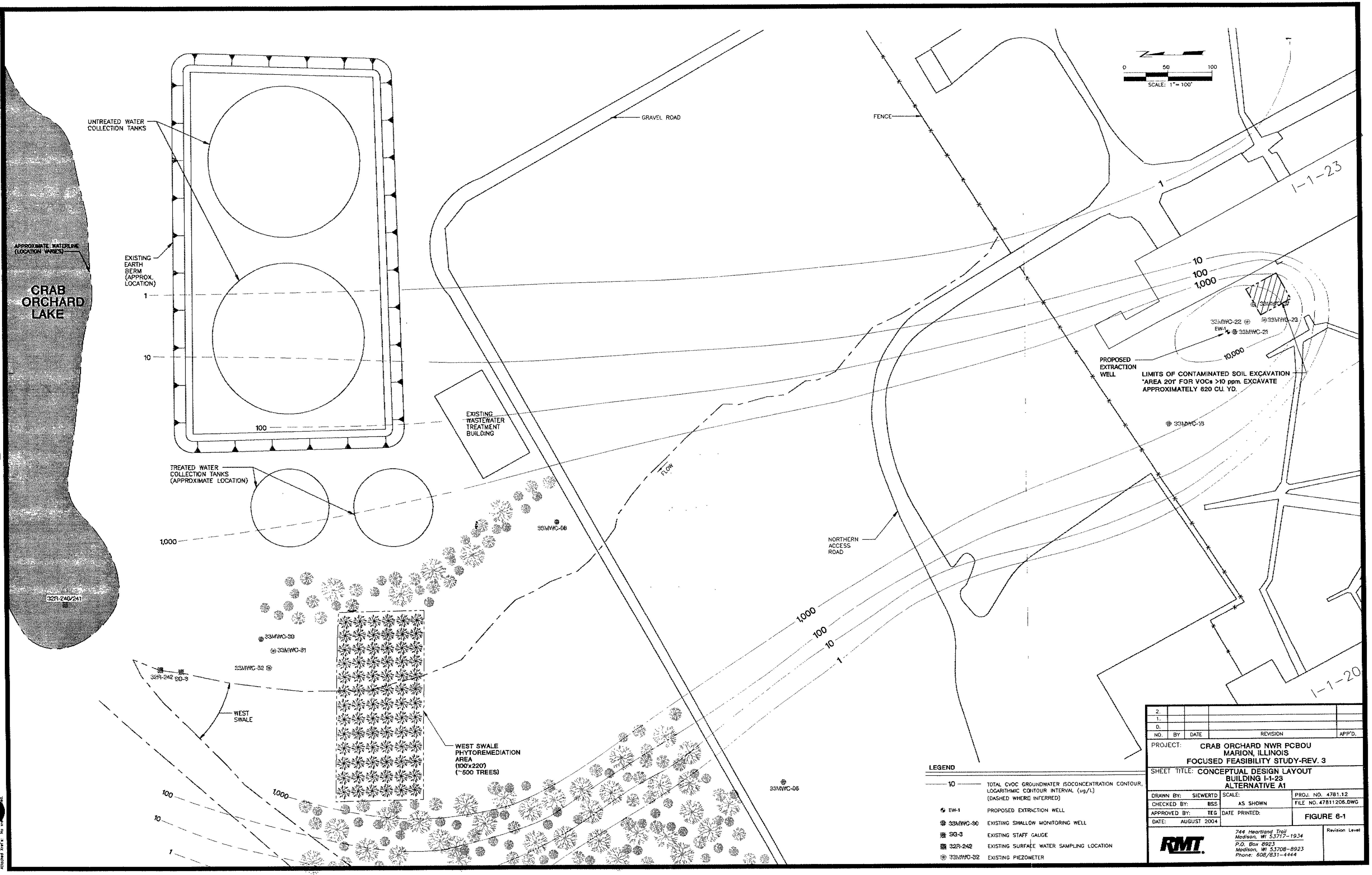

LEGEND

—— 10 ——	TOTAL CVOC GROUNDWATER ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
EW-1	PROPOSED EXTRACTION WELL
33MWC-30	EXISTING SHALLOW MONITORING WELL
SG-3	EXISTING STAFF GAUGE
32R-242	EXISTING SURFACE WATER SAMPLING LOCATION
33MWC-32	EXISTING PIEZOMETER

NO.	BY	DATE	REVISION	APP'D.
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PROJECT: CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE: CONCEPTUAL DESIGN LAYOUT
BUILDING I-1-23
ALTERNATIVE A1

DRAWN BY: SIEWERTD	SCALE:	PROJ. NO. 4781.12
CHECKED BY: BSS	AS SHOWN	FILE NO. 47811206.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE 6-1
DATE: AUGUST 2004		

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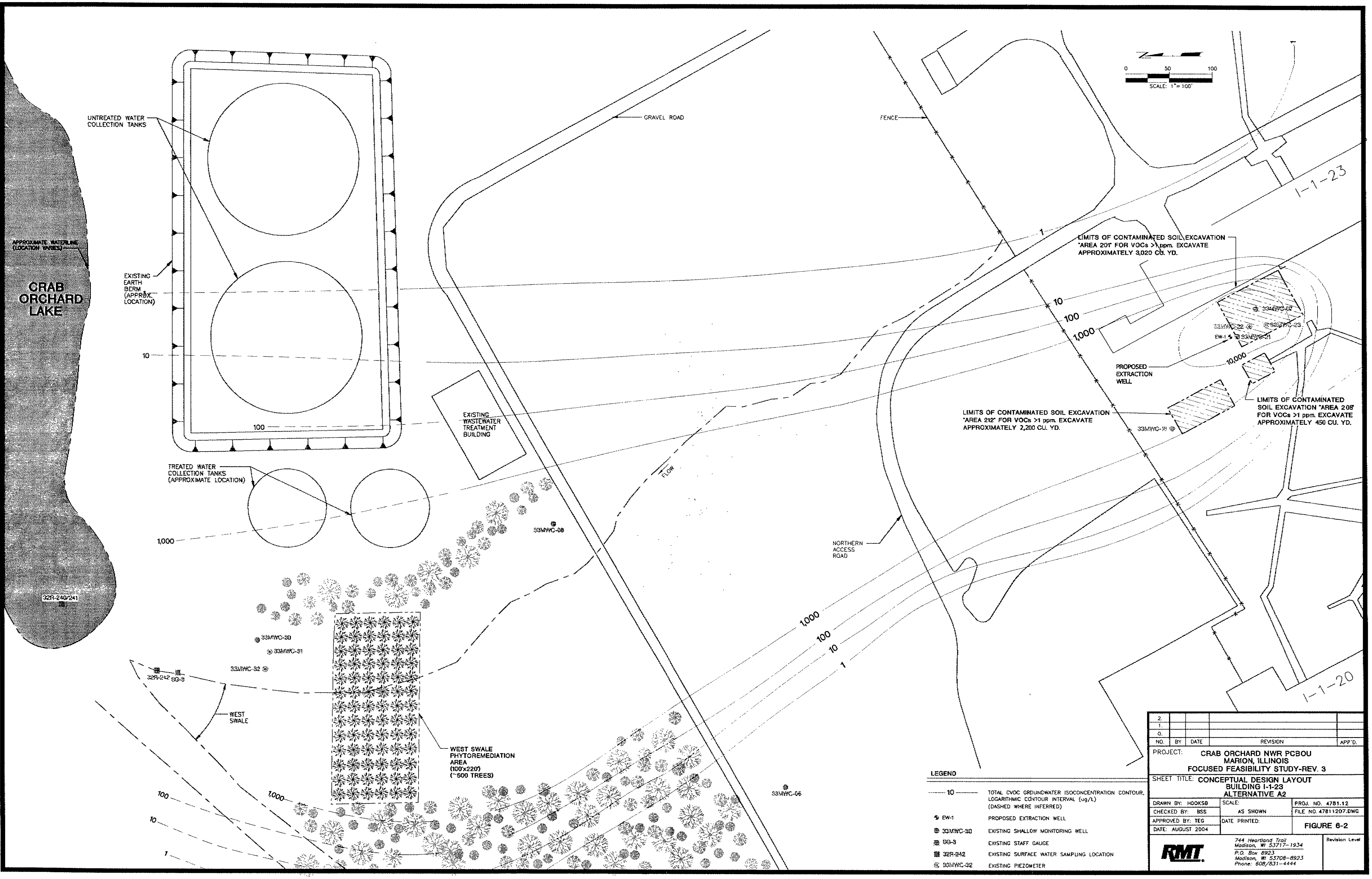

LEGEND

—— 10 ——	TOTAL CVOC GROUNDWATER ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
EW-1	PROPOSED EXTRACTION WELL
33MWC-30	EXISTING SHALLOW MONITORING WELL
SG-3	EXISTING STAFF GAUGE
32R-242	EXISTING SURFACE WATER SAMPLING LOCATION
33MWC-32	EXISTING PIEZOMETER

NO.	BY	DATE	REVISION	APP'D.
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PROJECT: CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE: CONCEPTUAL DESIGN LAYOUT
BUILDING I-1-23
ALTERNATIVE A2

DRAWN BY: HOOKSB	SCALE:	PROJ. NO. 4781.12
CHECKED BY: BSS	AS SHOWN	FILE NO. 47811207.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE 6-2
DATE: AUGUST 2004		

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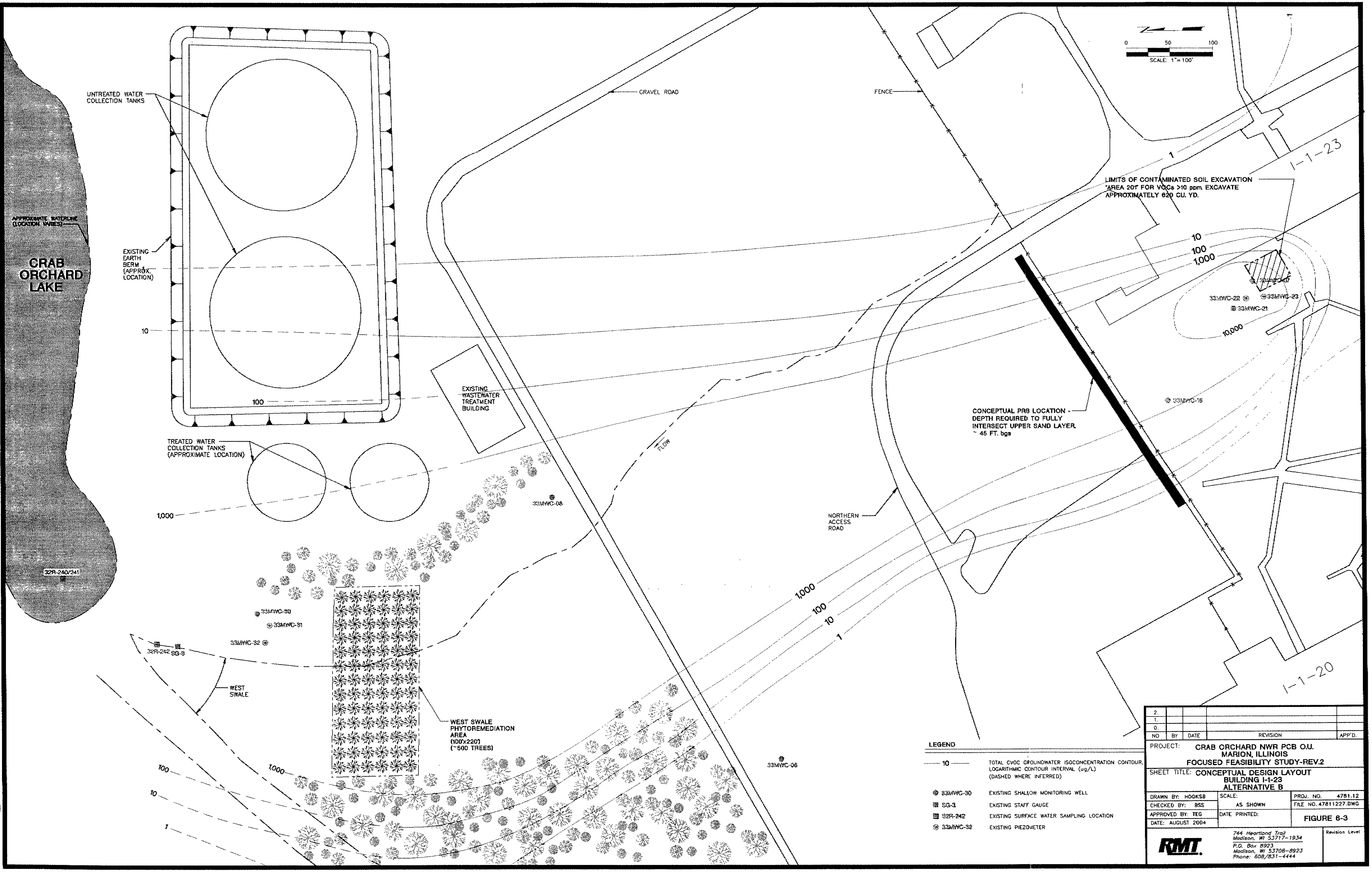

LEGEND

—— 10 ——	TOTAL CVOC GROUNDWATER ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
⊕ 33MWC-30	EXISTING SHALLOW MONITORING WELL
▦ SG-3	EXISTING STAFF GAUGE
▨ 32R-242	EXISTING SURFACE WATER SAMPLING LOCATION
◉ 33MWC-32	EXISTING PIEZOMETER

NO	BY	DATE	REVISION	APP'D.
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PROJECT: **CRAB ORCHARD NWR PCB O.U.**
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV.2

SHEET TITLE: **CONCEPTUAL DESIGN LAYOUT**
BUILDING I-1-23
ALTERNATIVE B

DRAWN BY: HOOKSB	SCALE: AS SHOWN	PROJ. NO. 4781.12
CHECKED BY: BSS		FILE NO. 47811227.DWG
APPROVED BY: TEG	DATE PRINTED:	**FIGURE 6-3**
DATE: AUGUST 2004		

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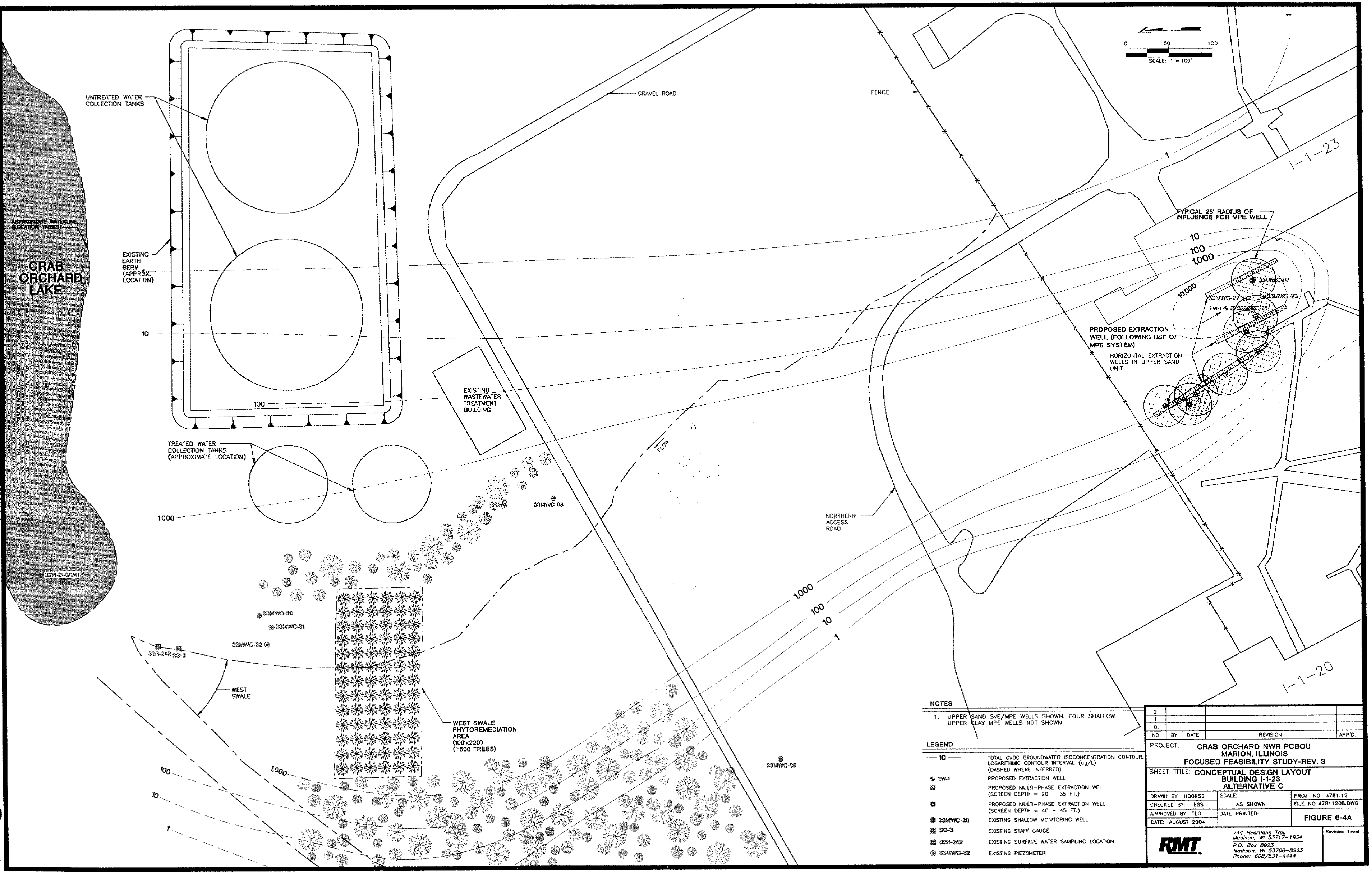

NOTES

1. UPPER SAND SVE/MPE WELLS SHOWN. FOUR SHALLOW UPPER CLAY MPE WELLS NOT SHOWN.

LEGEND

—10—	TOTAL CVOC GROUNDWATER ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
EW-1	PROPOSED EXTRACTION WELL
⊠	PROPOSED MULTI-PHASE EXTRACTION WELL (SCREEN DEPTH = 20 – 35 FT.)
●	PROPOSED MULTI-PHASE EXTRACTION WELL (SCREEN DEPTH = 40 – 45 FT.)
33MWC-30	EXISTING SHALLOW MONITORING WELL
SG-3	EXISTING STAFF GAUGE
32R-242	EXISTING SURFACE WATER SAMPLING LOCATION
33MWC-S2	EXISTING PIEZOMETER

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PROJECT: **CRAB ORCHARD NWR PCBOU**
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE: **CONCEPTUAL DESIGN LAYOUT**
BUILDING I-1-23
ALTERNATIVE C

DRAWN BY: HOOKSB	SCALE: AS SHOWN	PROJ. NO. 4781.12
CHECKED BY: BSS		FILE NO. 47811208.DWG
APPROVED BY: TEG	DATE PRINTED:	**FIGURE 6-4A**
DATE: AUGUST 2004		

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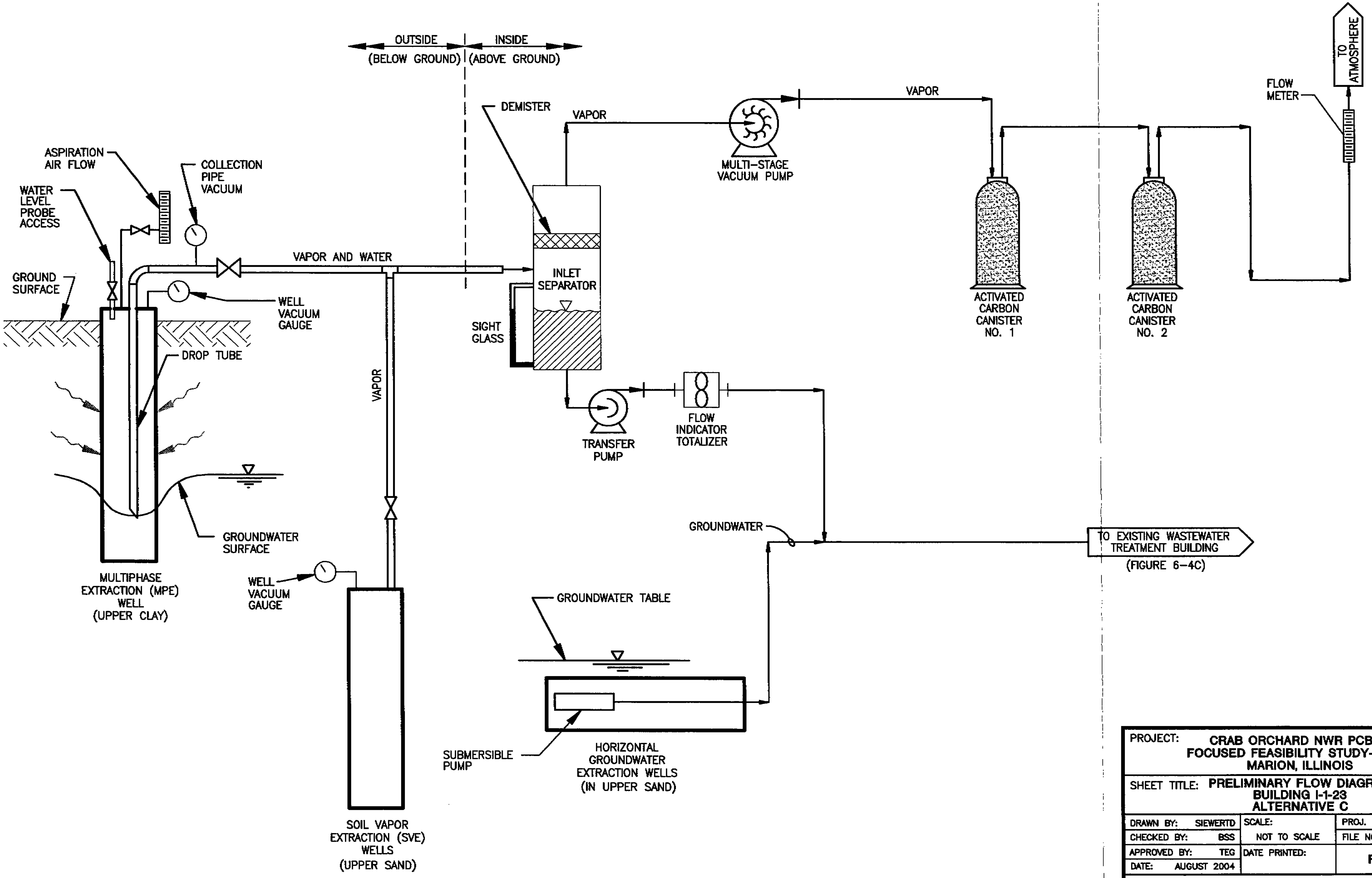

PROJECT: **CRAB ORCHARD NWR PCBOU
FOCUSED FEASIBILITY STUDY-REV. 3
MARION, ILLINOIS**

SHEET TITLE: **PRELIMINARY FLOW DIAGRAM
BUILDING I-1-23
ALTERNATIVE C**

DRAWN BY: SIEWERTD	SCALE:	PROJ. NO. 04781.12
CHECKED BY: BSS	NOT TO SCALE	FILE NO. 47811201.DWG
APPROVED BY: TEG	DATE PRINTED:	**FIGURE 6-4B**
DATE: AUGUST 2004		

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Phone: 608-831-4444
Fax: 608-831-3334

Drawing Name: 781\12\47811201.dwg
Operator Name: td
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Dwg Size: 92528 Bytes

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Plot Time: 4:08.41 PM
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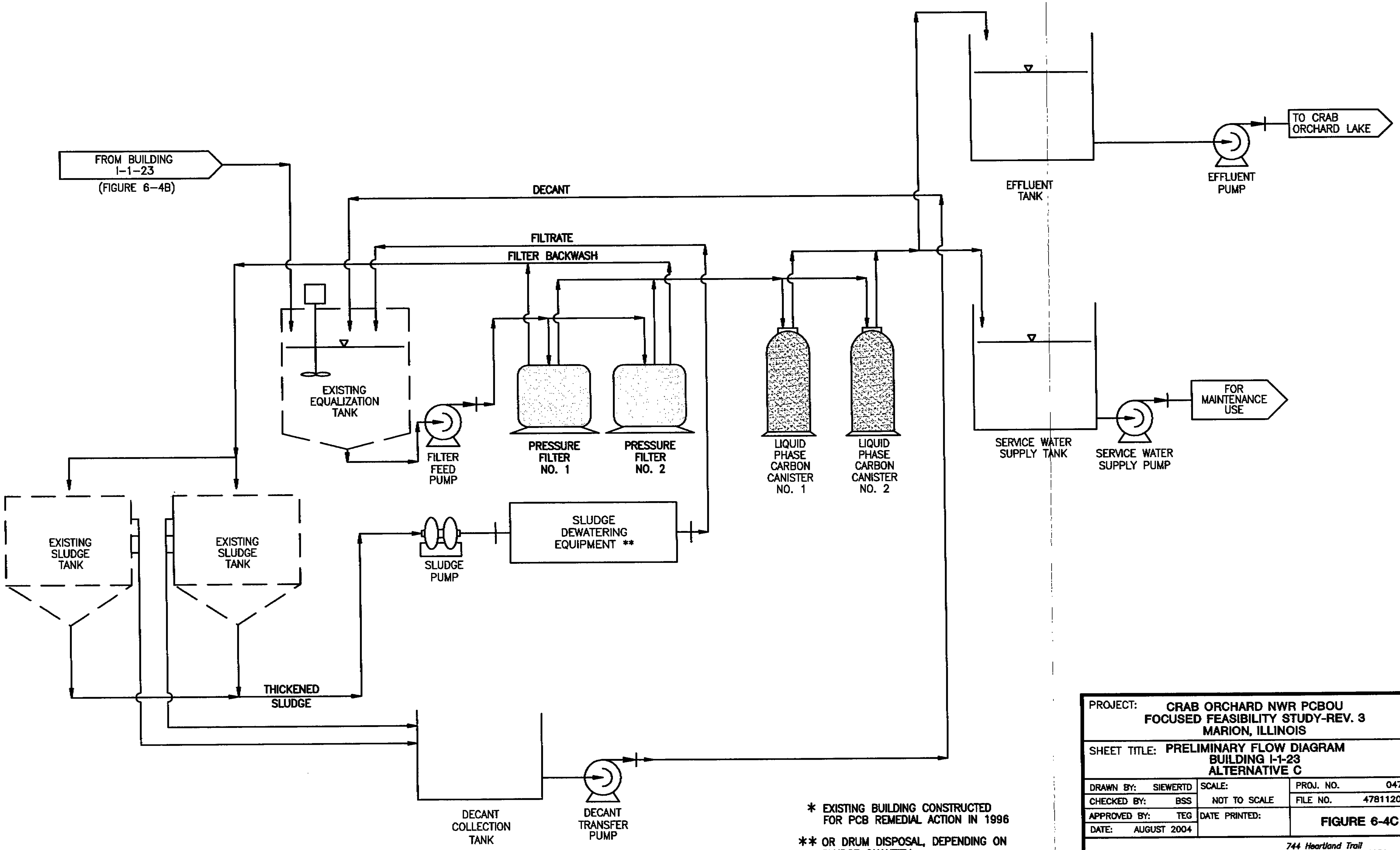
Attached Image's: No images attached



* EXISTING BUILDING CONSTRUCTED
FOR PCB REMEDIAL ACTION IN 1996

** OR DRUM DISPOSAL, DEPENDING ON
SLUDGE QUANTITY

PROJECT: **CRAB ORCHARD NWR PCBOU**
FOCUSED FEASIBILITY STUDY-REV. 3
MARION, ILLINOIS

SHEET TITLE: **PRELIMINARY FLOW DIAGRAM**
BUILDING I-1-23
ALTERNATIVE C

DRAWN BY: SIEWERTD	SCALE:	PROJ. NO.	04781.12
CHECKED BY: BSS	NOT TO SCALE	FILE NO.	47811202.DWG
APPROVED BY: TEG	DATE PRINTED:	**FIGURE 6-4C**	
DATE: AUGUST 2004			

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Fax: 608-831-3334

Plot Date: Monday, June 28, 2004
Plot Time: 4:13.55 PM
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Attached Image's: No images attached

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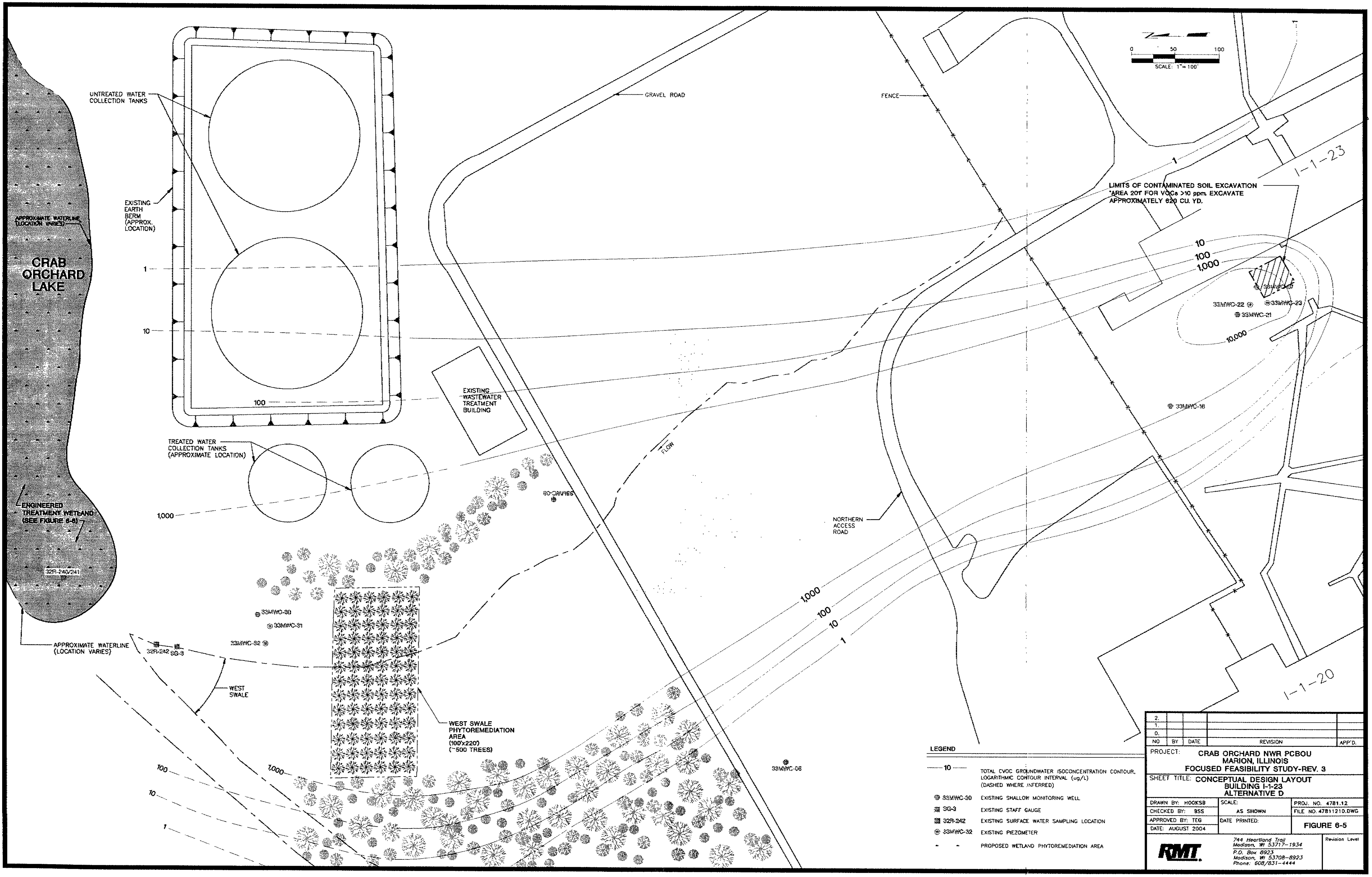

LEGEND

—— 10 ——	TOTAL CVOC GROUNDWATER ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
◉ 33MWC-30	EXISTING SHALLOW MONITORING WELL
▨ SG-3	EXISTING STAFF GAUGE
▨ 32R-242	EXISTING SURFACE WATER SAMPLING LOCATION
◉ 33MWC-32	EXISTING PIEZOMETER
- -	PROPOSED WETLAND PHYTOREMEDIATION AREA

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PROJECT: CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE: CONCEPTUAL DESIGN LAYOUT
BUILDING I-1-23
ALTERNATIVE D

DRAWN BY: HOOKSB
CHECKED BY: 9SS
APPROVED BY: TEG
DATE: AUGUST 2004
SCALE: AS SHOWN
DATE PRINTED:
PROJ. NO. 4781.12
FILE NO. 47811210.DWG

FIGURE 6-5

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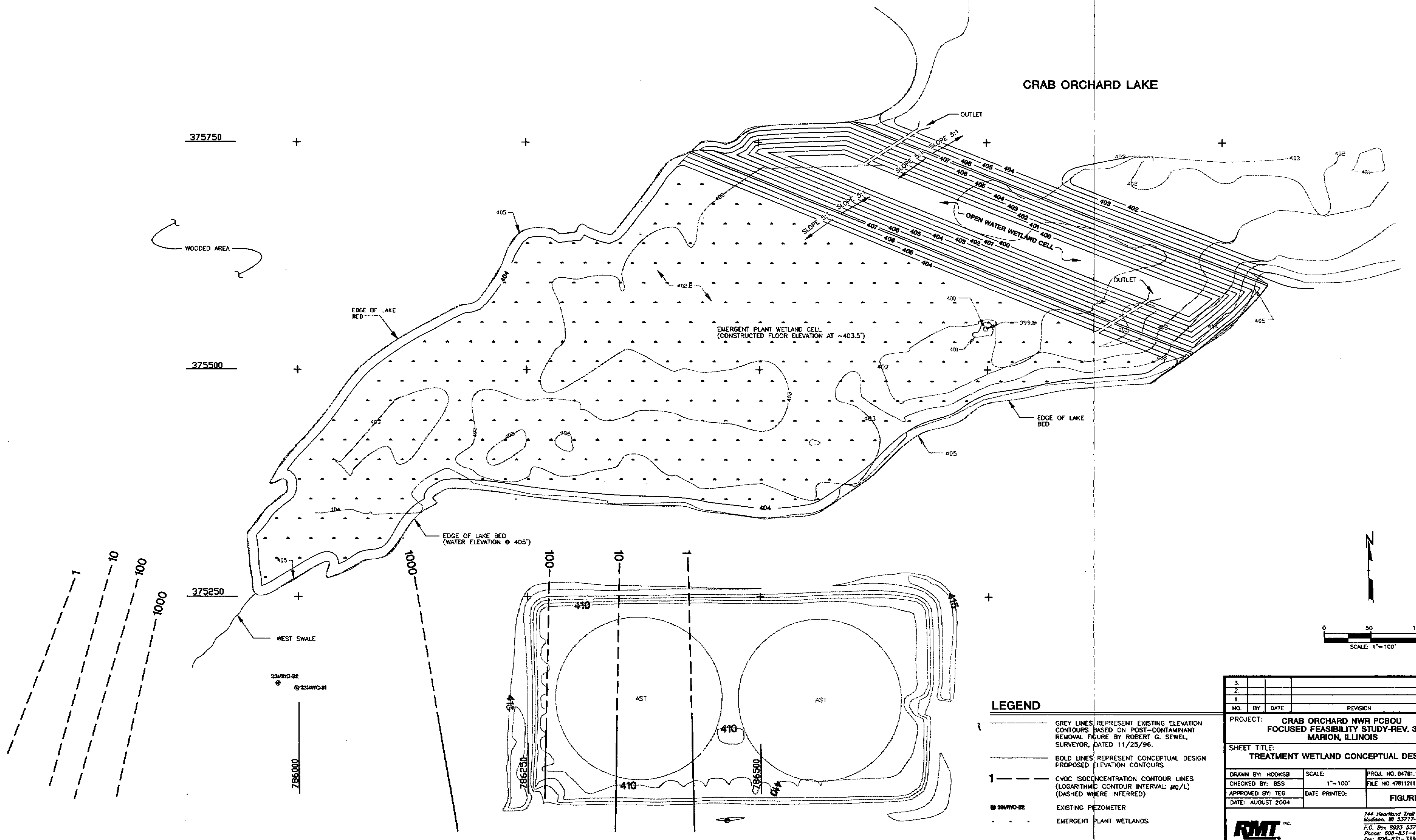

LEGEND

———	GREY LINES REPRESENT EXISTING ELEVATION CONTOURS BASED ON POST-CONTAMINANT REMOVAL FIGURE BY ROBERT G. SEWEL, SURVEYOR, DATED 11/25/96.
———	BOLD LINES REPRESENT CONCEPTUAL DESIGN PROPOSED ELEVATION CONTOURS
1 — — —	CVOC ISOCONCENTRATION CONTOUR LINES (LOGARITHMIC CONTOUR INTERVAL: µg/L) (DASHED WHERE INFERRED)
⊕ 33MWC-22	EXISTING PIEZOMETER
· · ·	EMERGENT PLANT WETLANDS

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PROJECT: **CRAB ORCHARD NWR PCBOU**
FOCUSED FEASIBILITY STUDY-REV. 3
MARION, ILLINOIS

SHEET TITLE:
TREATMENT WETLAND CONCEPTUAL DESIGN

DRAWN BY: HOOKSB	SCALE: 1"=100'	PROJ. NO. 04781.12
CHECKED BY: BSS		FILE NO. 47811211.DWG
APPROVED BY: TEG	DATE PRINTED:	**FIGURE 6-6**
DATE: AUGUST 2004		

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Dwg Size:
Plot Date:
Plot Time:
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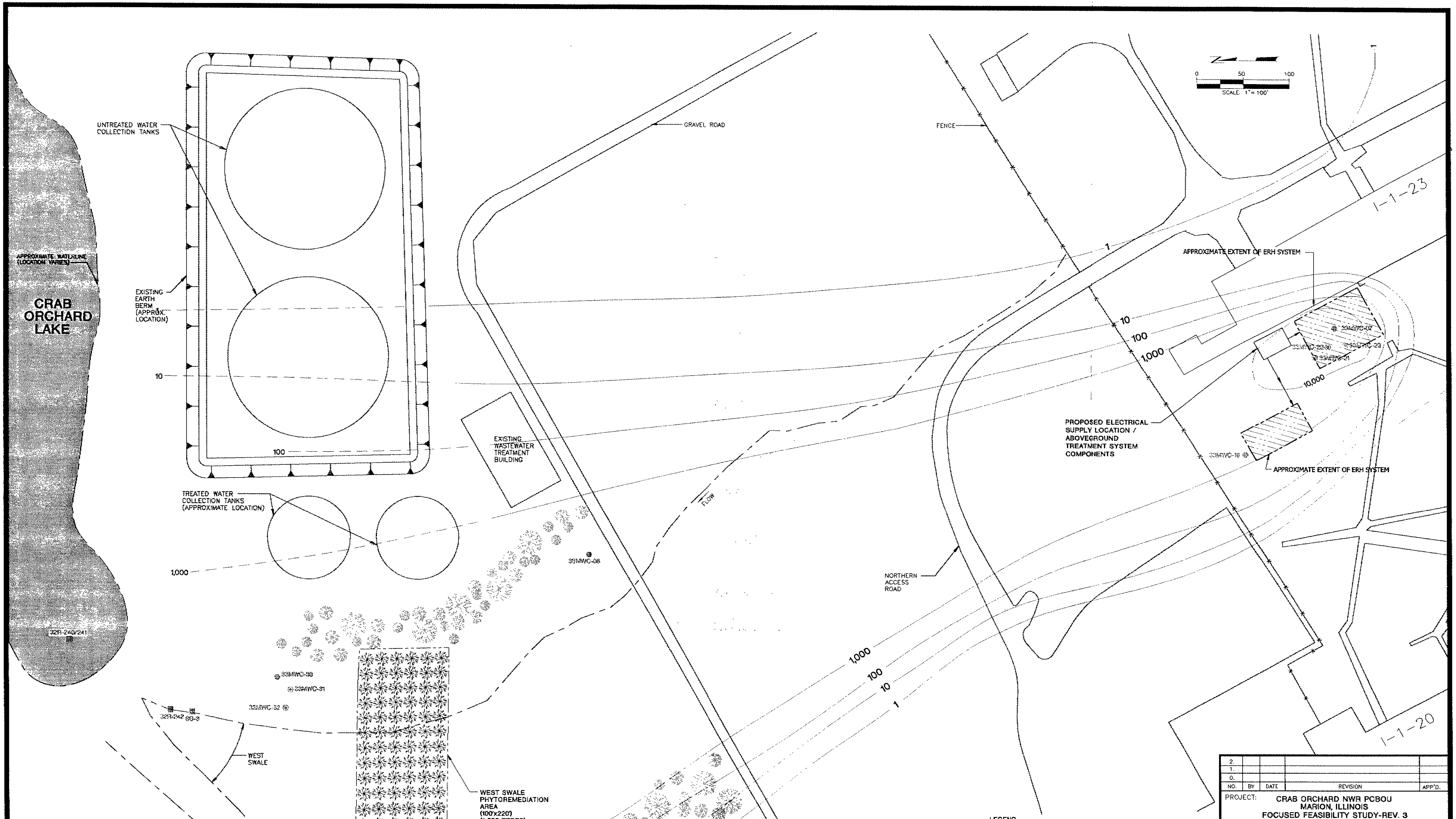

LEGEND

- - - 10 - - -	TOTAL CVOC GROUNDWATER ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
EW-1	PROPOSED EXTRACTION WELL
33MWC-30	EXISTING SHALLOW MONITORING WELL
SG-3	EXISTING STAFF GAUGE
32R-242	EXISTING SURFACE WATER SAMPLING LOCATION
33MWC-32	EXISTING PIEZOMETER

NO.	BY	DATE	REVISION	APP'D.
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PROJECT: CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE: CONCEPTUAL DESIGN LAYOUT
BUILDING I-1-23
ALTERNATIVE G

DRAWN BY: HOOKSB
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APPROVED BY: TEG
DATE: AUGUST 2004
SCALE: AS SHOWN
DATE PRINTED:
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FILE NO. 47811212.DWG
FIGURE 6-7A

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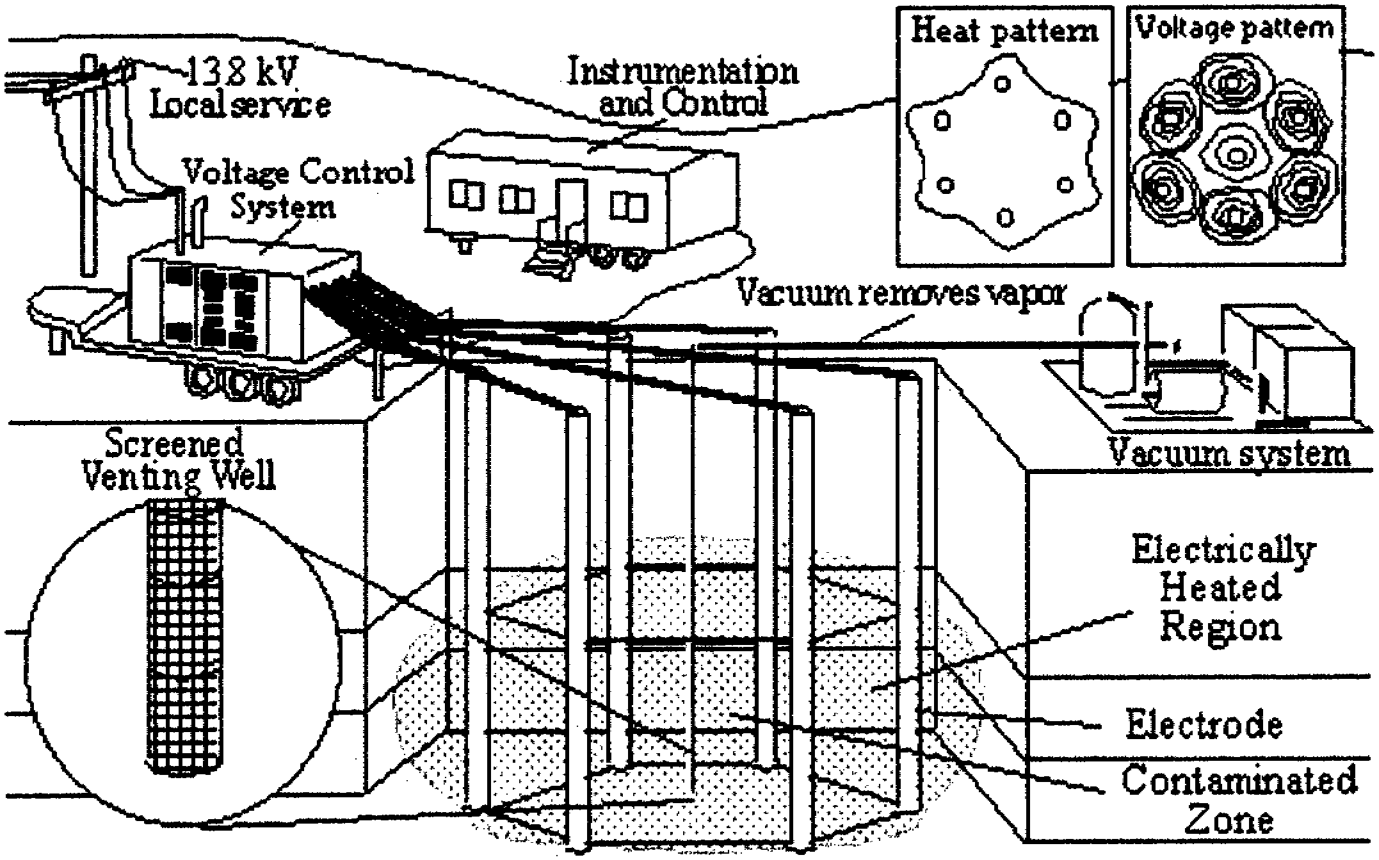

NOTE:
BASE MAP FROM U.S. DEPARTMENT OF ENERGY

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CRAB ORCHARD NWR PCBOU
FOCUSED FEASIBILITY STUDY-REV. 3
MARION, ILLINOIS

PRELIMINARY FLOW DIAGRAM
BUILDING I-1-23
ALTERNATIVE G

DRAWN BY:	DEFOEJ
APPROVED BY:	TEG
PROJECT NO.	4781.12
FILE NO.	47811204.DWG
DATE:	AUGUST 2004

FIGURE 6-7B

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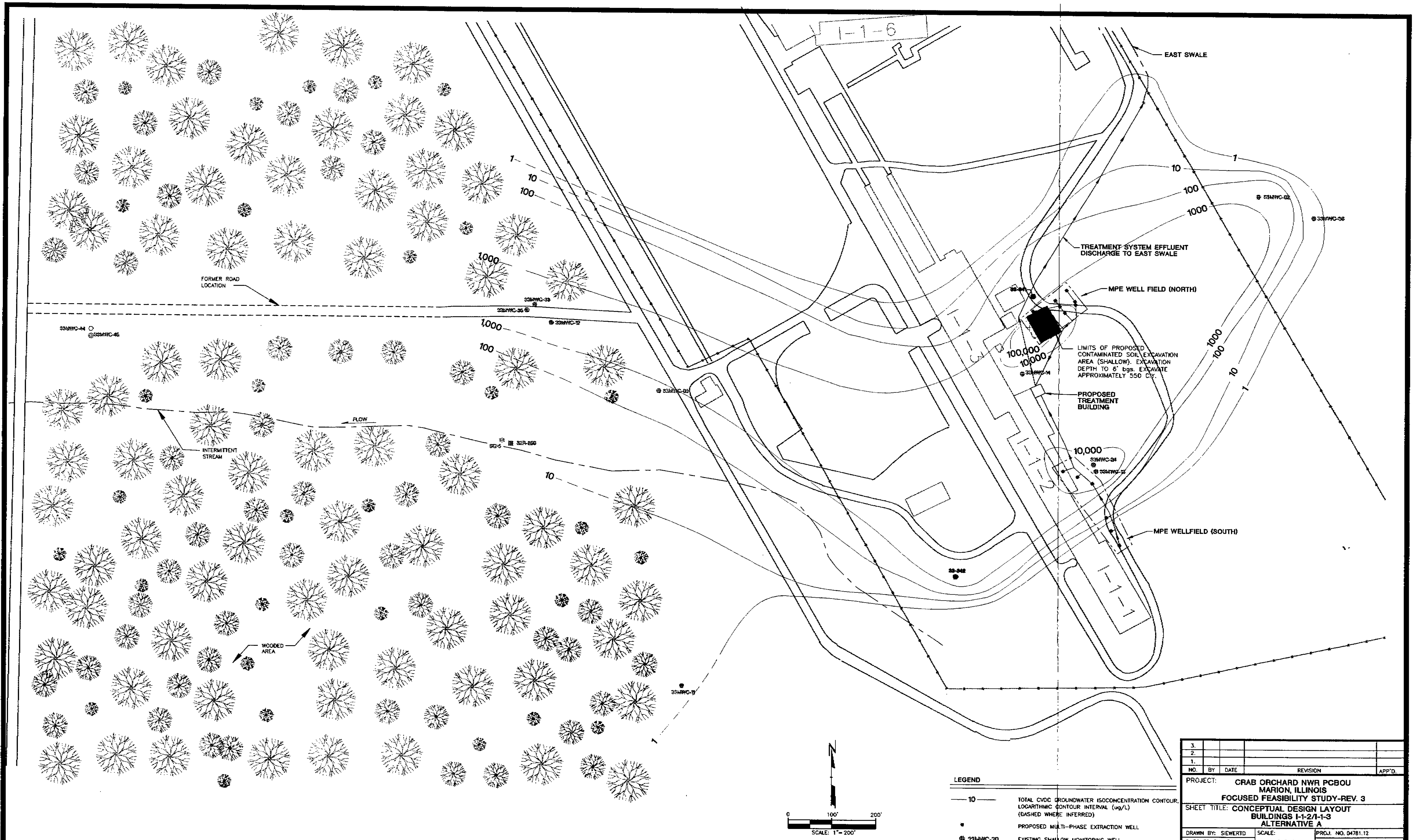

LEGEND

—— 10 ——	TOTAL CVOC GROUNDWATER ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
●	PROPOSED MULTI-PHASE EXTRACTION WELL
⊕ 33MWC-30	EXISTING SHALLOW MONITORING WELL
▨ SG-3	EXISTING STAFF GAUGE
▨ 32R-242	EXISTING SURFACE WATER SAMPLING LOCATION
⊙ 33MWC-32	EXISTING PIEZOMETER

NO.	BY	DATE	REVISION	APP'D.
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PROJECT: CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE: CONCEPTUAL DESIGN LAYOUT
BUILDINGS I-1-2/I-1-3
ALTERNATIVE A

DRAWN BY: SIEWERTD	SCALE: AS SHOWN	PROJ. NO. 04781.12
CHECKED BY: BSS		FILE NO. 47811213.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE 6-8A
DATE: AUGUST 2004		

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Plot Date: Wednesday, June 30,
Plot Time: 07:30:08 AM
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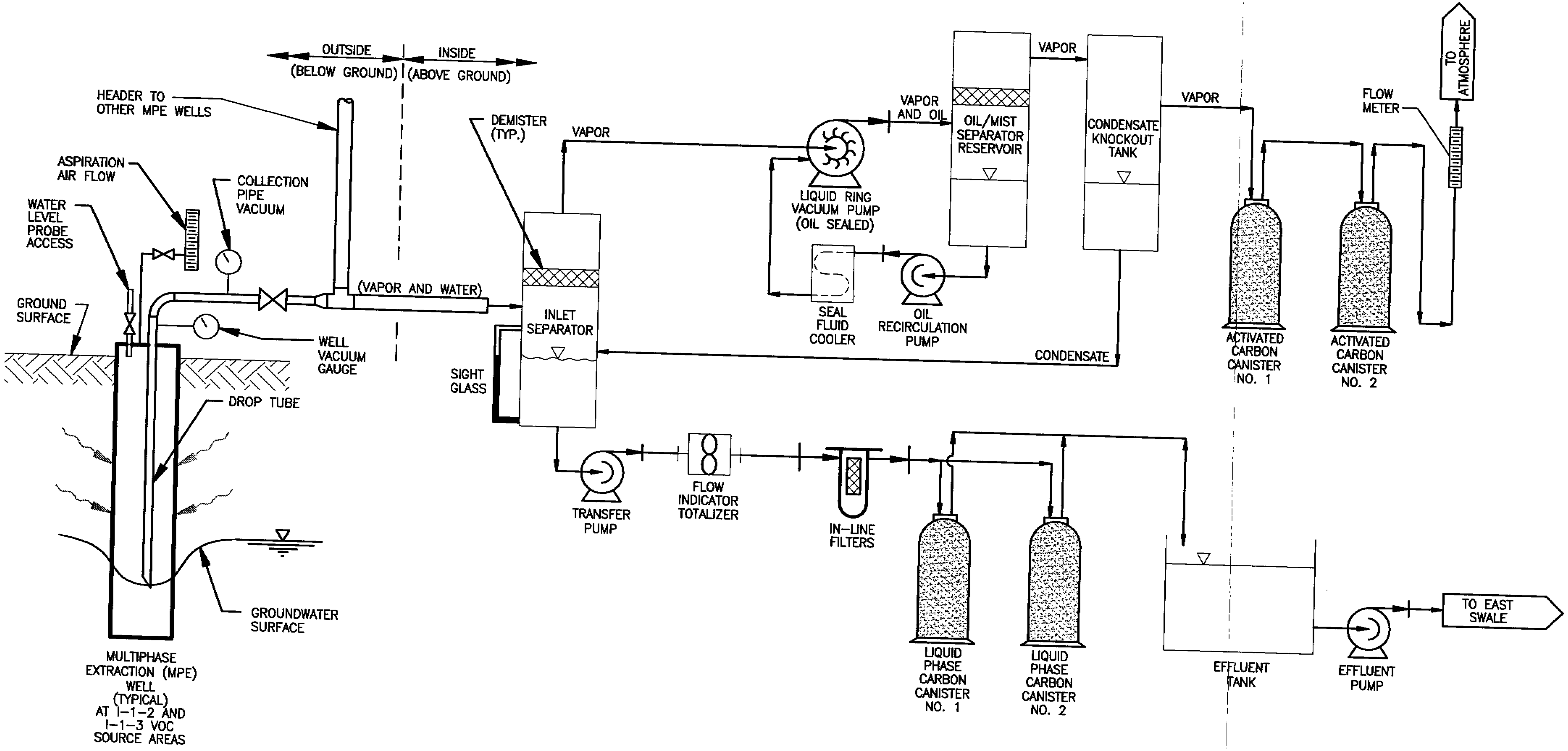

PROJECT: CRAB ORCHARD NWR PCBOU FOCUSED FEASIBILITY STUDY REV. 3 MARION, ILLINOIS		
SHEET TITLE: PRELIMINARY FLOW DIAGRAM BUILDINGS I-1-2 / I-1-3 ALTERNATIVE A		
DRAWN BY: SIEWERTD	SCALE:	PROJ. NO. 04781.12
CHECKED BY: BSS	NONE	FILE NO. 47811214.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE 6-8B
DATE: AUGUST 2004		

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Fax: 608-831-3334

Drawing Name: 4781\12\4781214.dwg
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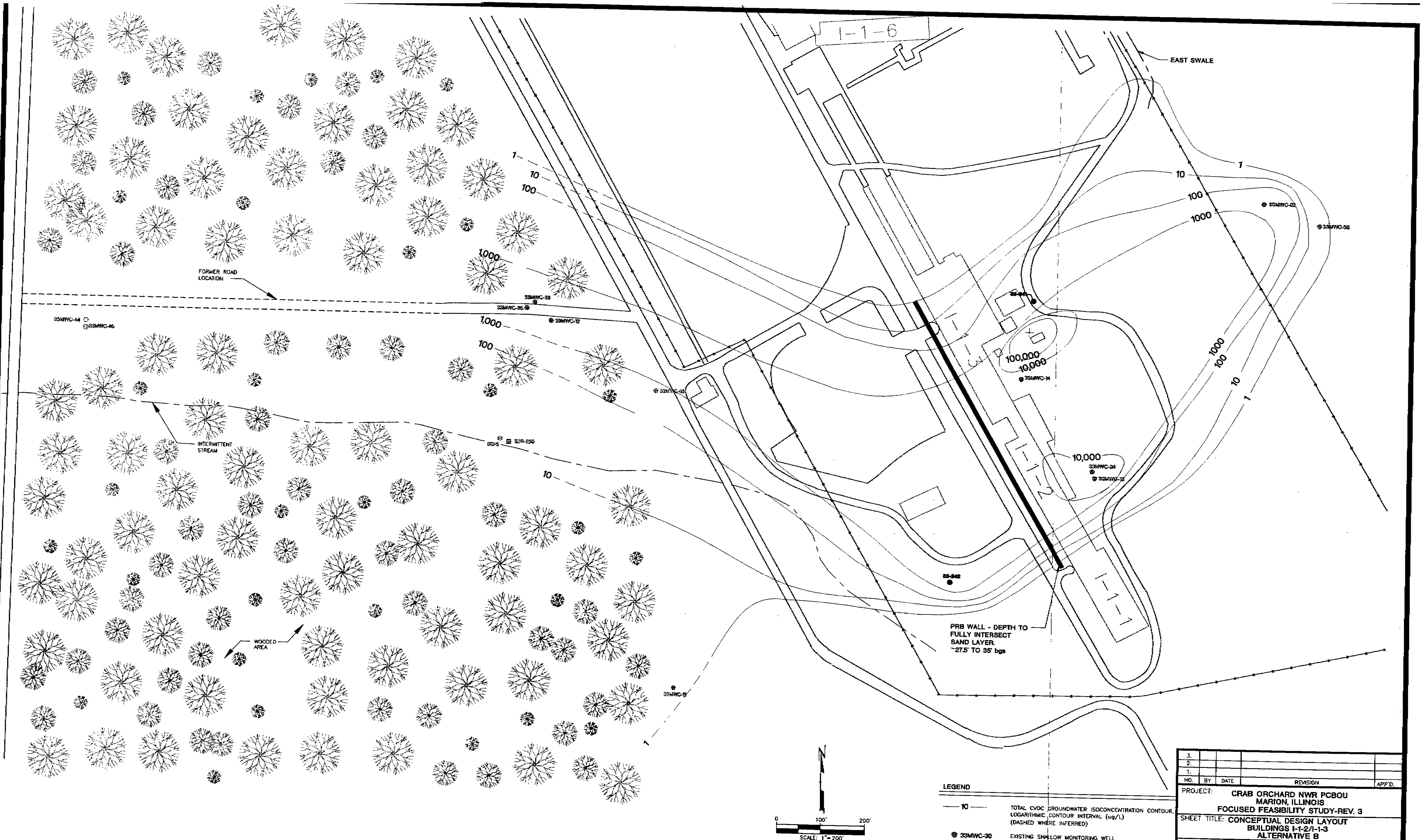

LEGEND

—— 10 ——	TOTAL CVOC GROUNDWATER ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
33MWC-30	EXISTING SHALLOW MONITORING WELL
SG-3	EXISTING STAFF GAUGE
32R-242	EXISTING SURFACE WATER SAMPLING LOCATION
33MWC-32	EXISTING PIEZOMETER

NO.	BY	DATE	REVISION	APP'D.
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PROJECT: CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE: CONCEPTUAL DESIGN LAYOUT
BUILDINGS I-1-2/I-1-3
ALTERNATIVE B

DRAWN BY: SIEWERTD	SCALE: AS SHOWN	PROJ. NO. 04781.12
CHECKED BY: BSS		FILE NO. 47811215.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE 6-9
DATE: AUGUST 2004		

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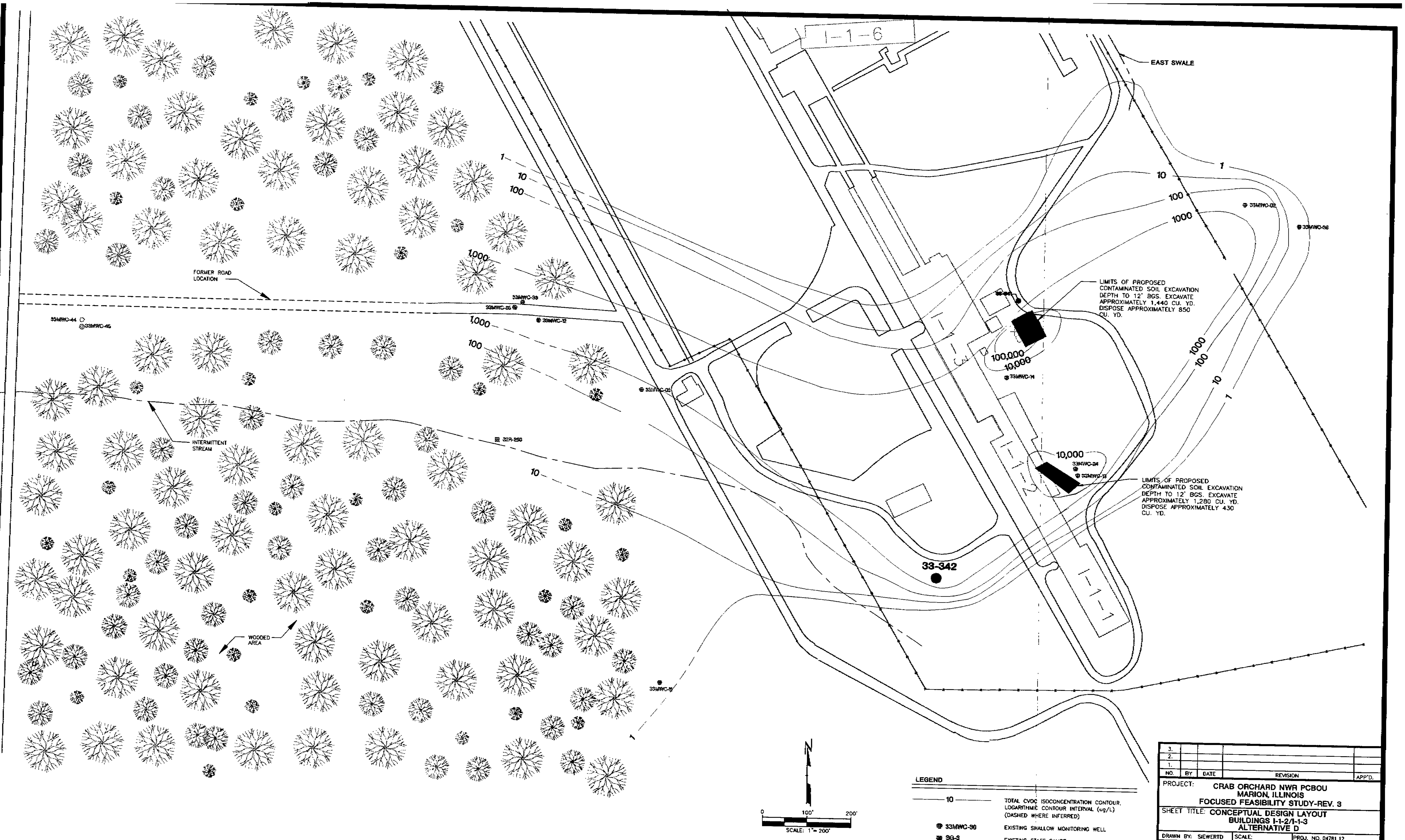

LIMITS OF PROPOSED CONTAMINATED SOIL EXCAVATION DEPTH TO 12' BGS. EXCAVATE APPROXIMATELY 1,440 CU. YD. DISPOSE APPROXIMATELY 850 CU. YD.

LIMITS OF PROPOSED CONTAMINATED SOIL EXCAVATION DEPTH TO 12' BGS. EXCAVATE APPROXIMATELY 1,280 CU. YD. DISPOSE APPROXIMATELY 430 CU. YD.

LEGEND

——— 10 ———	TOTAL CVOC ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
⊕ 33MWC-90	EXISTING SHALLOW MONITORING WELL
▨ SG-3	EXISTING STAFF GAUGE
▦ 32R-242	EXISTING SURFACE WATER SAMPLING LOCATION
⊛ 33MWC-32	EXISTING PIEZOMETER

NO.	BY	DATE	REVISION	APP'D.
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PROJECT: CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE: CONCEPTUAL DESIGN LAYOUT
BUILDINGS I-1-2/I-1-3
ALTERNATIVE D

DRAWN BY: SIEWERTD	SCALE:	PROJ. NO. 04781.12
CHECKED BY: BSS	AS SHOWN	FILE NO. 47811216.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE 6-10
DATE: AUGUST 2004		

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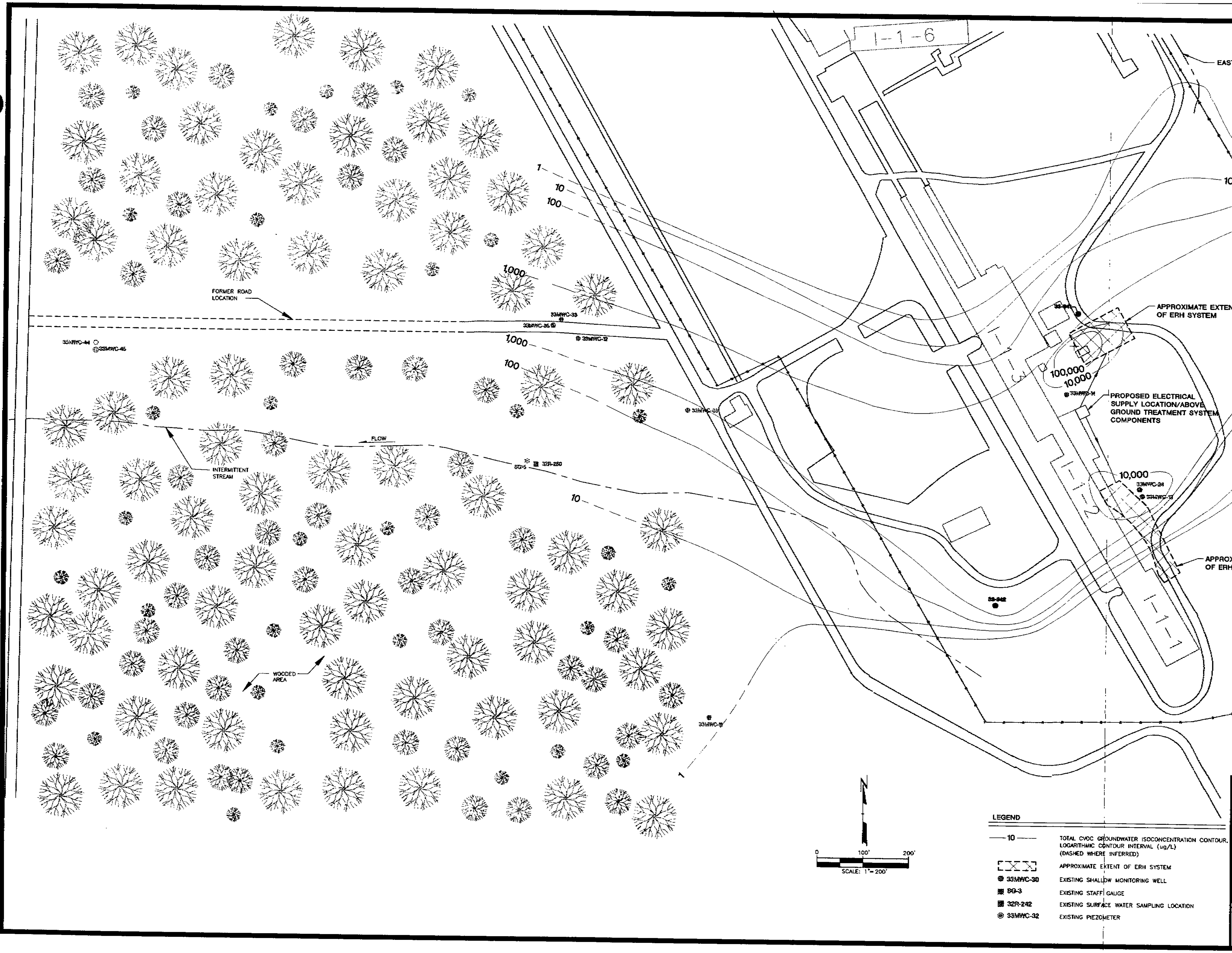

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PROJECT: CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE: CONCEPTUAL DESIGN LAYOUT
BUILDINGS I-1-2/I-1-3
ALTERNATIVE F

DRAWN BY: SIEWERTD	SCALE:	PROJ. NO. 04781.12
CHECKED BY: BSS	AS SHOWN	FILE NO. 47811217.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE 6-11
DATE: AUGUST 2004		

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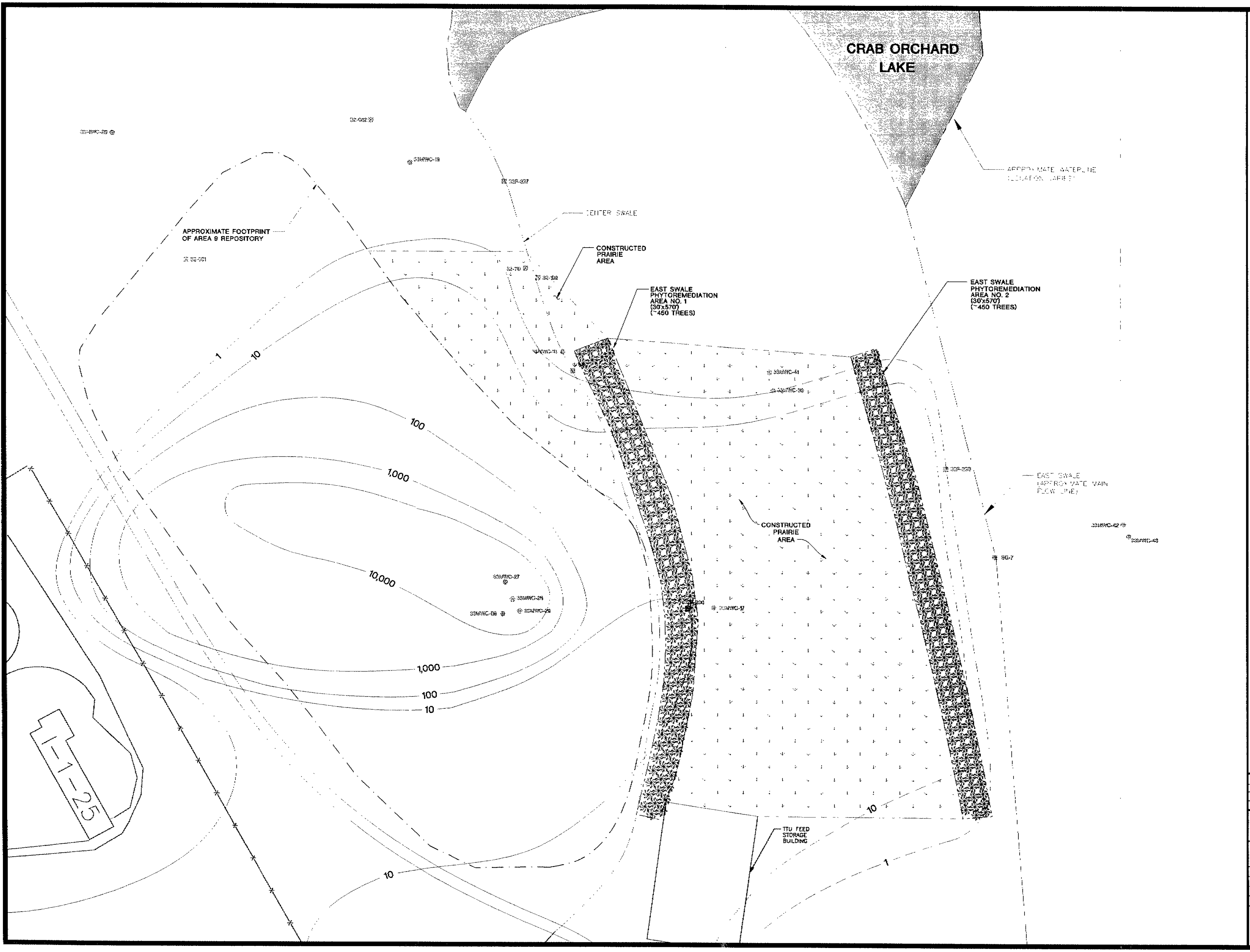

LEGEND

— 10 —	TOTAL CVOC GROUNDWATER ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
	EXISTING SHALLOW MONITORING WELL
	EXISTING PIEZOMETER
	EXISTING STAFF GAUGE
	EXISTING SURFACE WATER SAMPLING LOCATION
	MONITORING WELL, ABANDONED (APPROXIMATE LOCATION)
— — —	APPROXIMATE CENTERLINE OF SURFACE DRAINAGE CHANNEL/SWALE
	FENCE
— · —	APPROXIMATE FOOTPRINT OF AREA 9 REPOSITORY
▨	PROPOSED PHYTOREMEDIATION AREA (APPROXIMATE LOCATION)
☐	PROPOSED CONSTRUCTED PRAIRIE AREA (APPROXIMATE LOCATION)

0 50' 100'
SCALE: 1"= 100'

NO	BY	DATE	REVISION	APP'D.
3.				
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1.				

PROJECT: CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY-REV. 3

SHEET TITLE: CONCEPTUAL DESIGN LAYOUT
REPOSITORY-ALTERNATIVES A & B

DRAWN BY: SIEWERTD	SCALE: 1"=100'	PROJ. NO. 04781 12
CHECKED BY: BSS		FILE NO. 47811218.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE 6-12
DATE: AUGUST 2004		

RMT INC

744 Heartland Trail
Madison, WI 53717-1934
P.O. Box 8923 53708-8923
Phone: 608-831-4444
Fax: 608-831-3334

Dwg Size: 15406
Plot Date: Wedne 2004
Plot Time: 07:58
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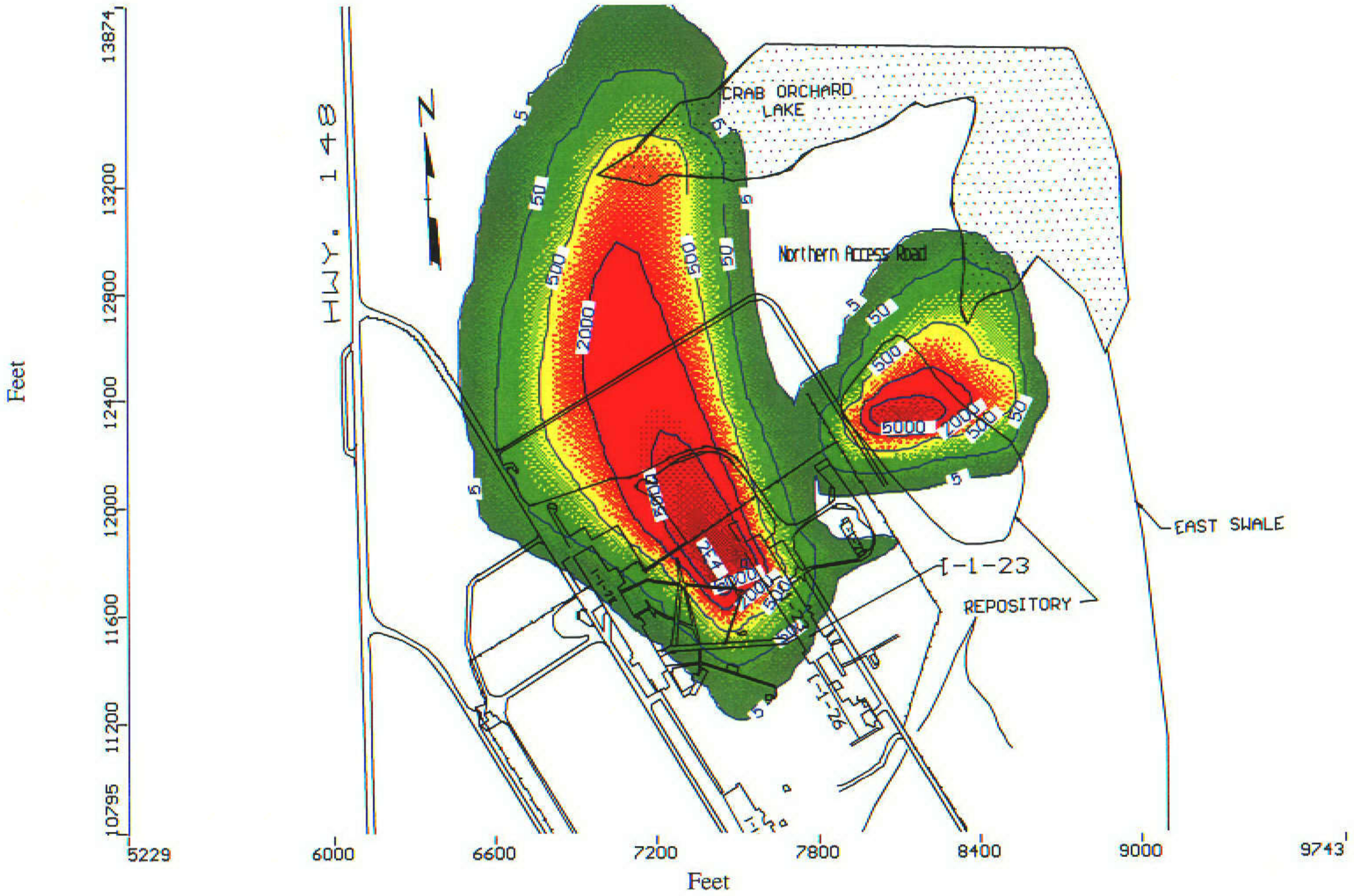
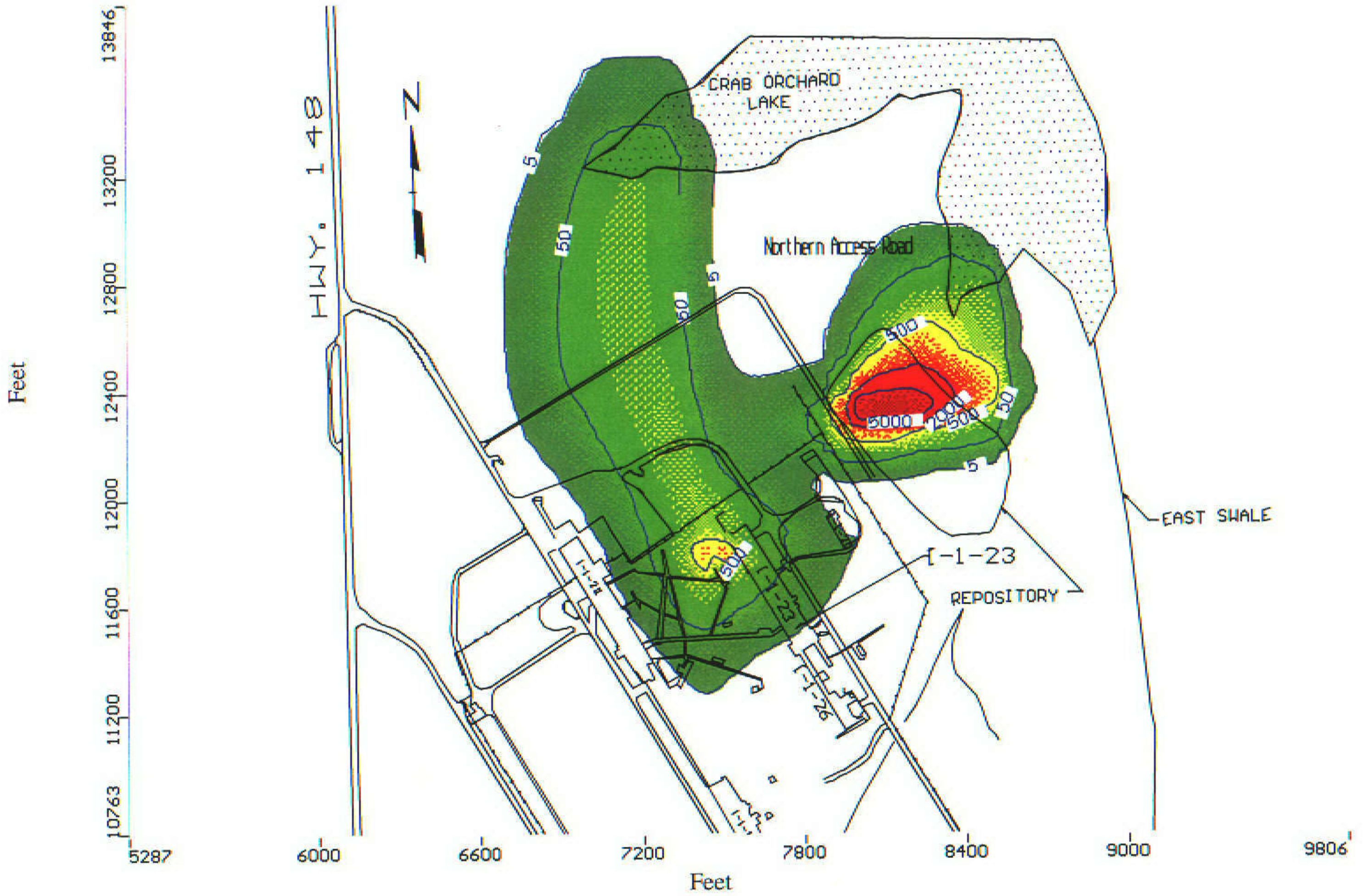


Building I-1-23 – Current Conditions; TCE (µg/L)

Figure 7-1

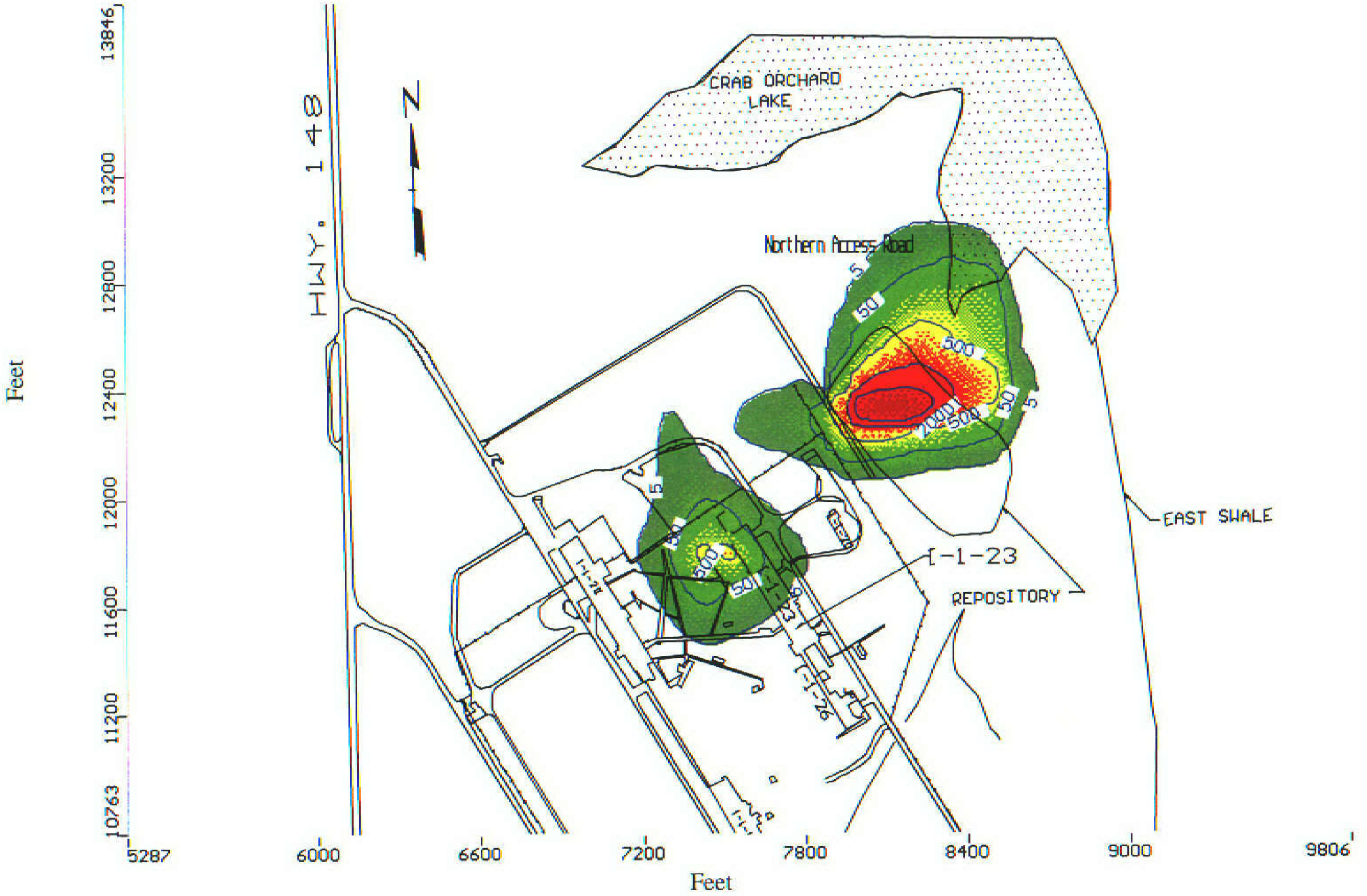
I:\WPMSN\00-04781\12\Figures.ppt



Building I-1-23 - Alternative A1
Excavate to 10 mg/kg / Long-term Pumping – Year 15; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-2



Building I-1-23 - Alternative A1

Excavate to 10 mg/kg / Long-term Pumping – Year 40; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-3

PLOT DATA
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Operator Name: siewertd

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Dwg Size: 83277 Bytes
Plot Date: Tuesday, June 10, 2003

Plot Time: 3:13.30 PM
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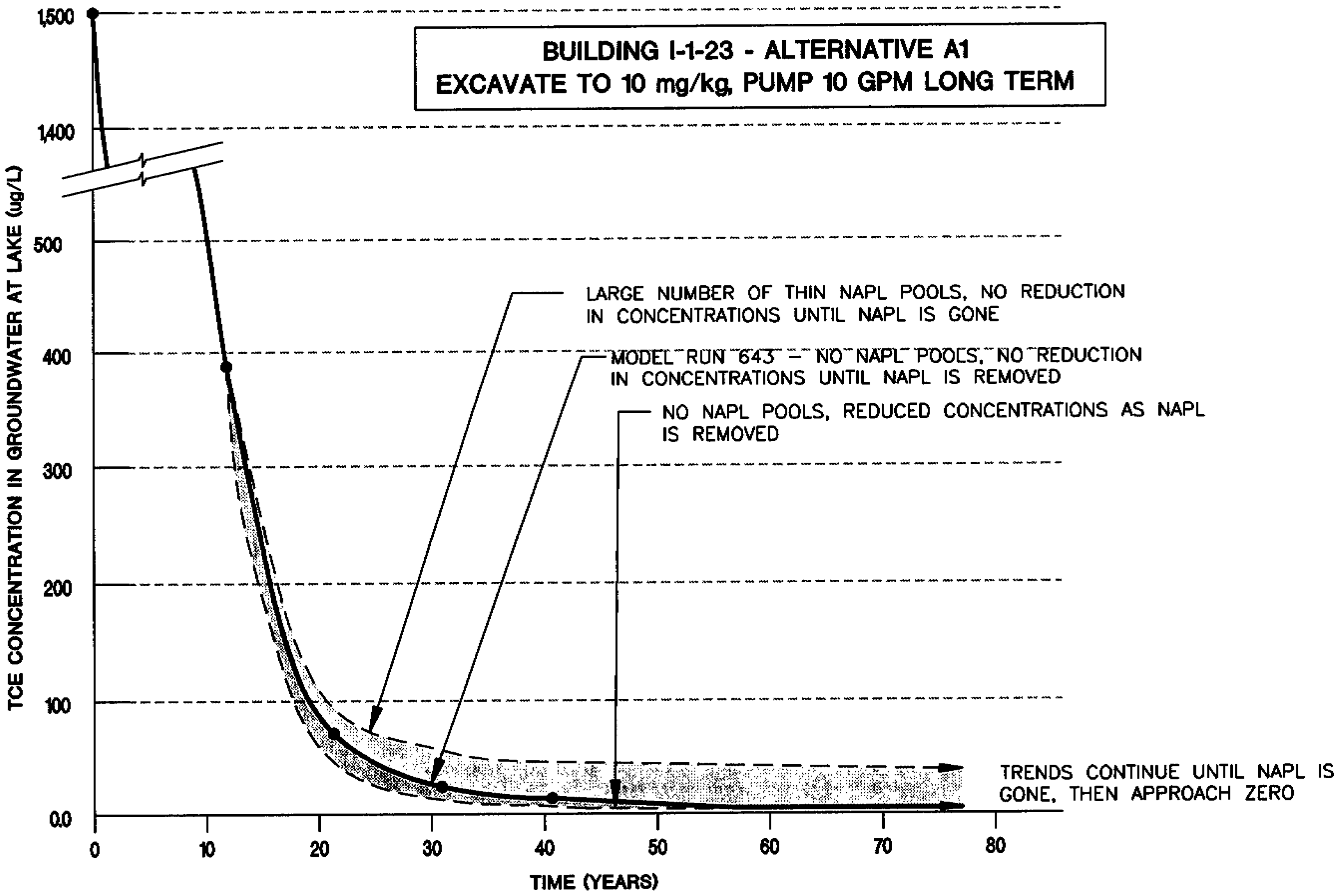


BUILDING I-1-23 - ALTERNATIVE A1
EXCAVATE TO 10 mg/kg, PUMP 10 GPM LONG TERM

LARGE NUMBER OF THIN NAPL POOLS, NO REDUCTION IN CONCENTRATIONS UNTIL NAPL IS GONE

MODEL RUN 643 – NO NAPL POOLS, NO REDUCTION IN CONCENTRATIONS UNTIL NAPL IS REMOVED

NO NAPL POOLS, REDUCED CONCENTRATIONS AS NAPL IS REMOVED

TRENDS CONTINUE UNTIL NAPL IS GONE, THEN APPROACH ZERO

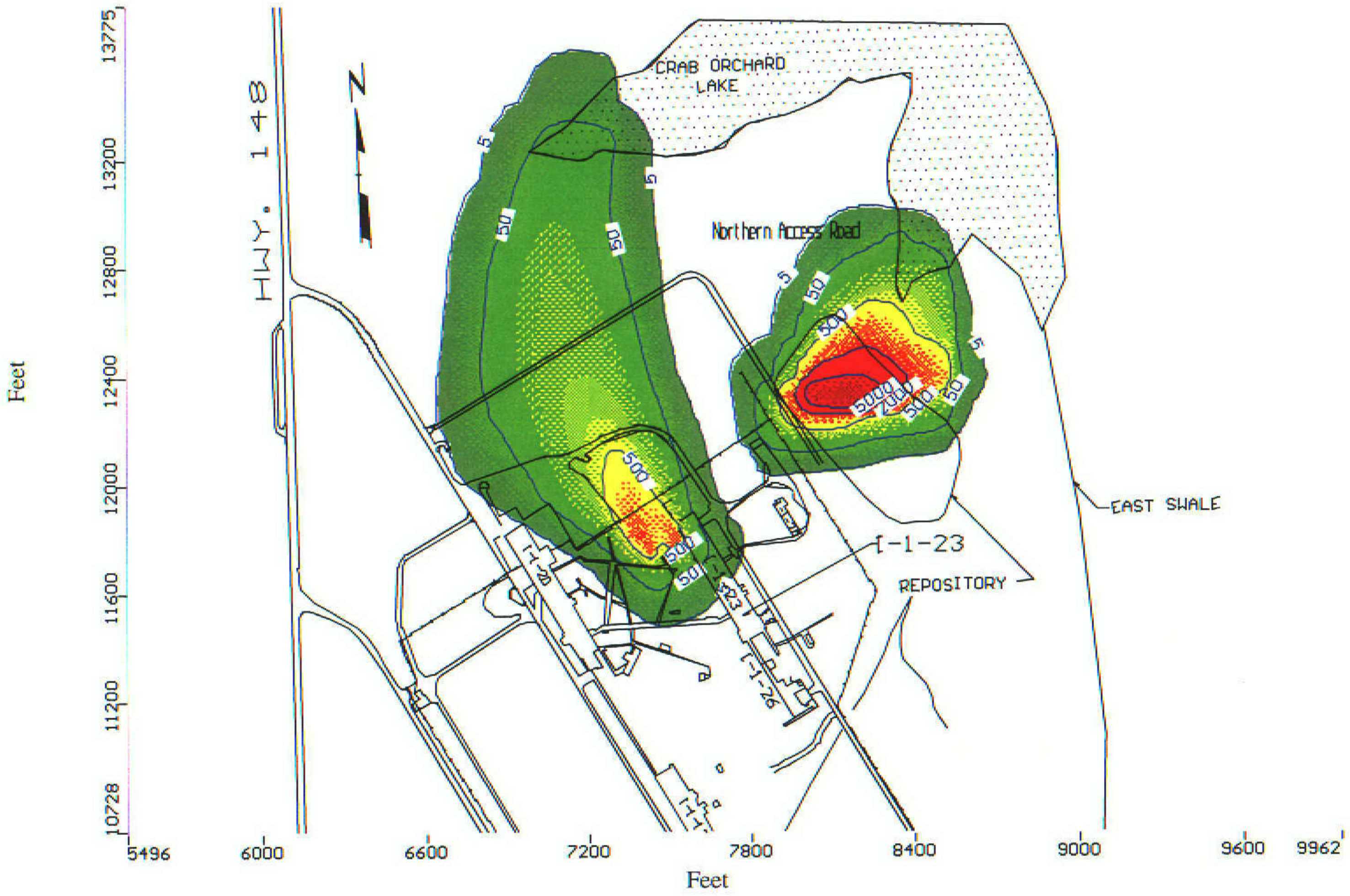
RMT INC.

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER AT LAKE OVER TIME

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811225.DWG
DATE:	AUGUST 2004

FIGURE 7-4



Building I-1-23 - Alternative A1

Excavate to 10 mg/kg / Pump 40 Years.; Rebound 30 Years.; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-5

PLOT DATA
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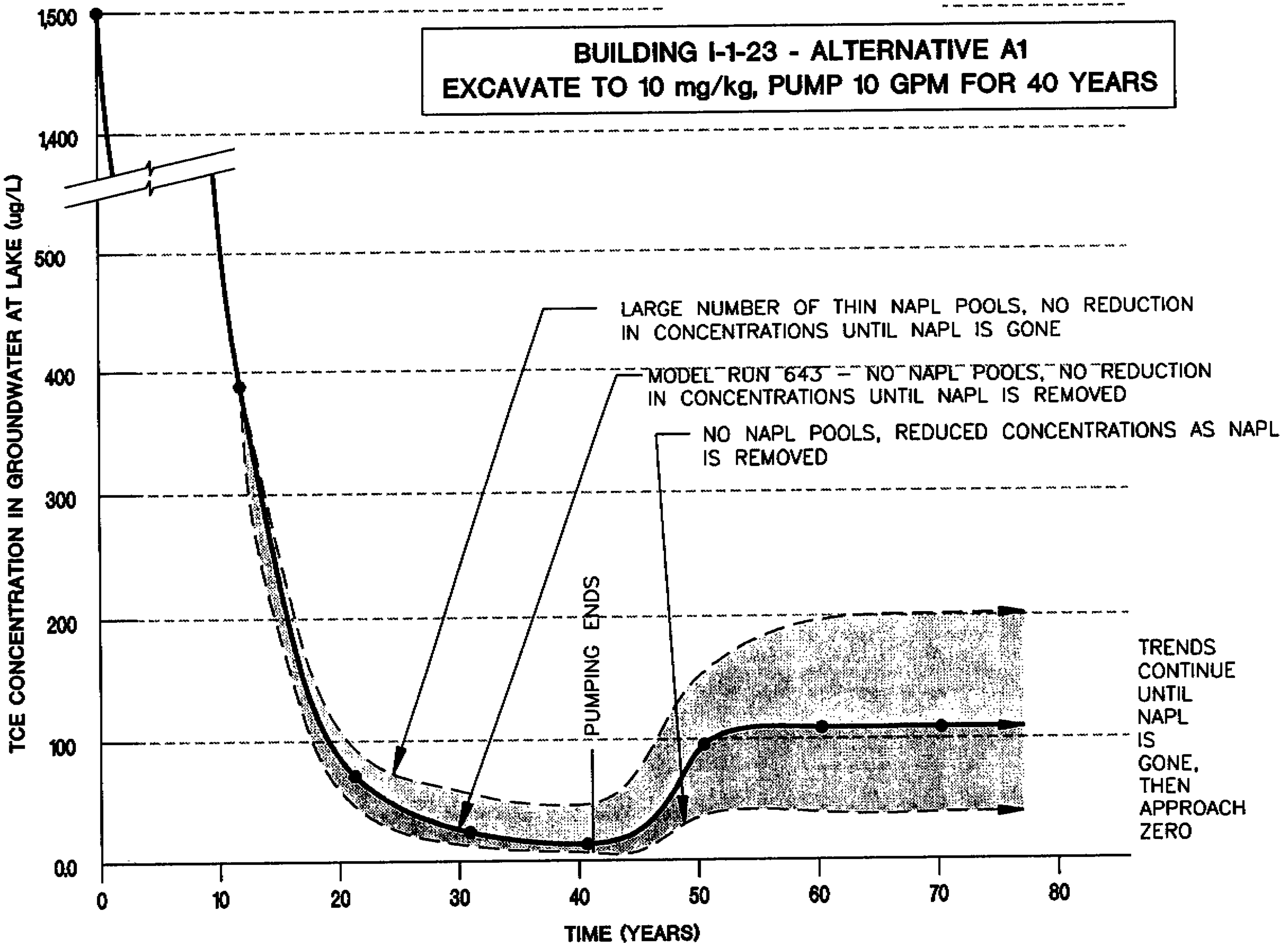


BUILDING I-1-23 - ALTERNATIVE A1
EXCAVATE TO 10 mg/kg, PUMP 10 GPM FOR 40 YEARS

LARGE NUMBER OF THIN NAPL POOLS, NO REDUCTION IN CONCENTRATIONS UNTIL NAPL IS GONE

MODEL RUN 643 – NO NAPL POOLS, NO REDUCTION IN CONCENTRATIONS UNTIL NAPL IS REMOVED

NO NAPL POOLS, REDUCED CONCENTRATIONS AS NAPL IS REMOVED

TRENDS CONTINUE UNTIL NAPL IS GONE, THEN APPROACH ZERO

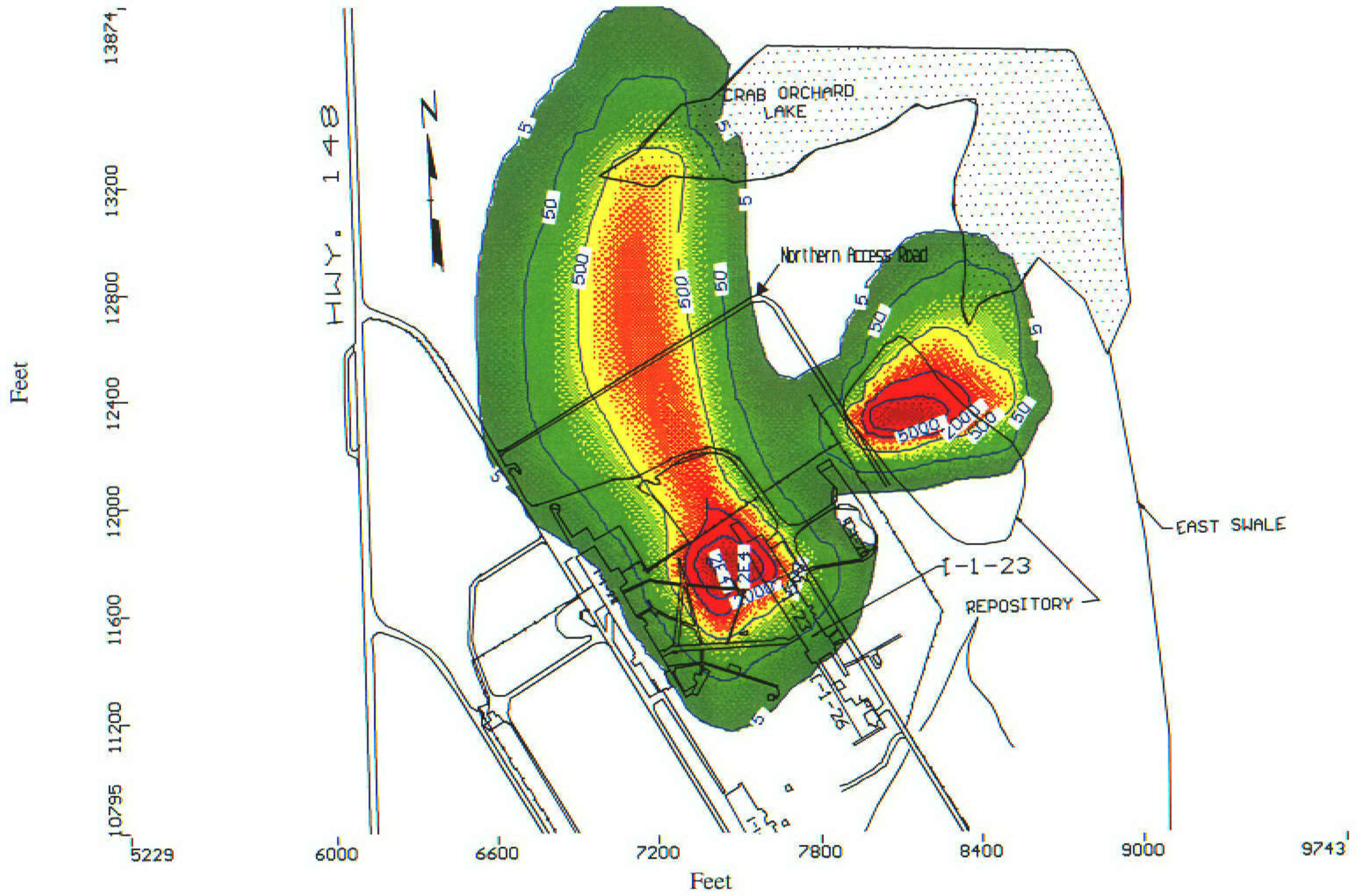
RMT INC.

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER AT LAKE OVER TIME

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811225.DWG
DATE:	AUGUST 2004

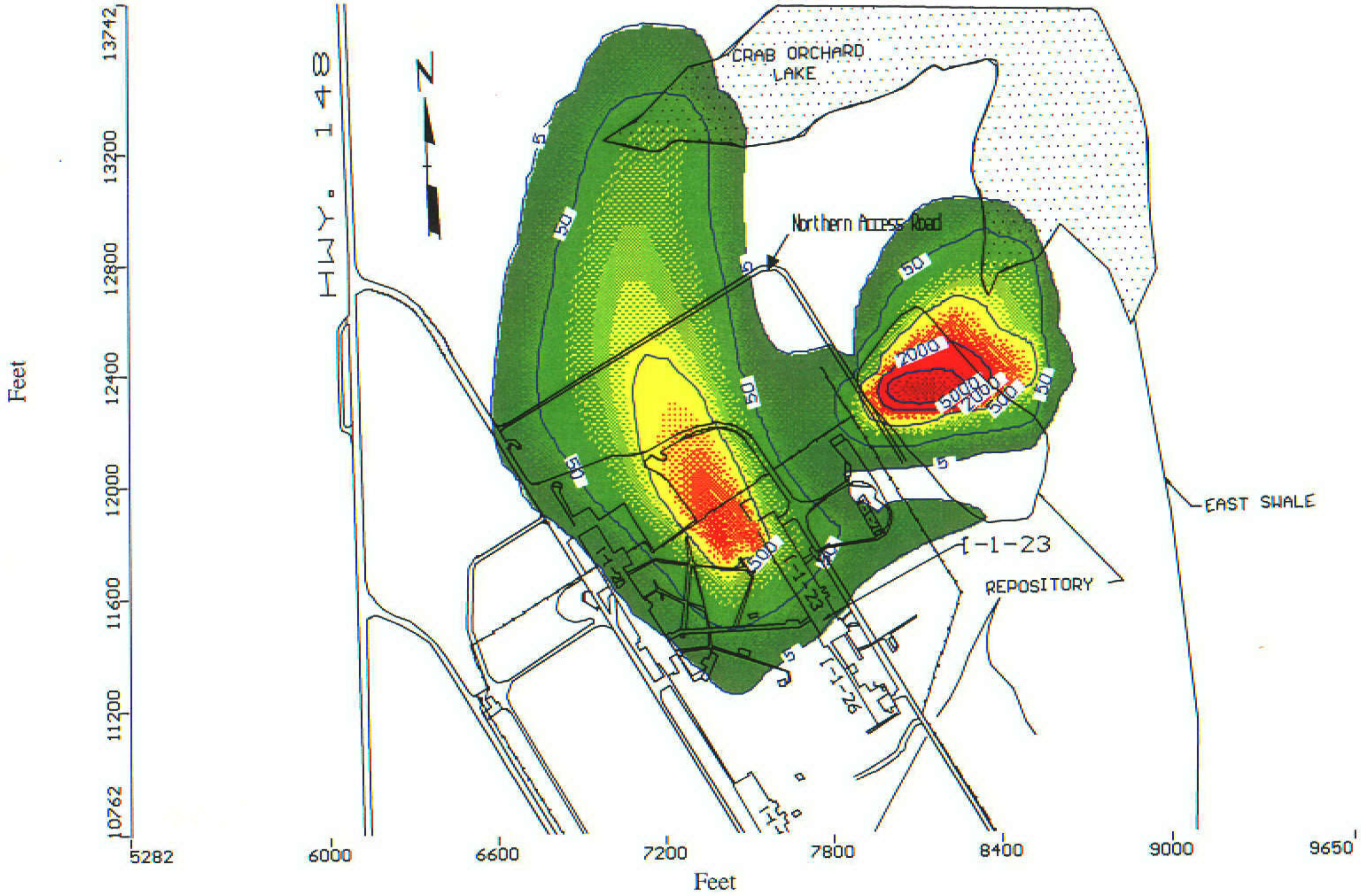
FIGURE 7-6



Building I-1-23 - Alternative A1
Excavate to 10 mg/kg / 11 Years Pumping – Year 5; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-7

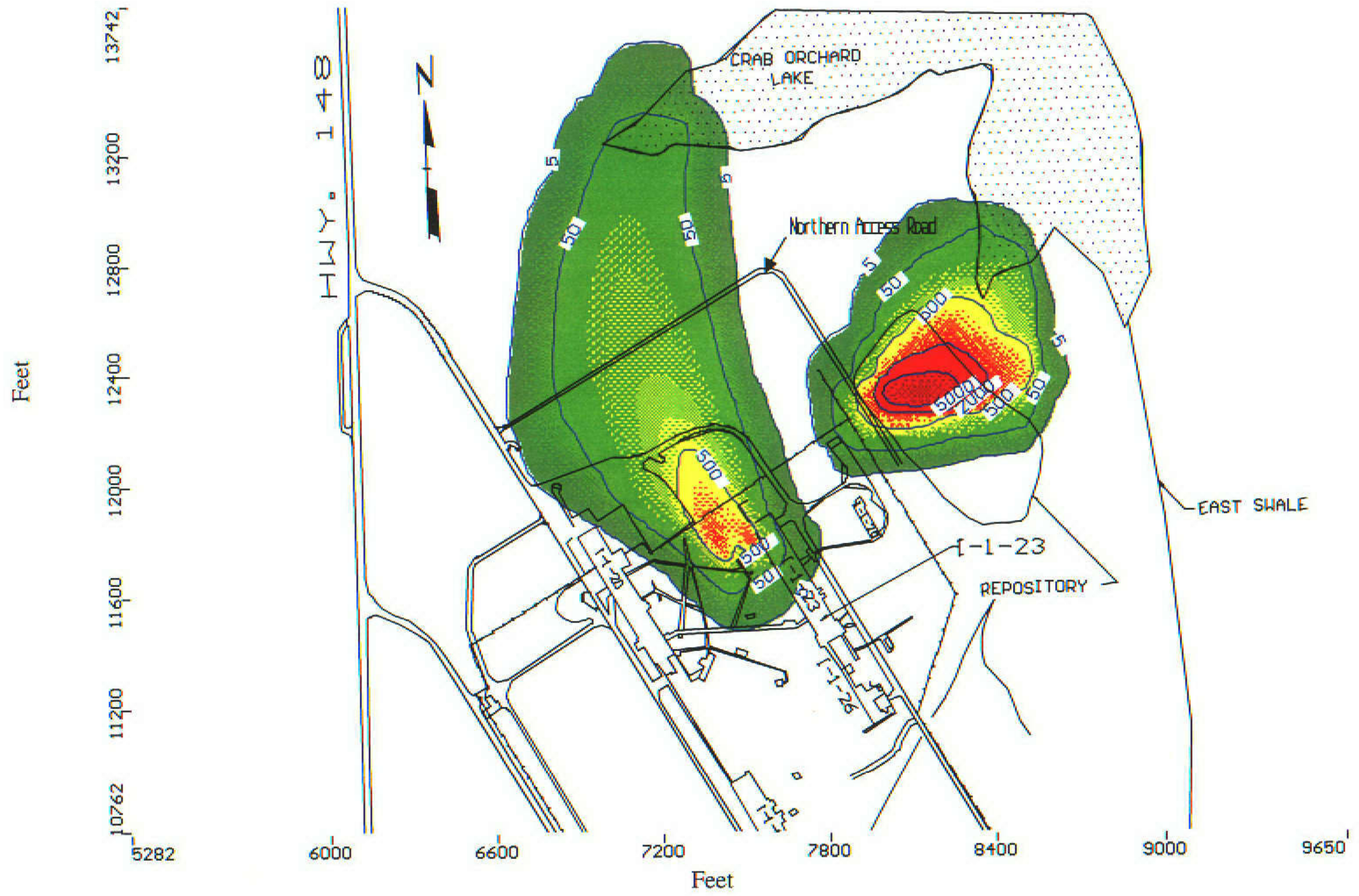


Building I-1-23 - Alternative A1

Excavate to 10 mg/kg / 11 Years Pumping – Year 15; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-8



Building I-1-23 - Alternative A1

Excavate to 10 mg/kg / 11 Years Pumping – Year 49; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-9

PLOT DATA
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Operator Name: siewertd

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Plot Time: 3:13.30 PM
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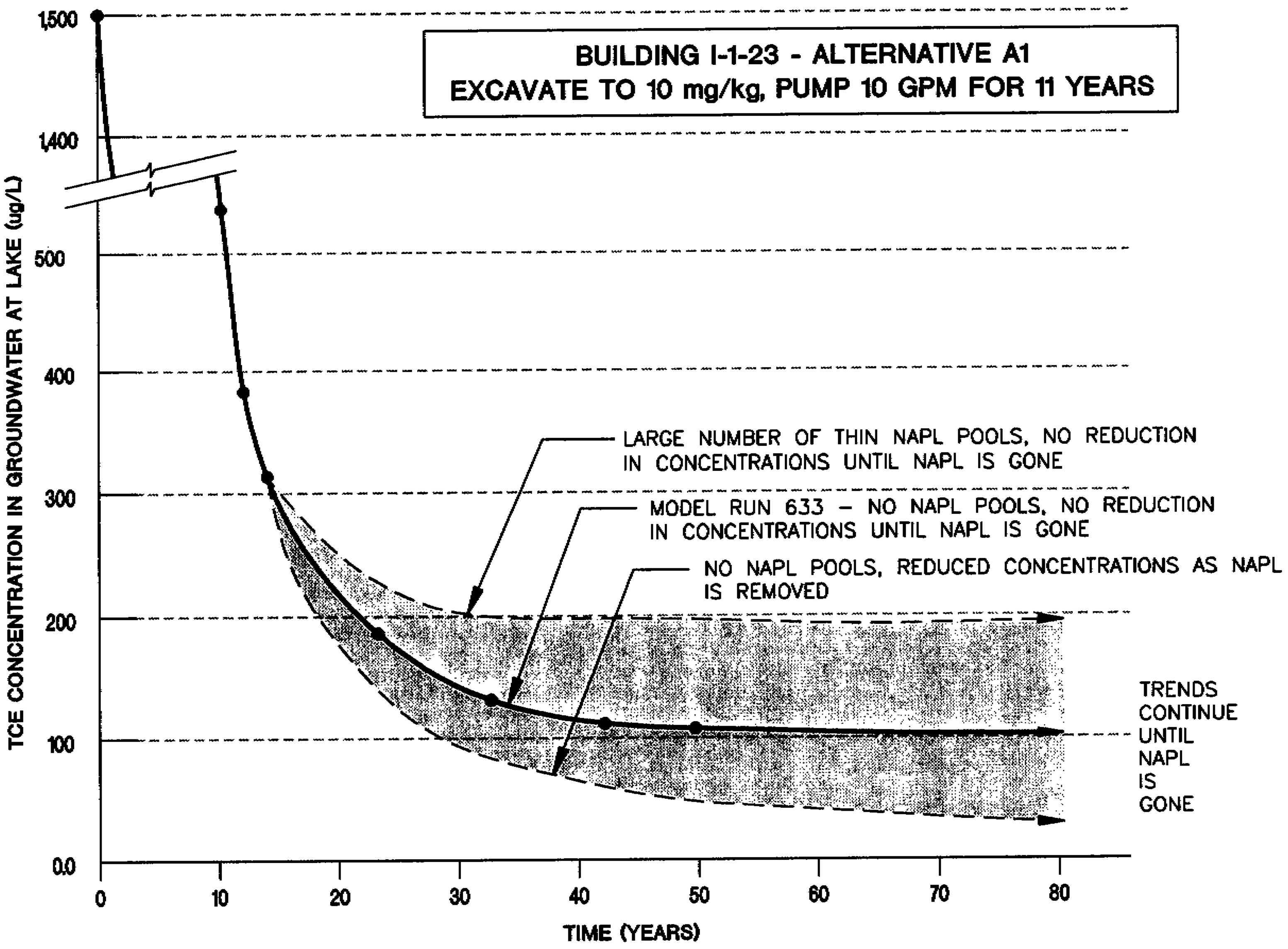

BUILDING I-1-23 - ALTERNATIVE A1
EXCAVATE TO 10 mg/kg, PUMP 10 GPM FOR 11 YEARS

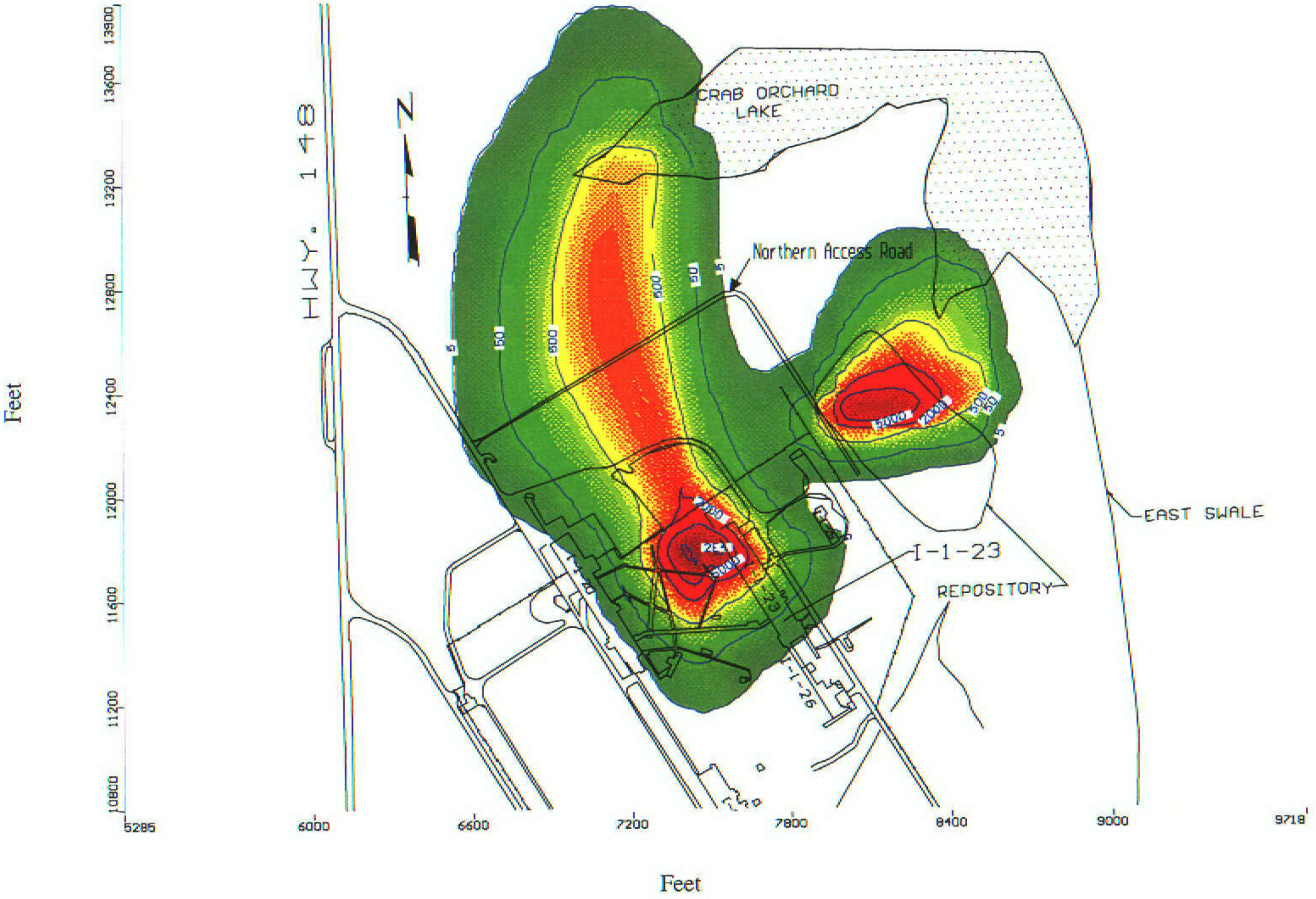
RMT INC.

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER AT LAKE OVER TIME

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811225.DWG
DATE:	AUGUST 2004

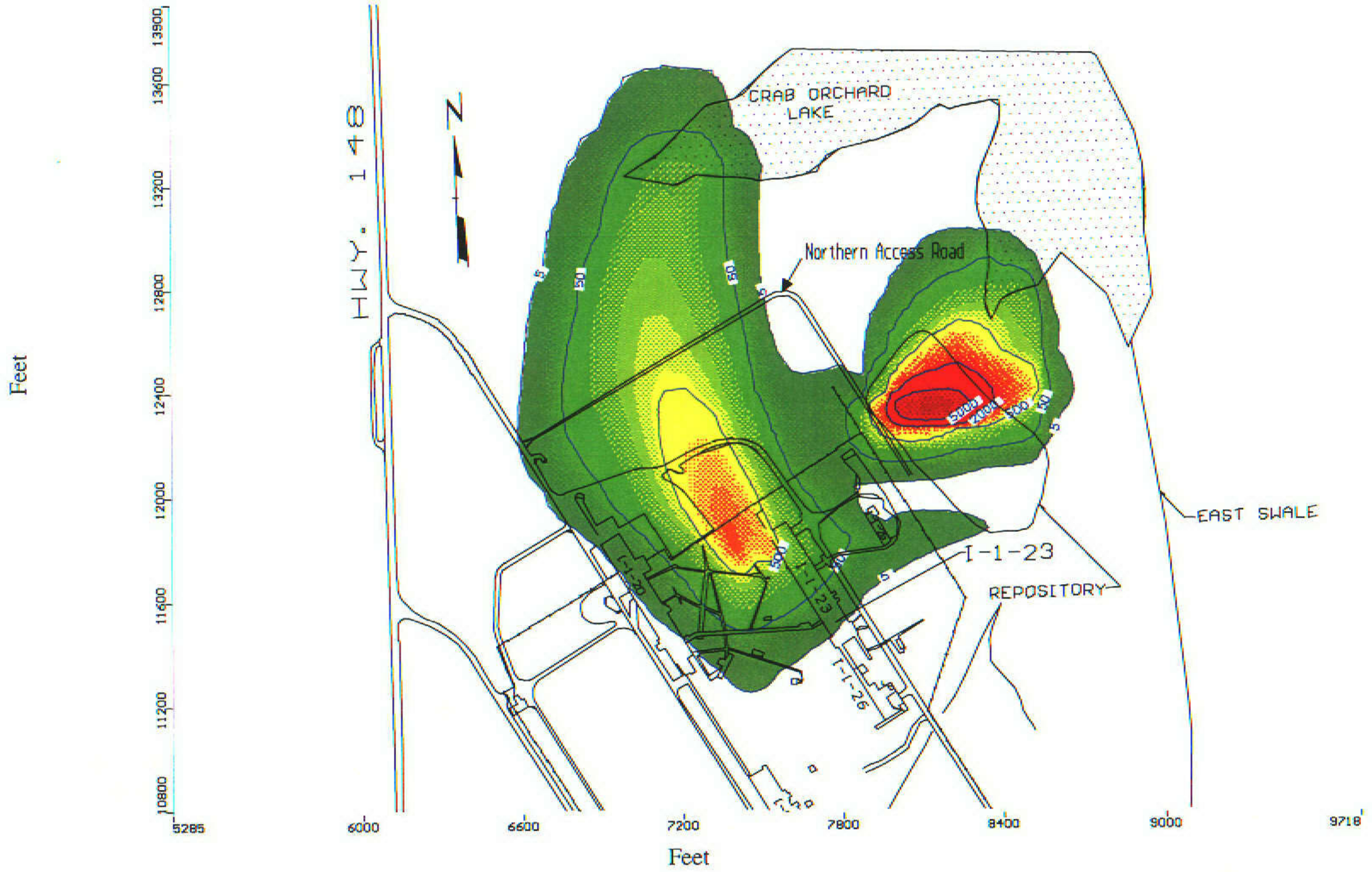
FIGURE 7-10



Building I-1-23 - Alternative A2
Excavate to 1 mg/kg / 11 Years Pumping – Year 5: TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-11

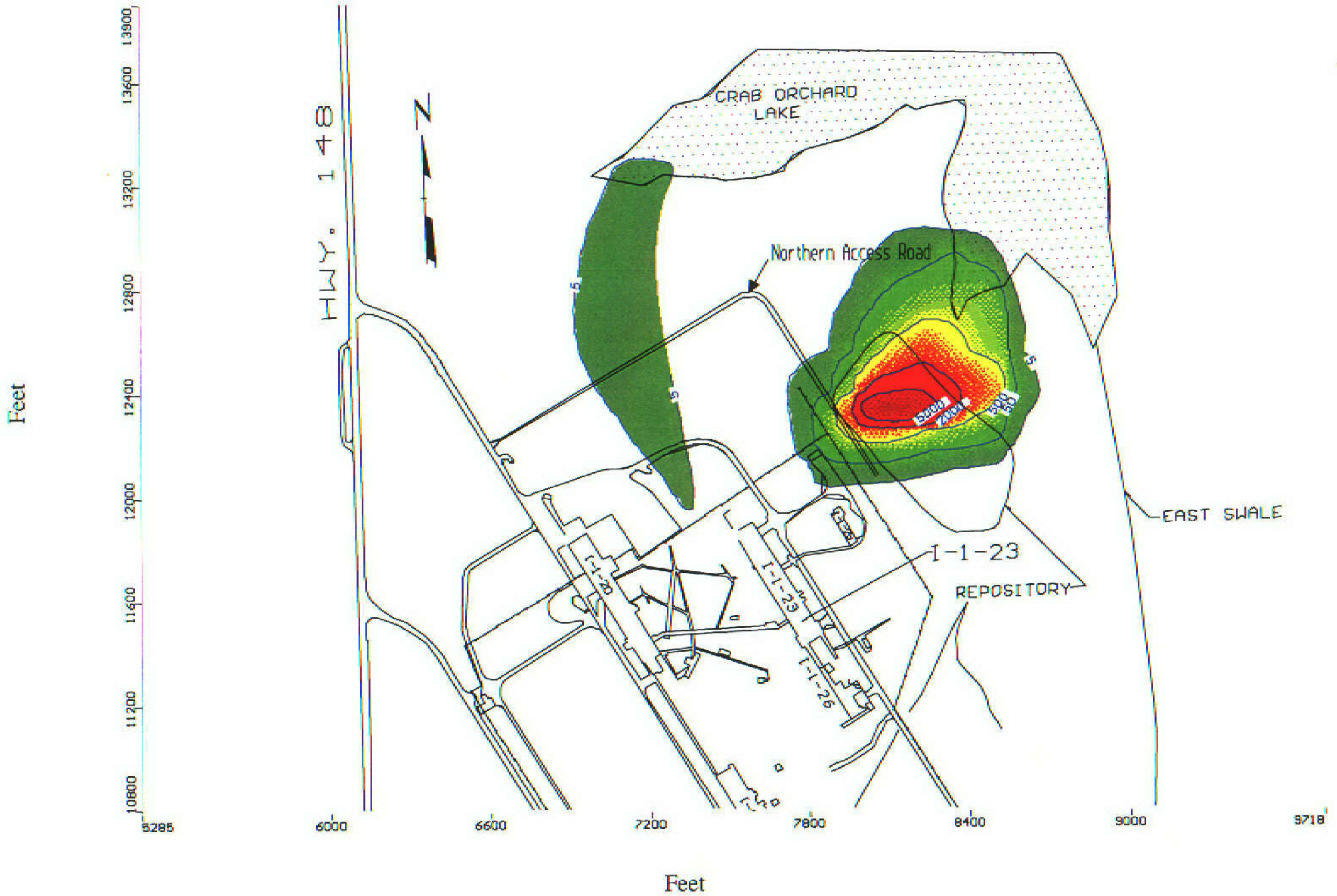


Building I-1-23 - Alternative A2

Excavate to 1 mg/kg / 11 Years Pumping – Year 15: TCE (μg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-12



Building I-1-23 - Alternative A2
Excavate to 1 mg/kg / 11 Years Pumping – Year 39: TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-13

PLOT DATA
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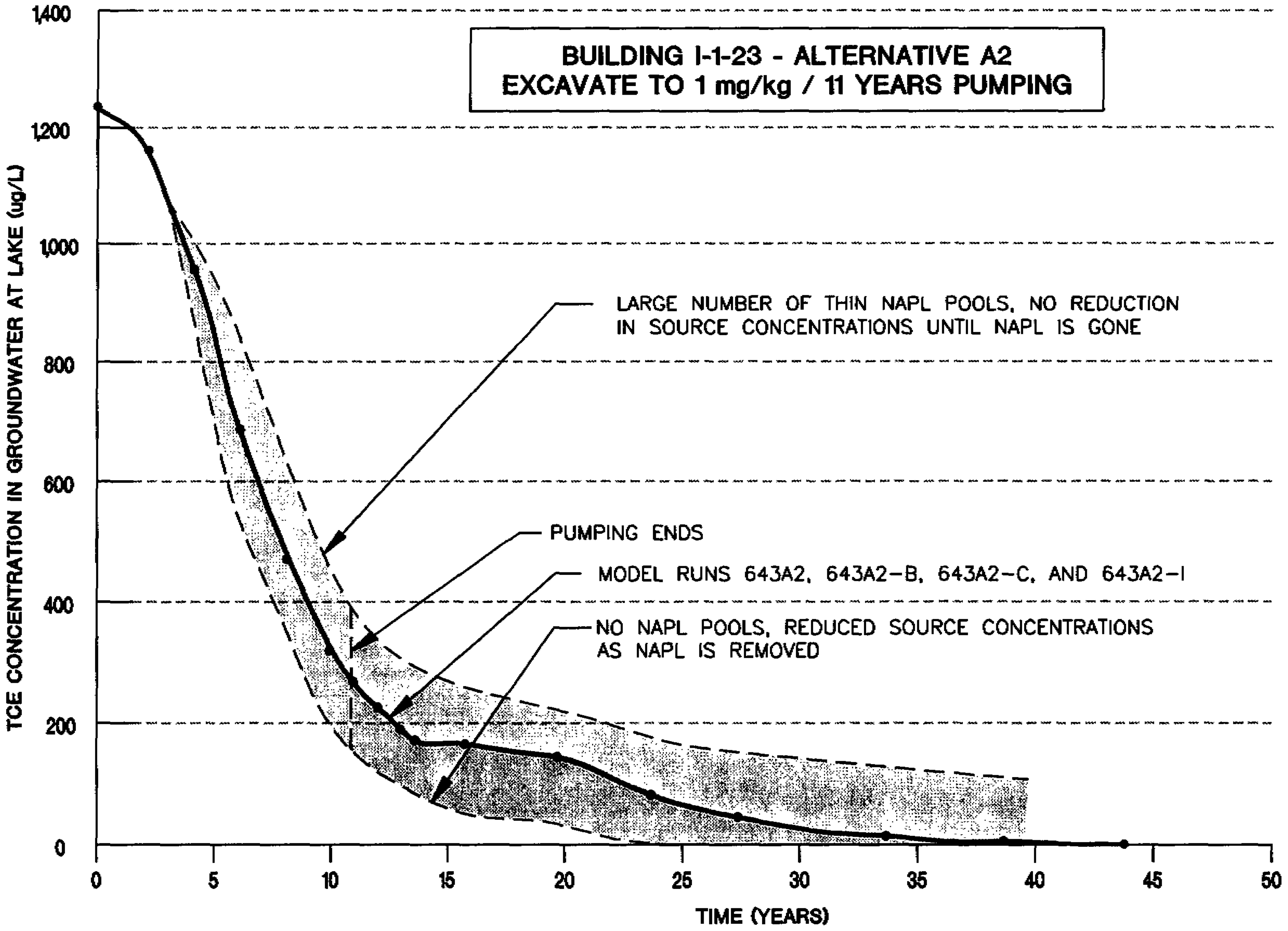


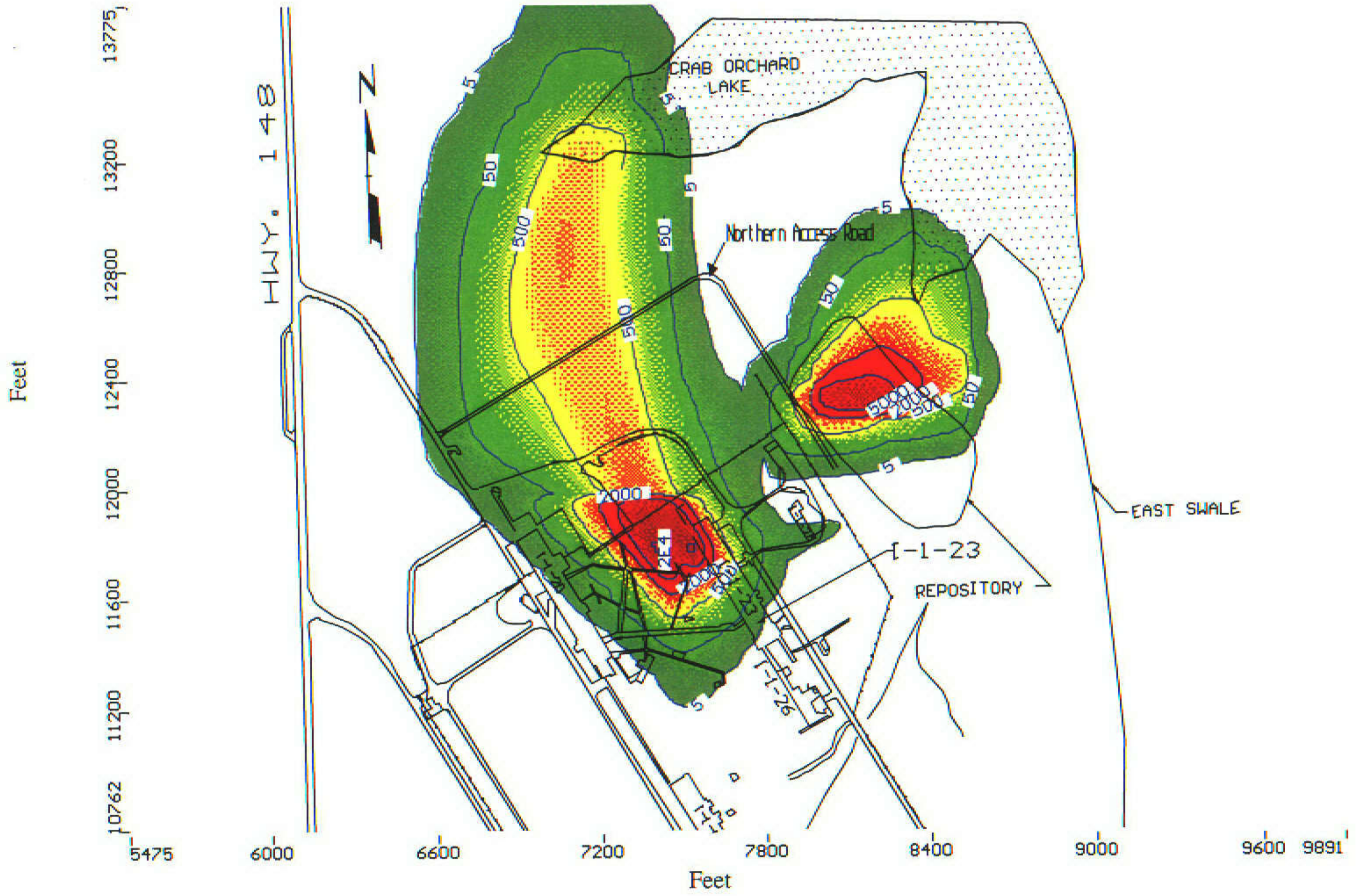
RMT INC.

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER AT LAKE OVER TIME

DRAWN BY: SIEWERTD
APPROVED BY: TEG
PROJECT NO. 04781.12
FILE NO. 47811205.DWG
DATE: AUGUST 2004

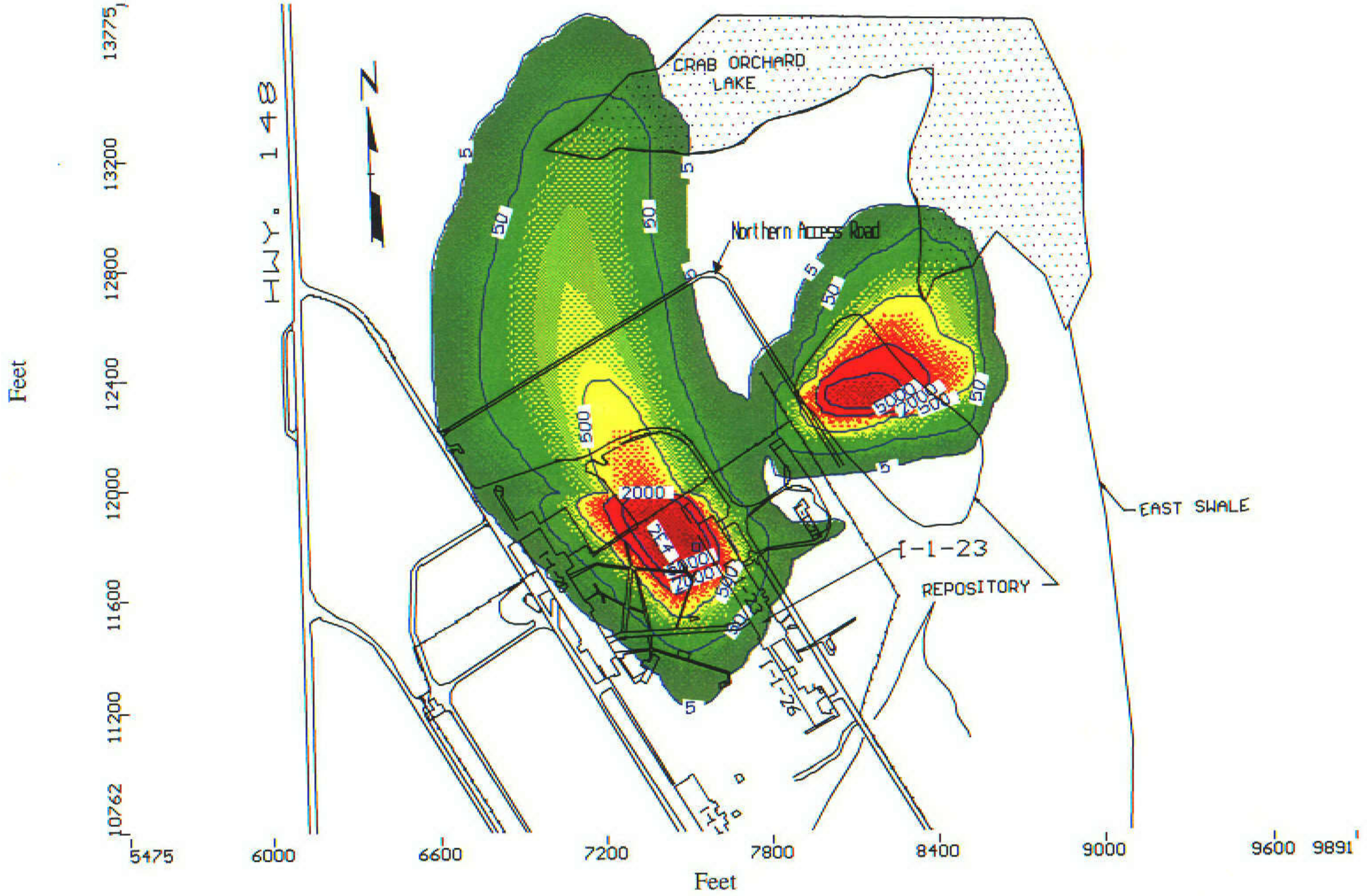
FIGURE 7-14



Building I-1-23 - Alternative B

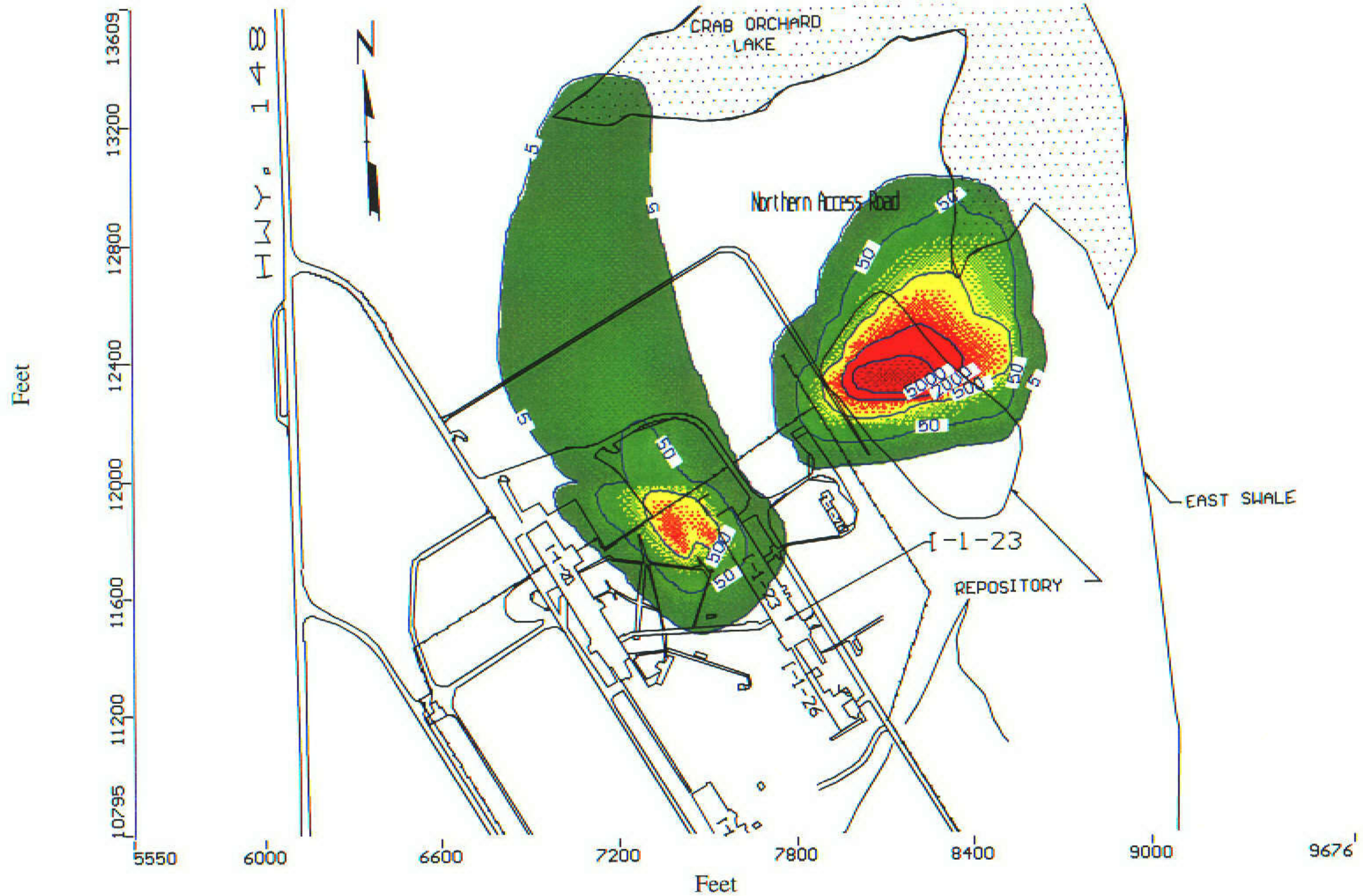
Excavate to 10 mg/kg plus PRB - Year 5; TCE (μg/L)

Figure 7-15



Building I-1-23 - Alternative B
Excavate to 10 mg/kg plus PRB - Year 15; TCE (µg/L)

Figure 7-16



Building I-1-23 - Alternative B

Excavate to 10 mg/kg plus PRB - Year 50; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-17

PLOT DATA
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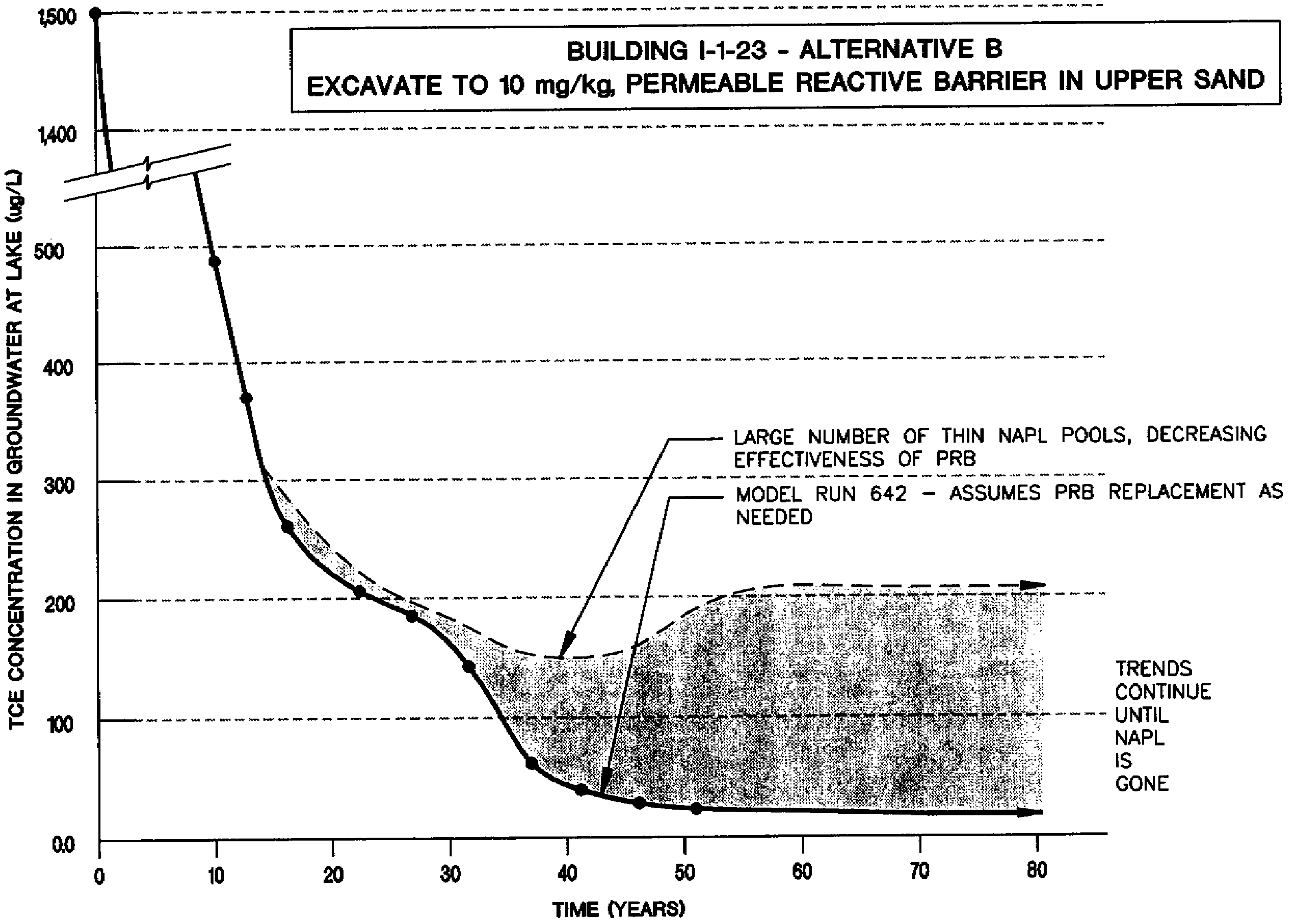


BUILDING I-1-23 - ALTERNATIVE B
EXCAVATE TO 10 mg/kg, PERMEABLE REACTIVE BARRIER IN UPPER SAND

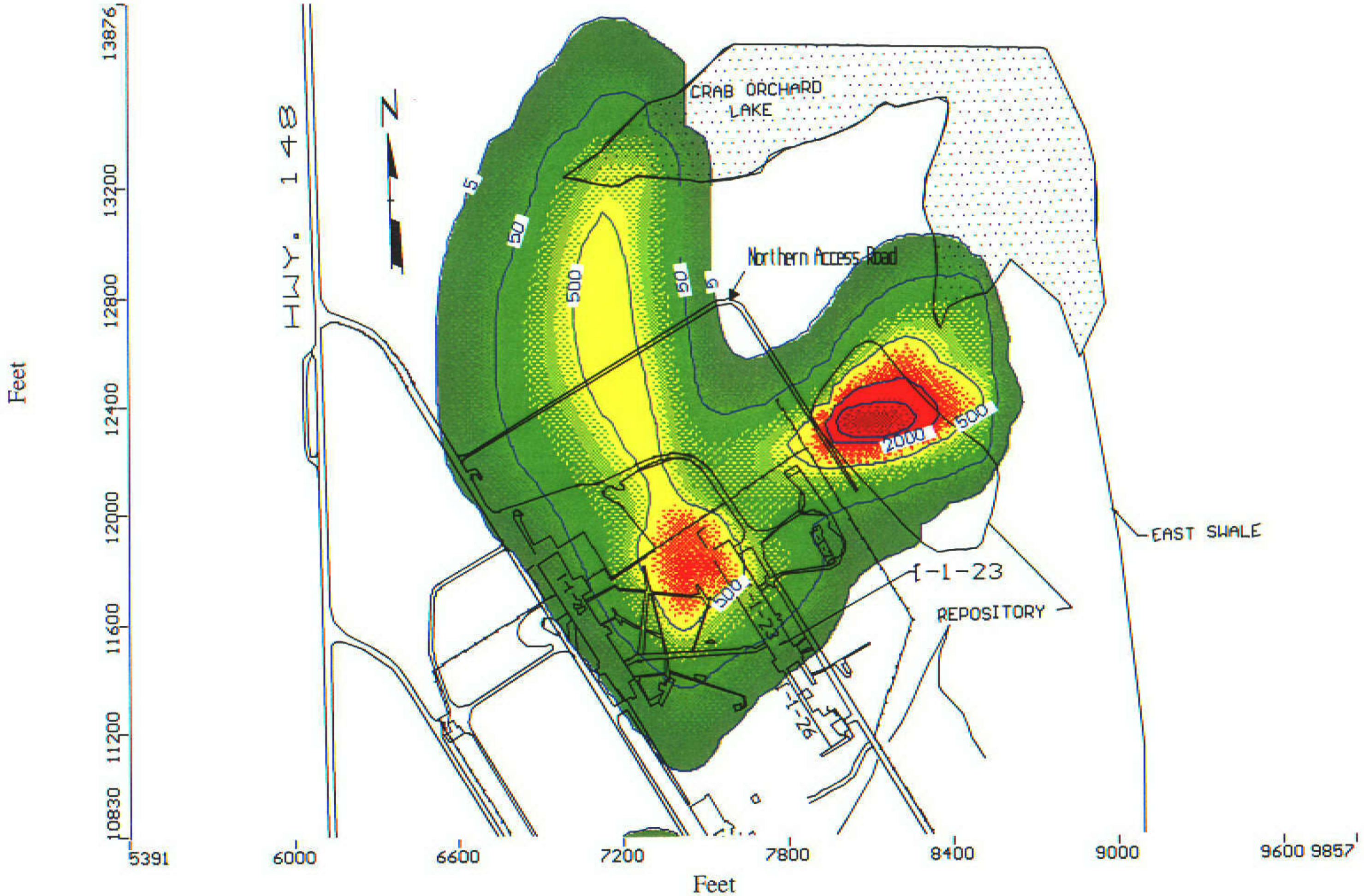
RMT INC.

CRAB ORCHARD NWR PCB O.U.
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY

TCE CONCENTRATION IN GROUNDWATER AT LAKE OVER TIME

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811225.DWG
DATE:	AUGUST 2004

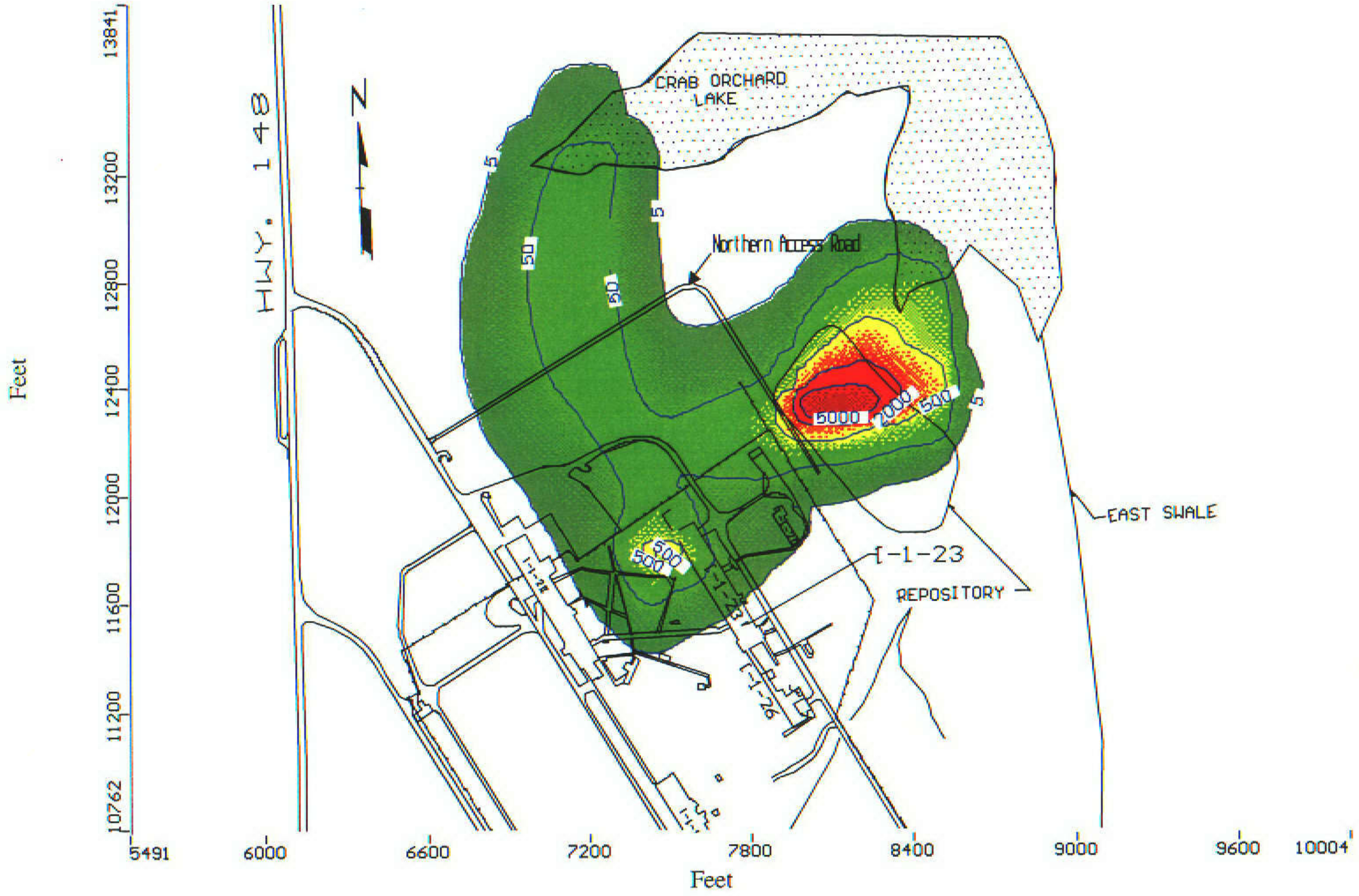
FIGURE 7-18



Building I-1-23 - Alternative C

MPE w/Fracturing/Long-term Pumping – Year 5; TCE (µg/L)

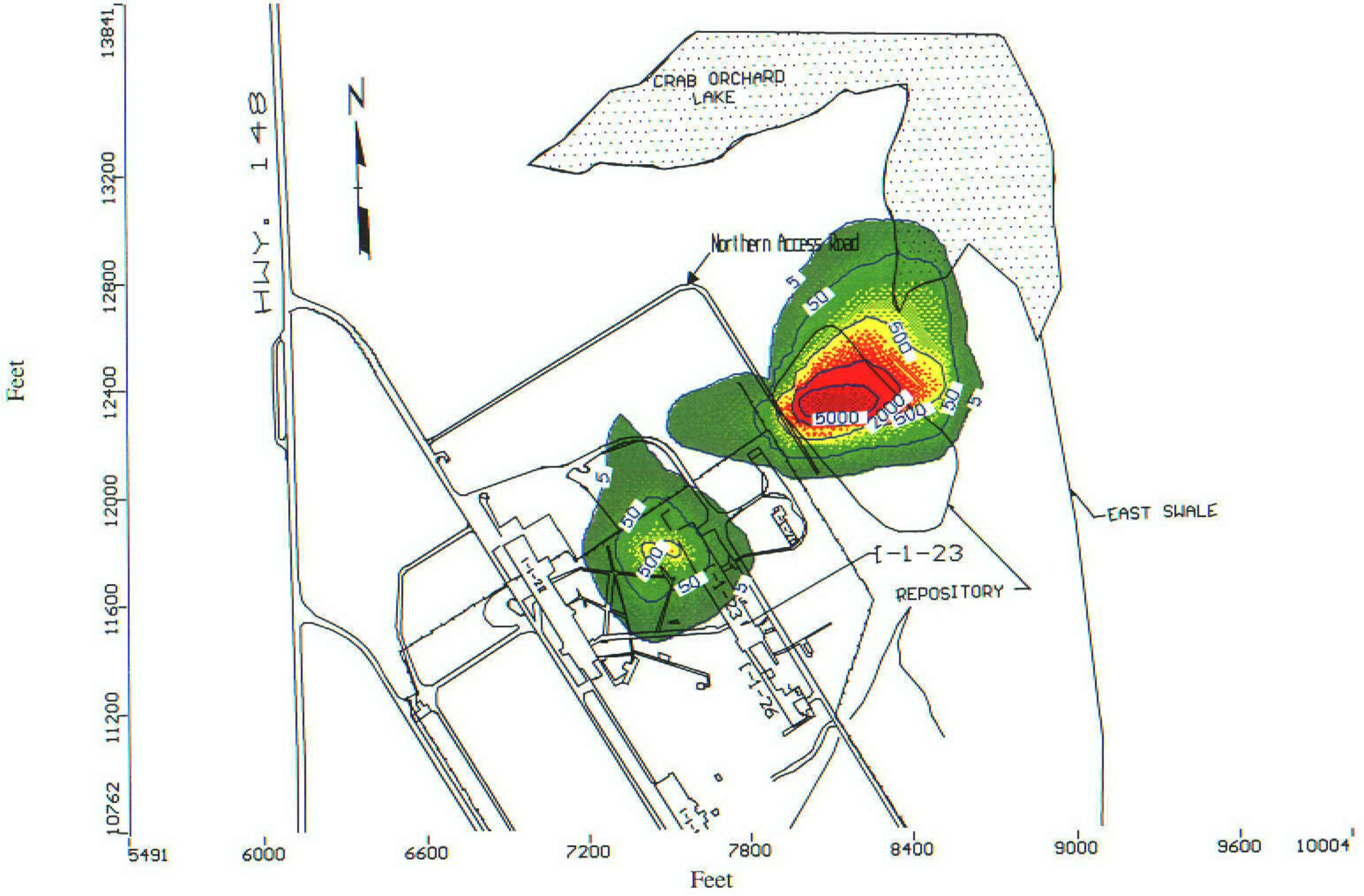
Figure 7-19



Building I-1-23 - Alternative C
MPE w/Fracturing/Long-term Pumping – Year 15; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-20



Building I-1-23 - Alternative C
MPE w/Fracturing/Long-term Pumping – Year 50; TCE (µg/L)

Figure 7-21

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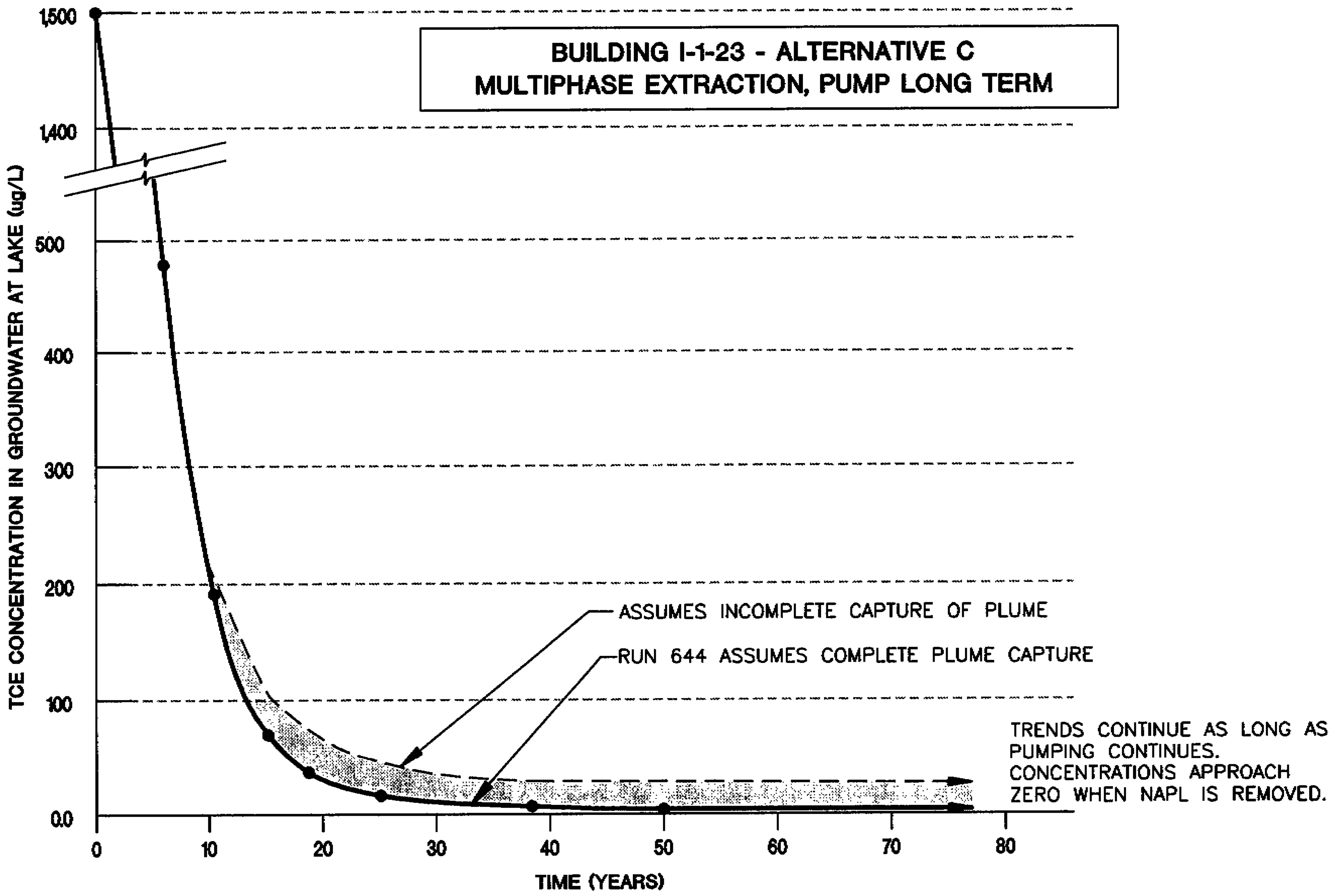


BUILDING I-1-23 - ALTERNATIVE C
MULTIPHASE EXTRACTION, PUMP LONG TERM

ASSUMES INCOMPLETE CAPTURE OF PLUME

RUN 644 ASSUMES COMPLETE PLUME CAPTURE

TRENDS CONTINUE AS LONG AS PUMPING CONTINUES. CONCENTRATIONS APPROACH ZERO WHEN NAPL IS REMOVED.

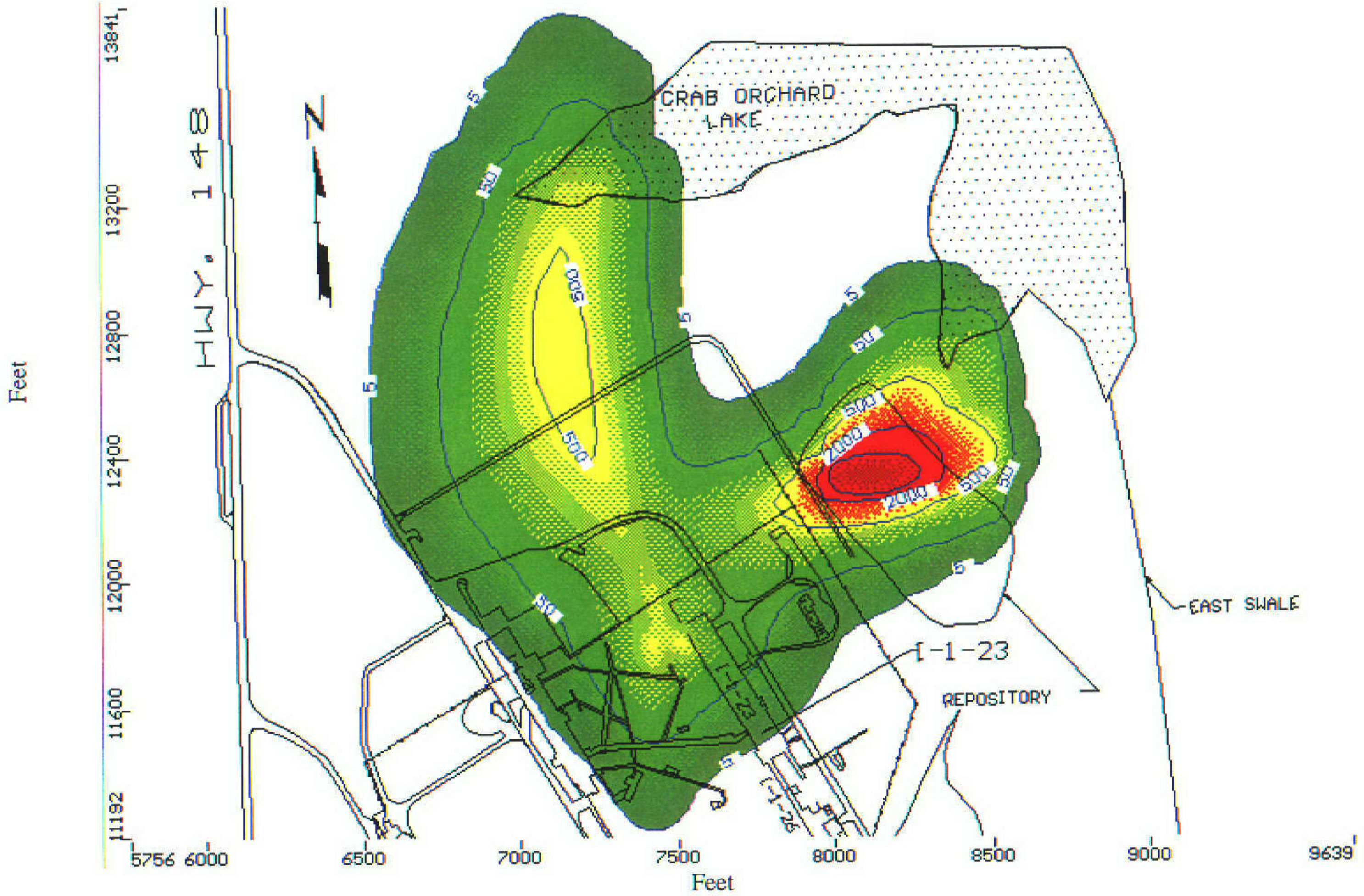
RMT INC.

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER AT LAKE OVER TIME

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811225.DWG
DATE:	AUGUST 2004

FIGURE 7-22

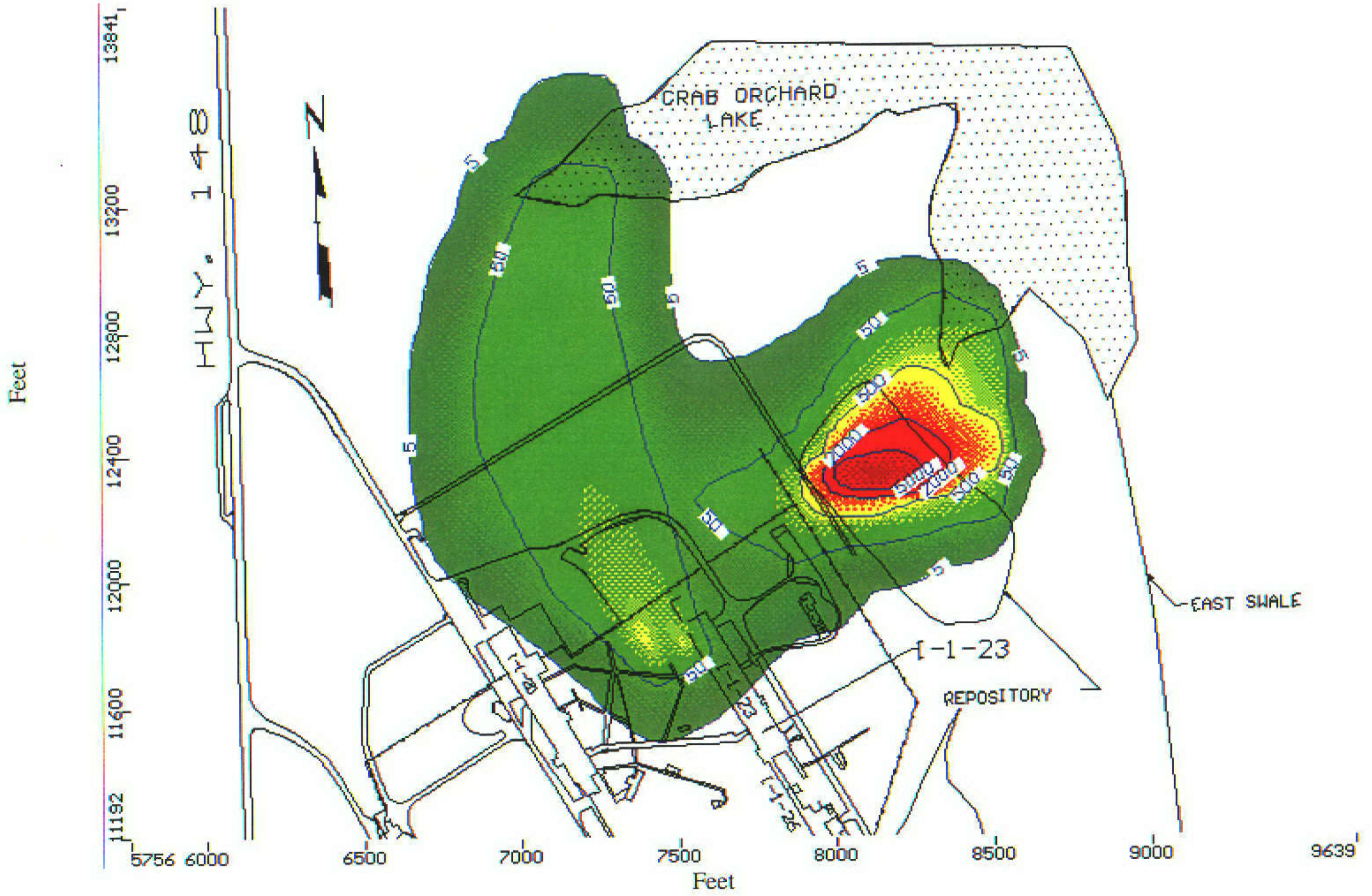


Building I-1-23 - Alternative C

Multi-phase Extraction/Short-term Pumping – Year 5; TCE (µg/L)

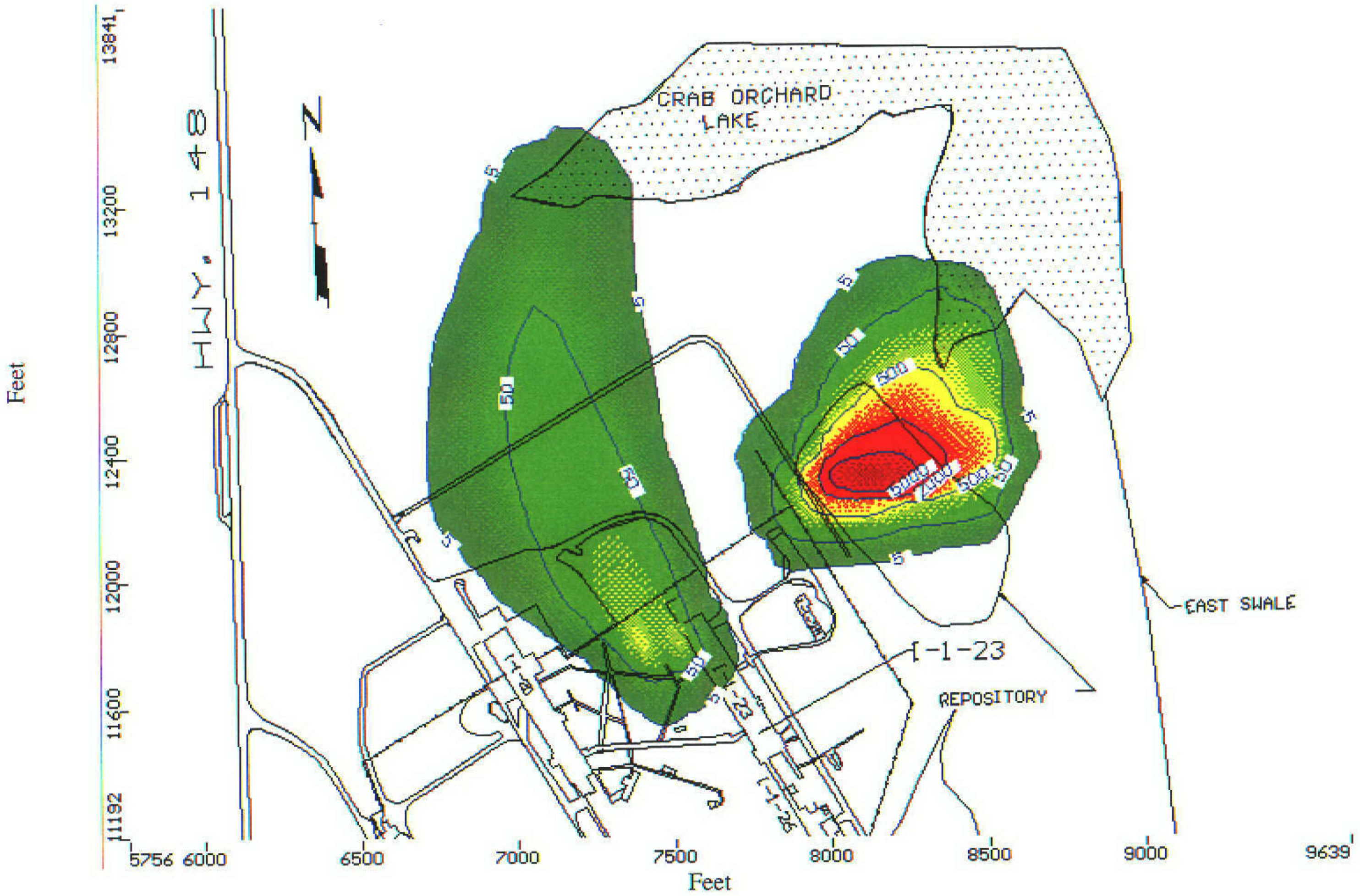
I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-23



Building I-1-23 - Alternative C
Multi-phase Extraction/Short-term Pumping – Year 15; TCE (µg/L)

Figure 7-24



Building I-1-23 - Alternative C

Multi-phase Extraction/Short-term Pumping – Year 49; TCE (µg/L)

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Figure 7-25

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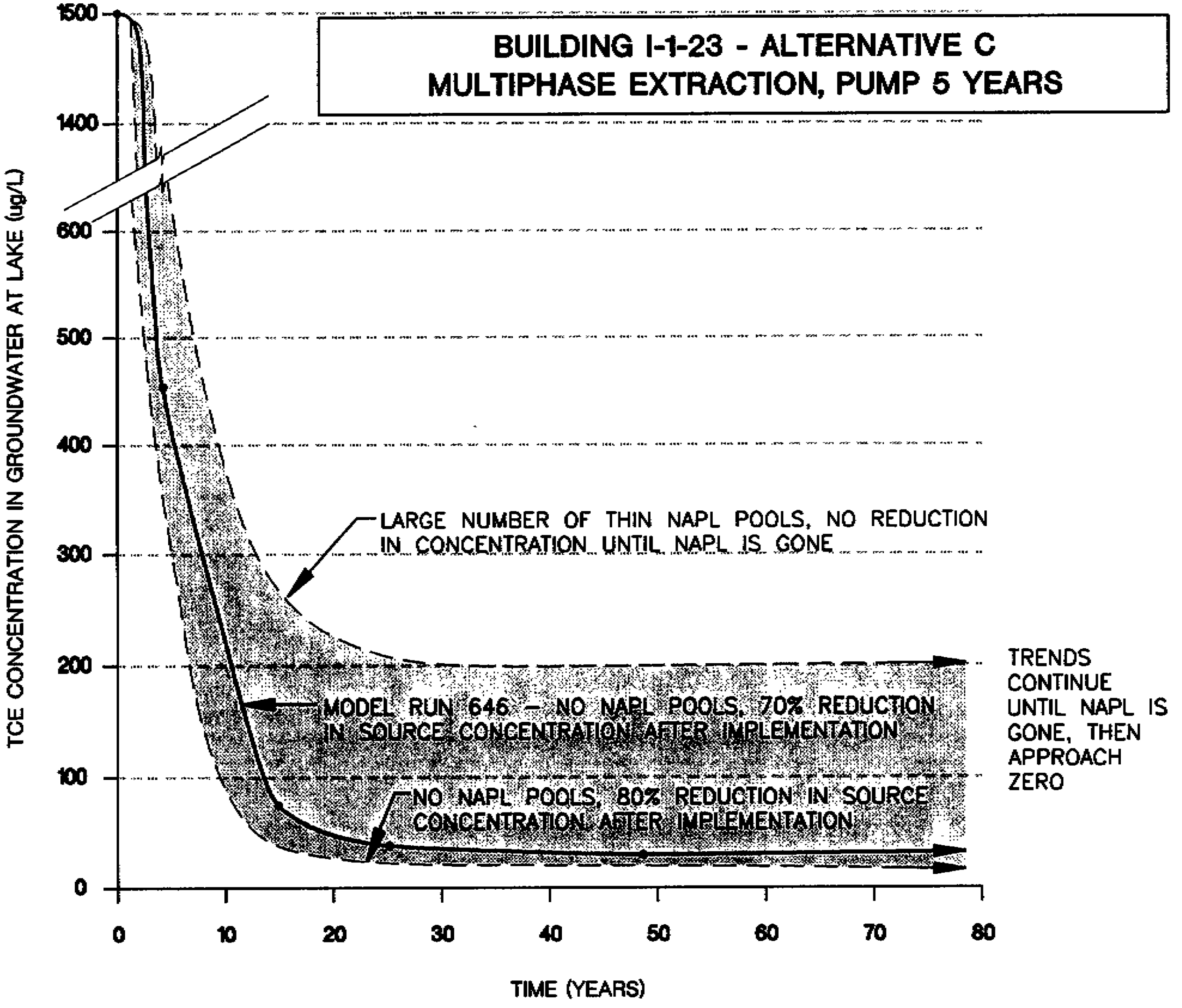


BUILDING I-1-23 - ALTERNATIVE C
MULTIPHASE EXTRACTION, PUMP 5 YEARS

LARGE NUMBER OF THIN NAPL POOLS, NO REDUCTION IN CONCENTRATION UNTIL NAPL IS GONE

MODEL RUN 646 - NO NAPL POOLS, 70% REDUCTION IN SOURCE CONCENTRATION AFTER IMPLEMENTATION

NO NAPL POOLS, 80% REDUCTION IN SOURCE CONCENTRATION AFTER IMPLEMENTATION

TRENDS CONTINUE UNTIL NAPL IS GONE, THEN APPROACH ZERO

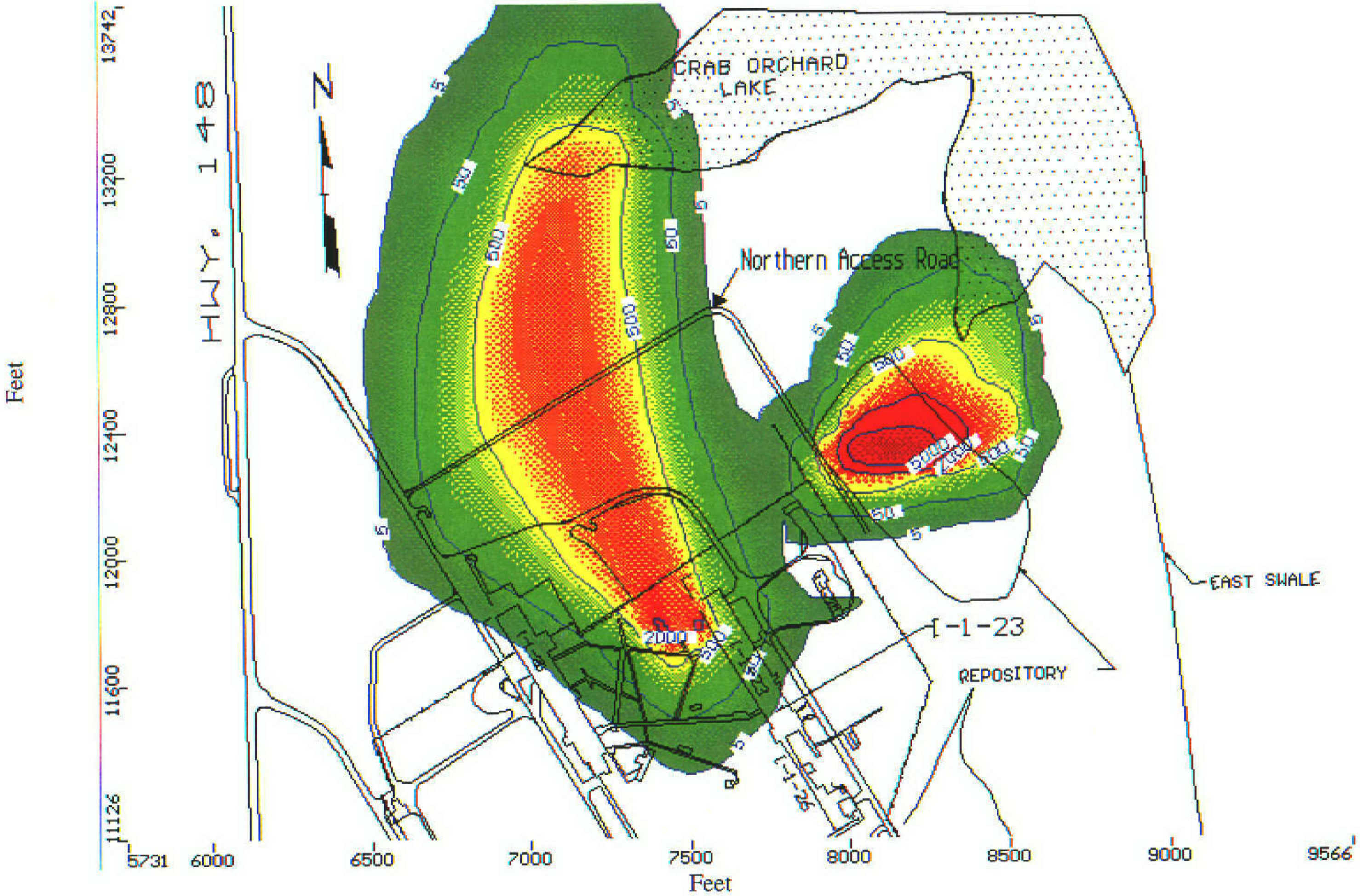
RMT

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER AT LAKE OVER TIME

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811220.DWG
DATE:	AUGUST 2004

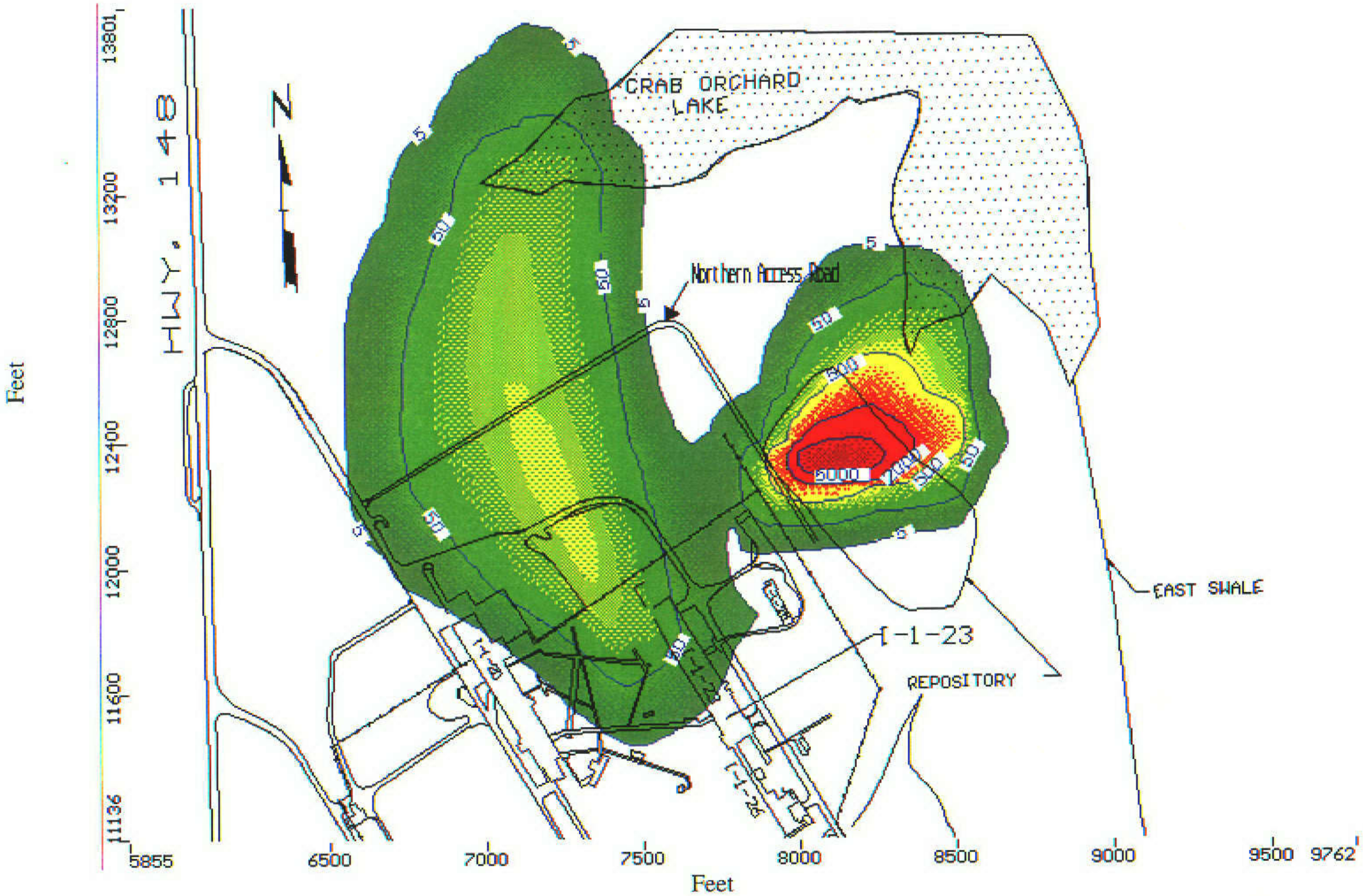
FIGURE 7-26



Building I-1-23 - Alternative F
Reductive Dechlorination – Year 5; TCE (µg/L)

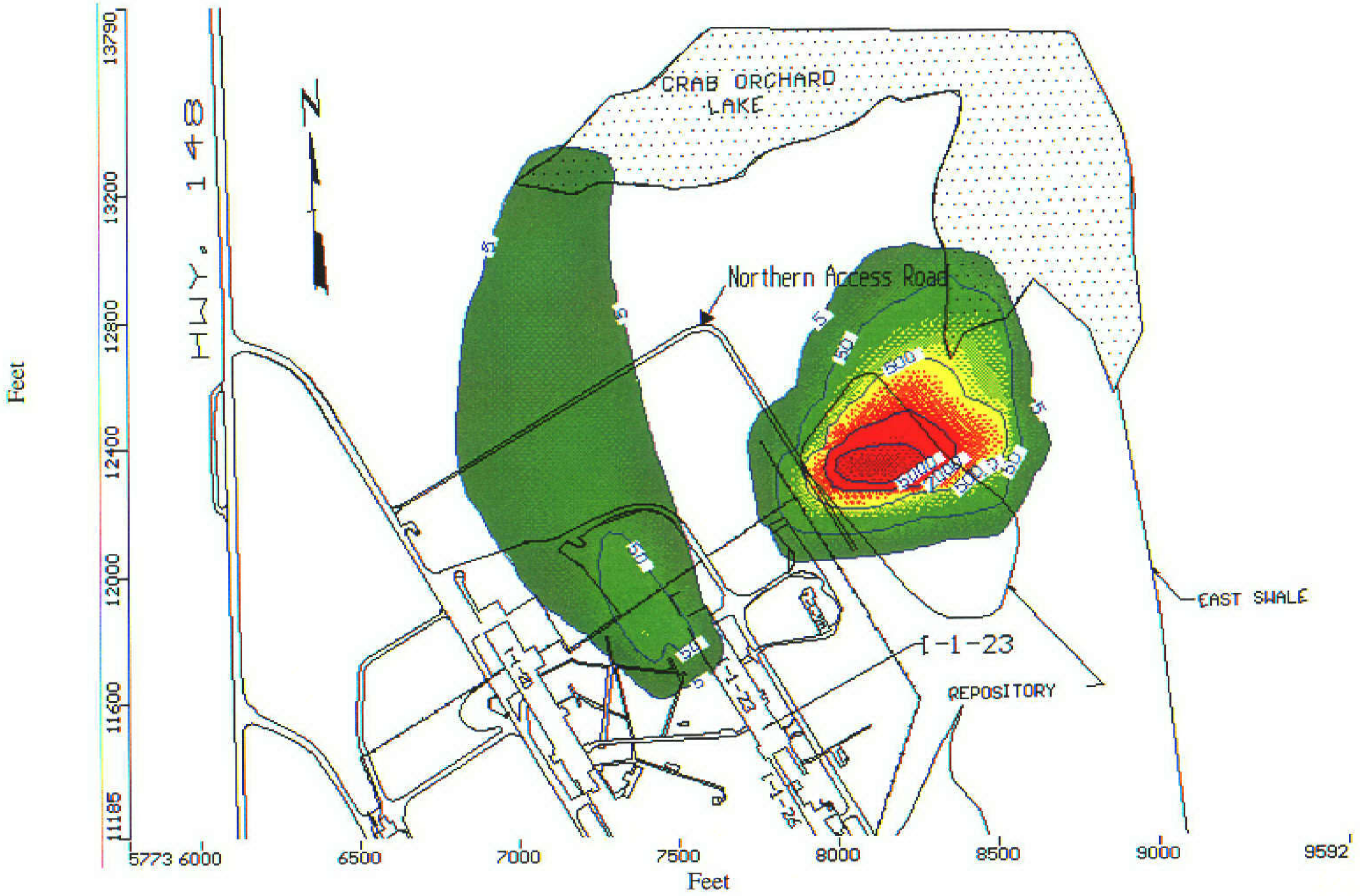
I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-27



Building I-1-23 - Alternative F
Reductive Dechlorination – Year 15; TCE (µg/L)

Figure 7-28



Building I-1-23 - Alternative F
Reductive Dechlorination – Year 47; TCE (μg/L)

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Figure 7-29

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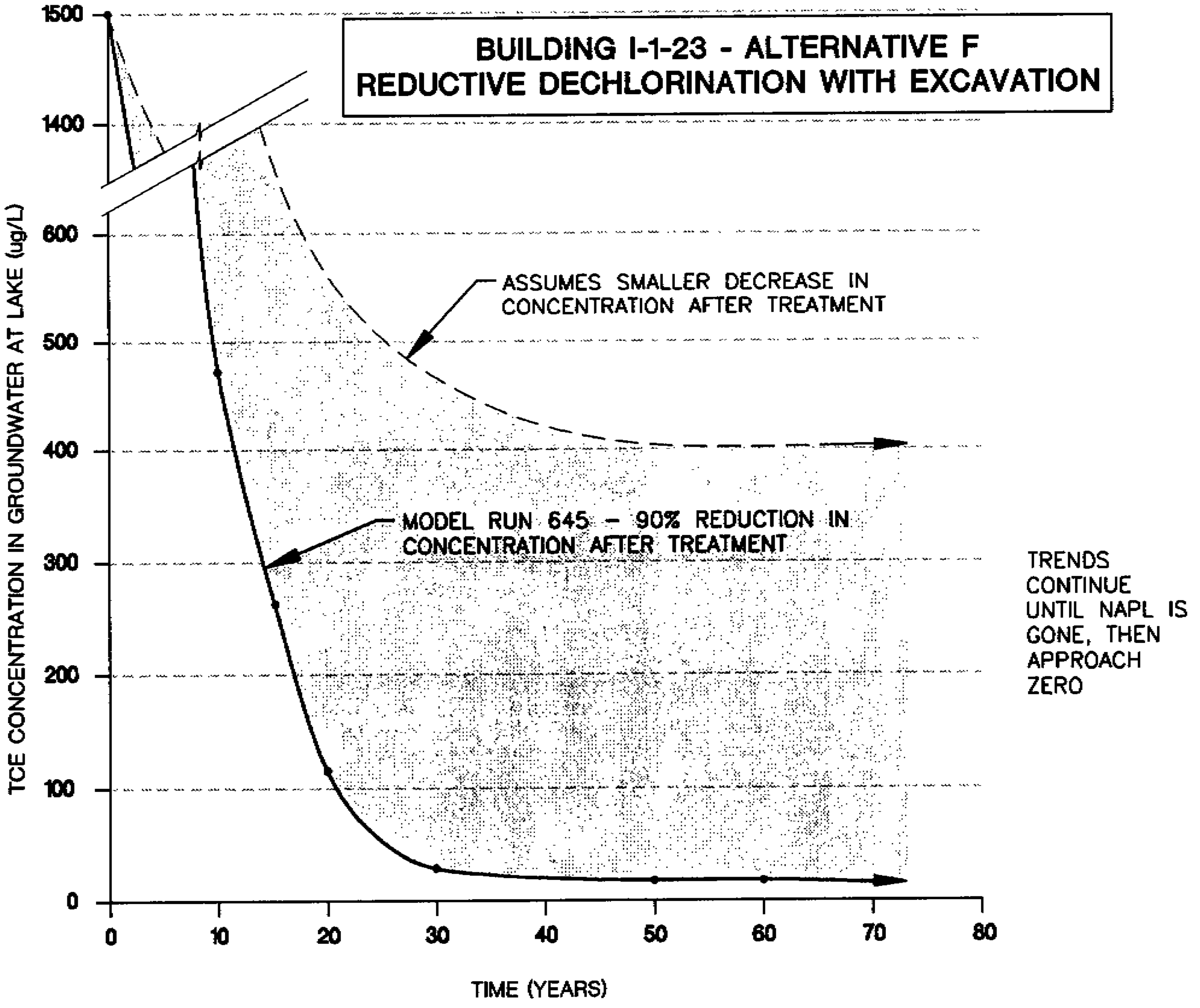


BUILDING I-1-23 - ALTERNATIVE F
REDUCTIVE DECHLORINATION WITH EXCAVATION

TRENDS
CONTINUE
UNTIL NAPL IS
GONE, THEN
APPROACH
ZERO

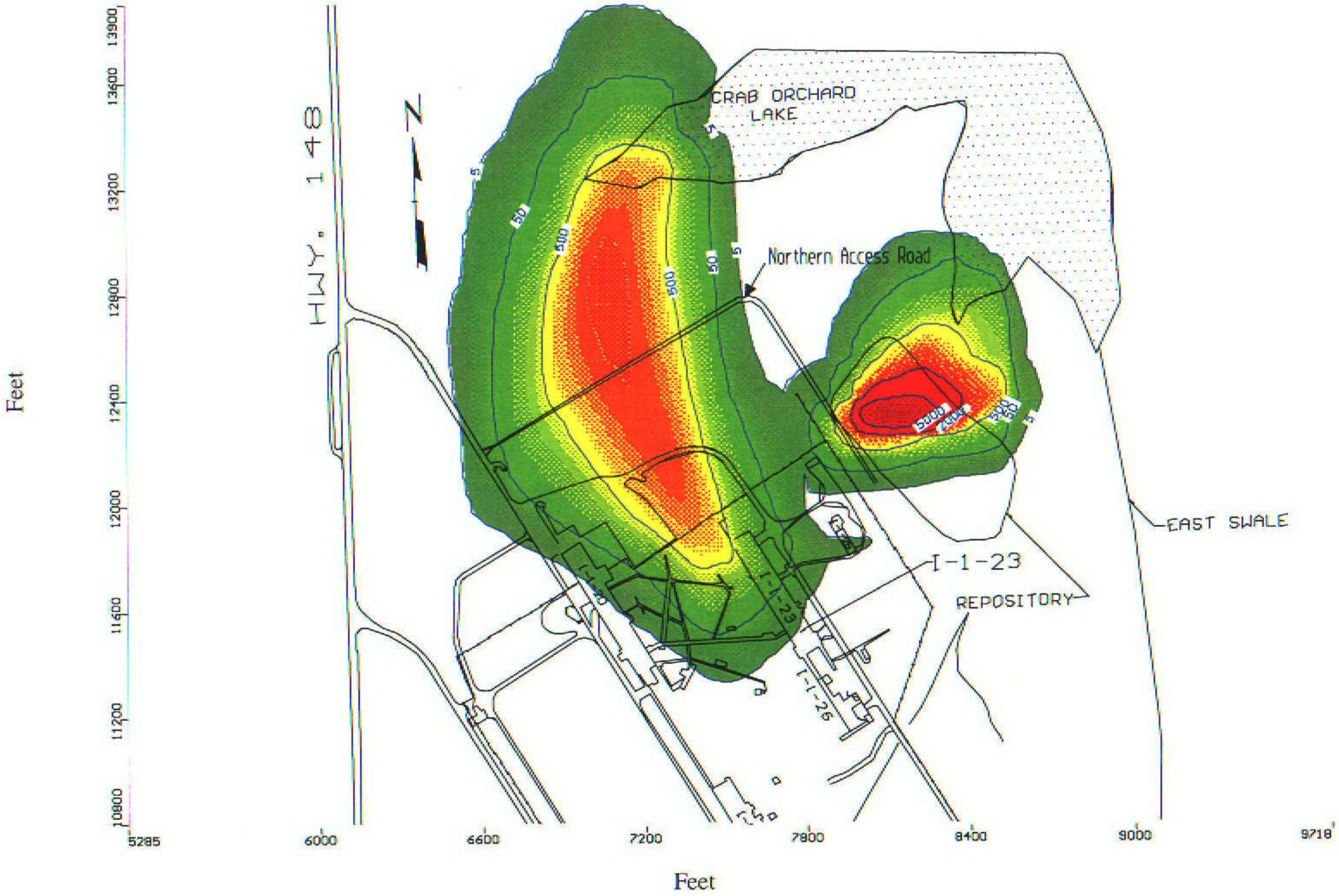
RMT

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER AT LAKE OVER TIME

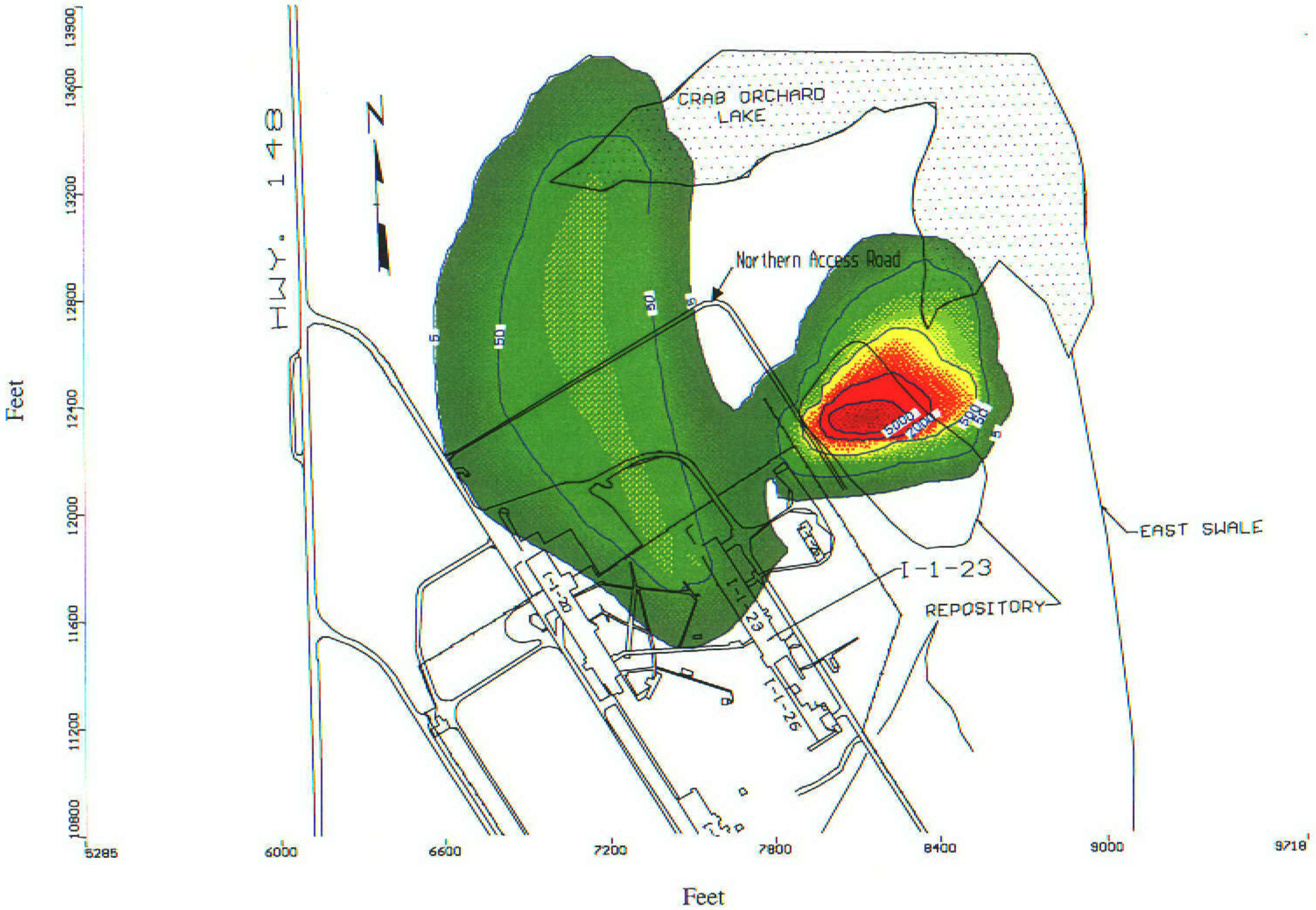
DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811221.DWG
DATE:	AUGUST 2004

FIGURE 30



Building I-1-23 - Alternative G
Electrical Resistive Heating – Year 5; TCE (µg/L)

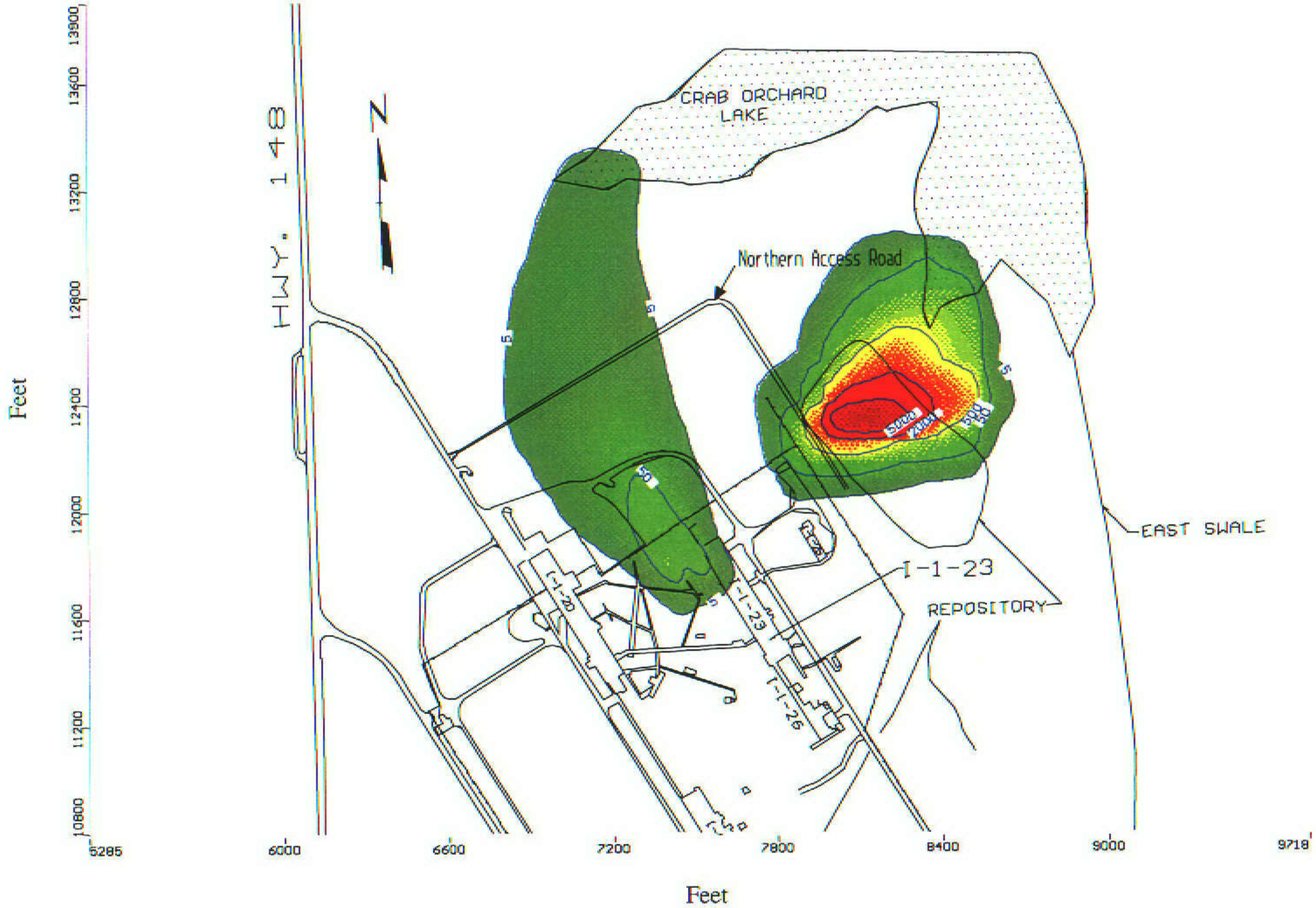
Figure 7-31



Building I-1-23 - Alternative G
Electrical Resistive Heating – Year 15; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

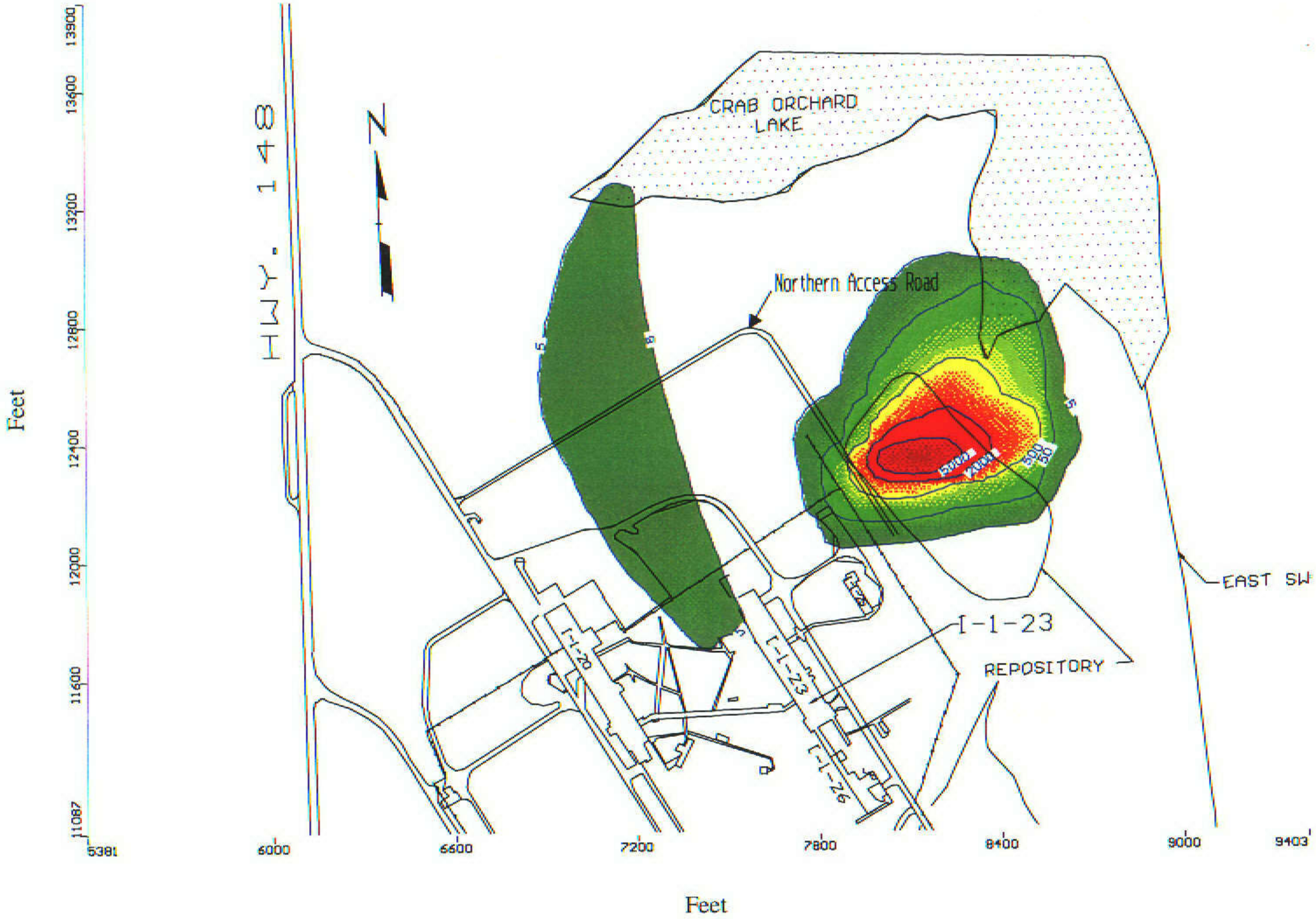
Figure 7-32



Building I-1-23 - Alternative G
Electrical Resistive Heating – Year 50; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-33



Building I-1-23 - Alternative G
Electrical Resistive Heating – Year 75; TCE (µg/L)

I:\WPMSN\00-04781\12\Figures.ppt

Figure 7-34

PLOT DATA
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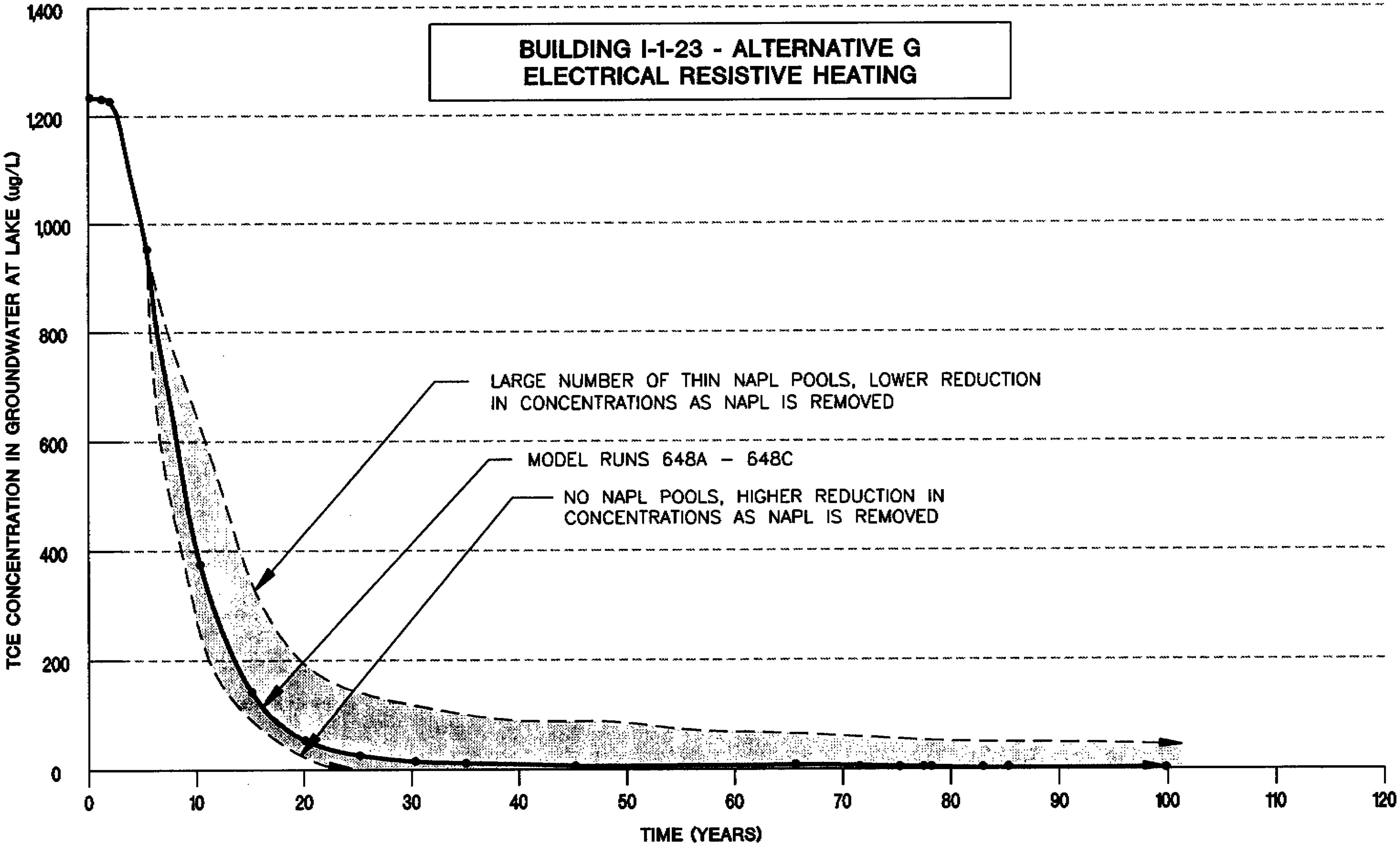


BUILDING I-1-23 - ALTERNATIVE G
ELECTRICAL RESISTIVE HEATING

LARGE NUMBER OF THIN NAPL POOLS, LOWER REDUCTION IN CONCENTRATIONS AS NAPL IS REMOVED

MODEL RUNS 648A – 648C

NO NAPL POOLS, HIGHER REDUCTION IN CONCENTRATIONS AS NAPL IS REMOVED

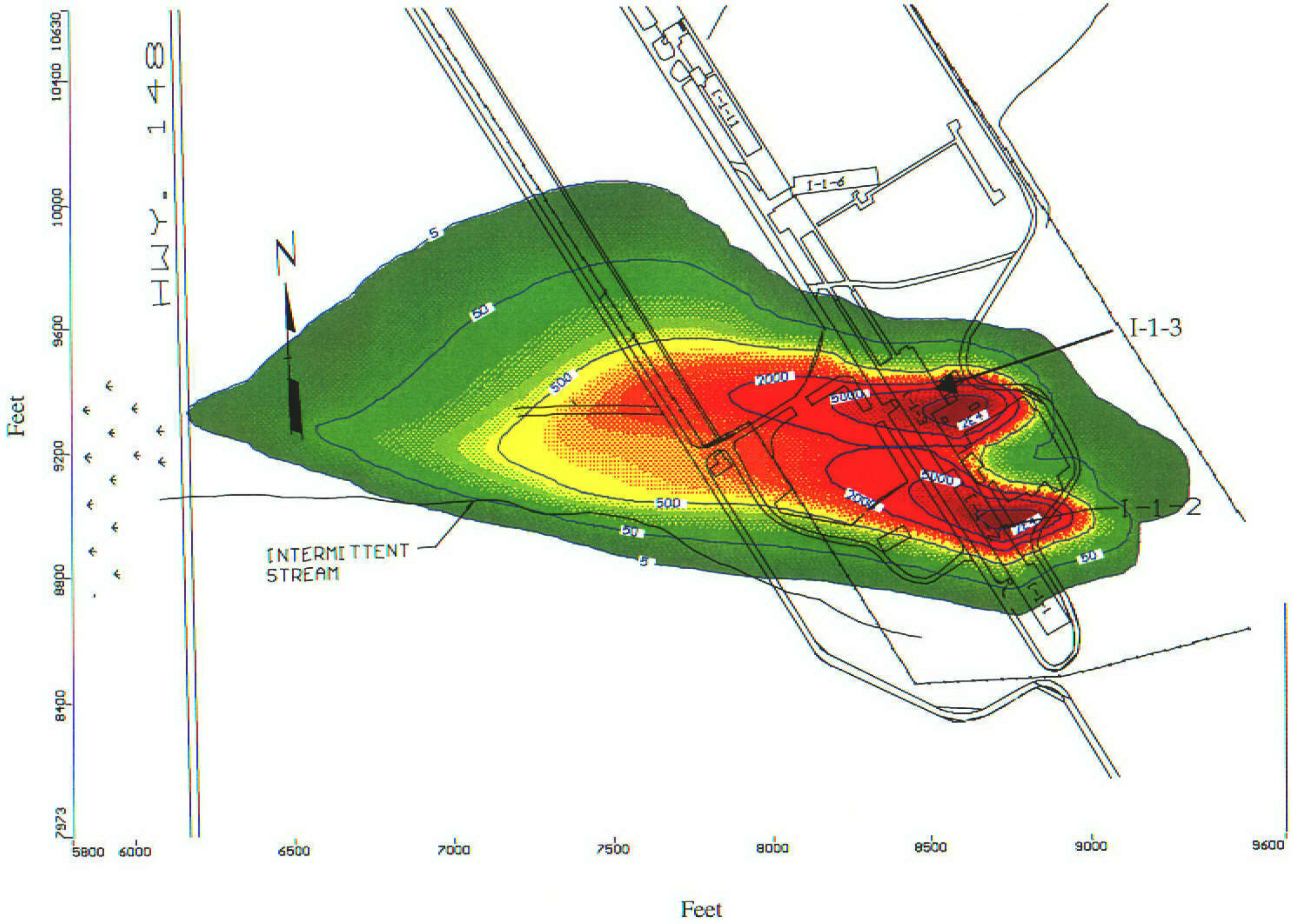
RMT INC.

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER AT LAKE OVER TIME

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811205.DWG
DATE:	AUGUST 2004

FIGURE 7-35



Buildings I-1-2/I-1-3 – Current Conditions; TCE (µg/L)

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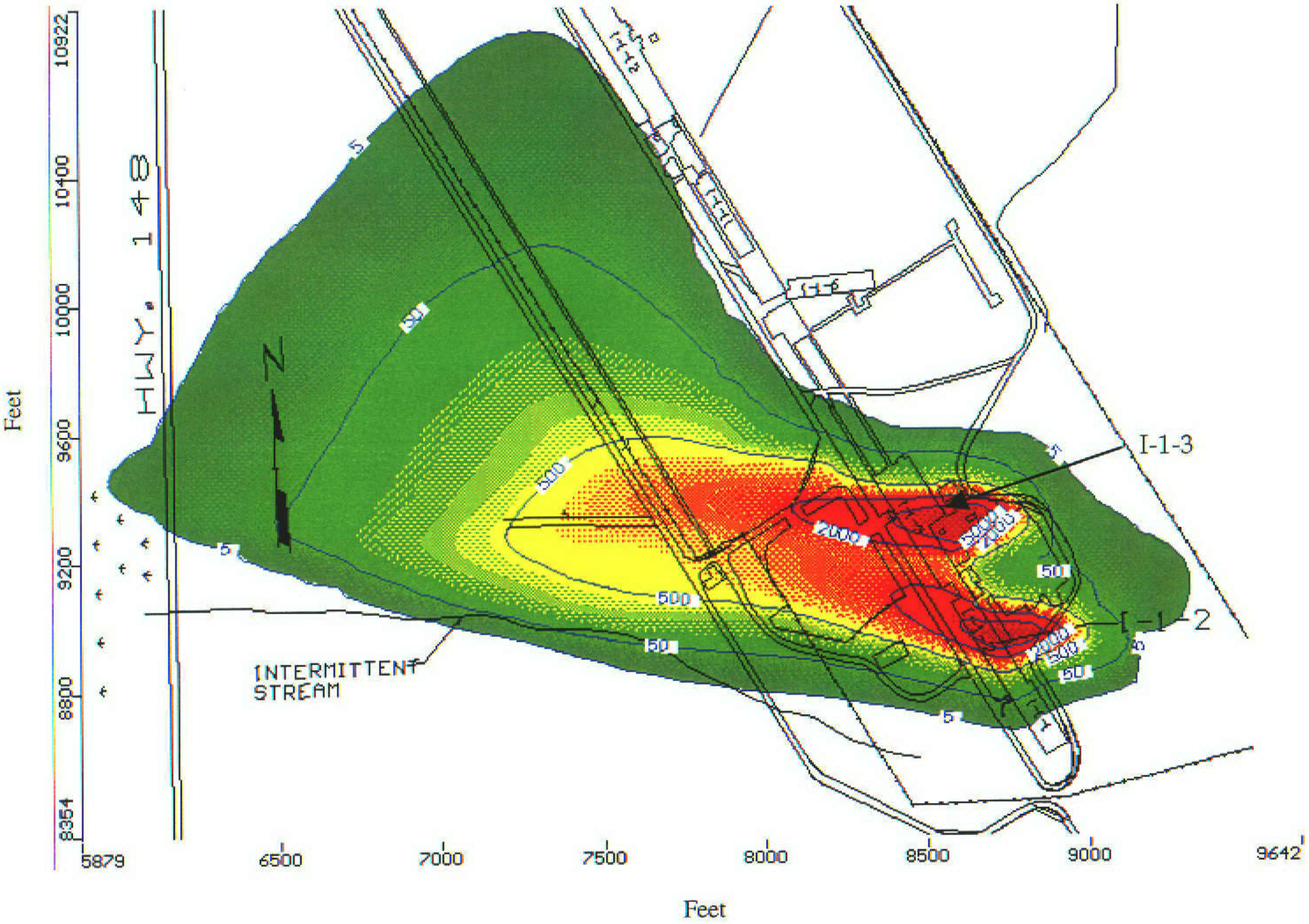
Figure 7-36



Buildings I-1-2/I-1-3 - Alternative A
MPE w/Fracturing – Year 5; TCE (µg/L)

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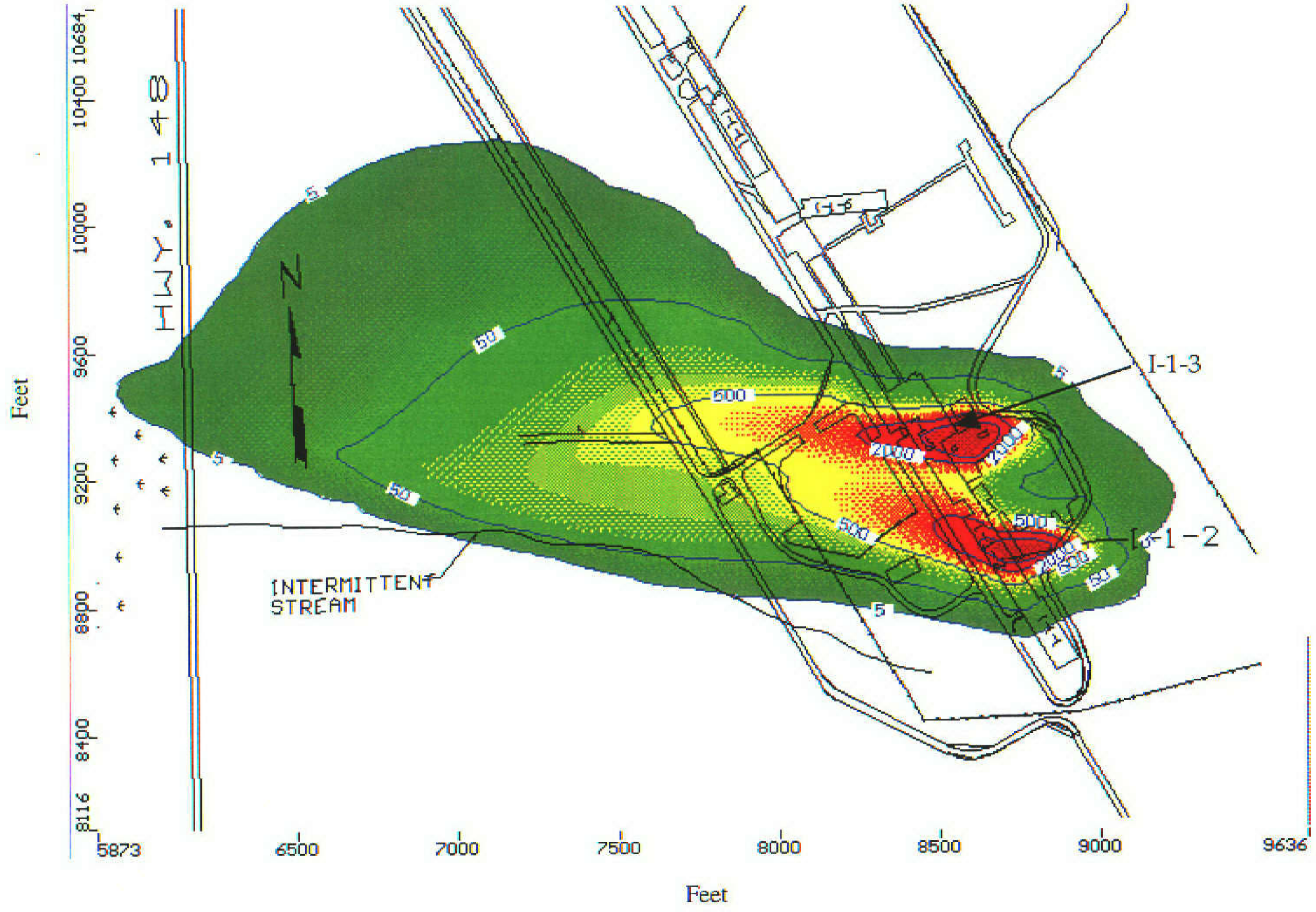
Figure 7-37



Buildings I-1-2/I-1-3 - Alternative A
MPE w/Fracturing – Year 14; TCE (µg/L)

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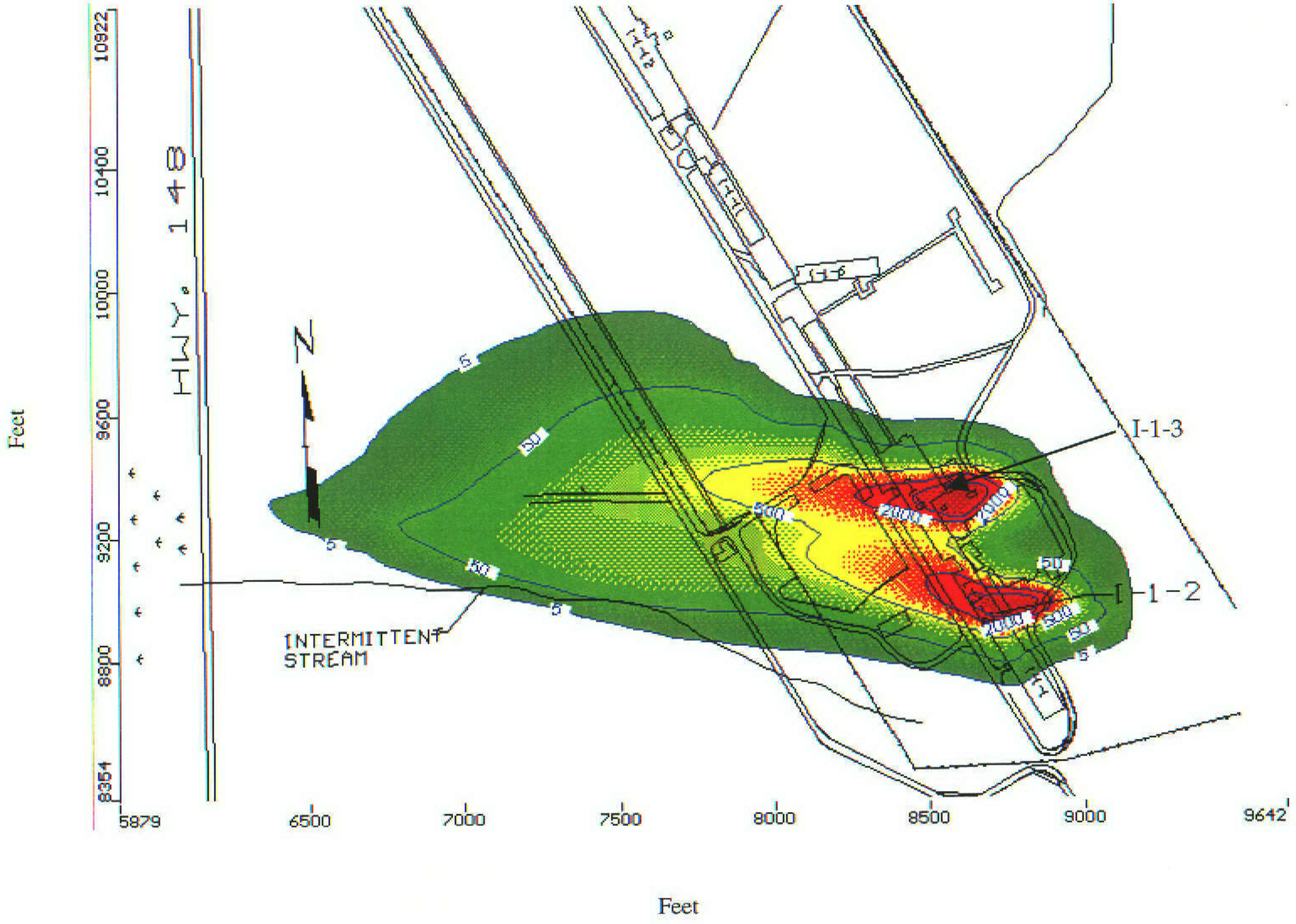
Figure 7-38



Buildings I-1-2/I-1-3 - Alternative A
MPE w/Fracturing – Year 47; TCE (µg/L)

Figure 7-39

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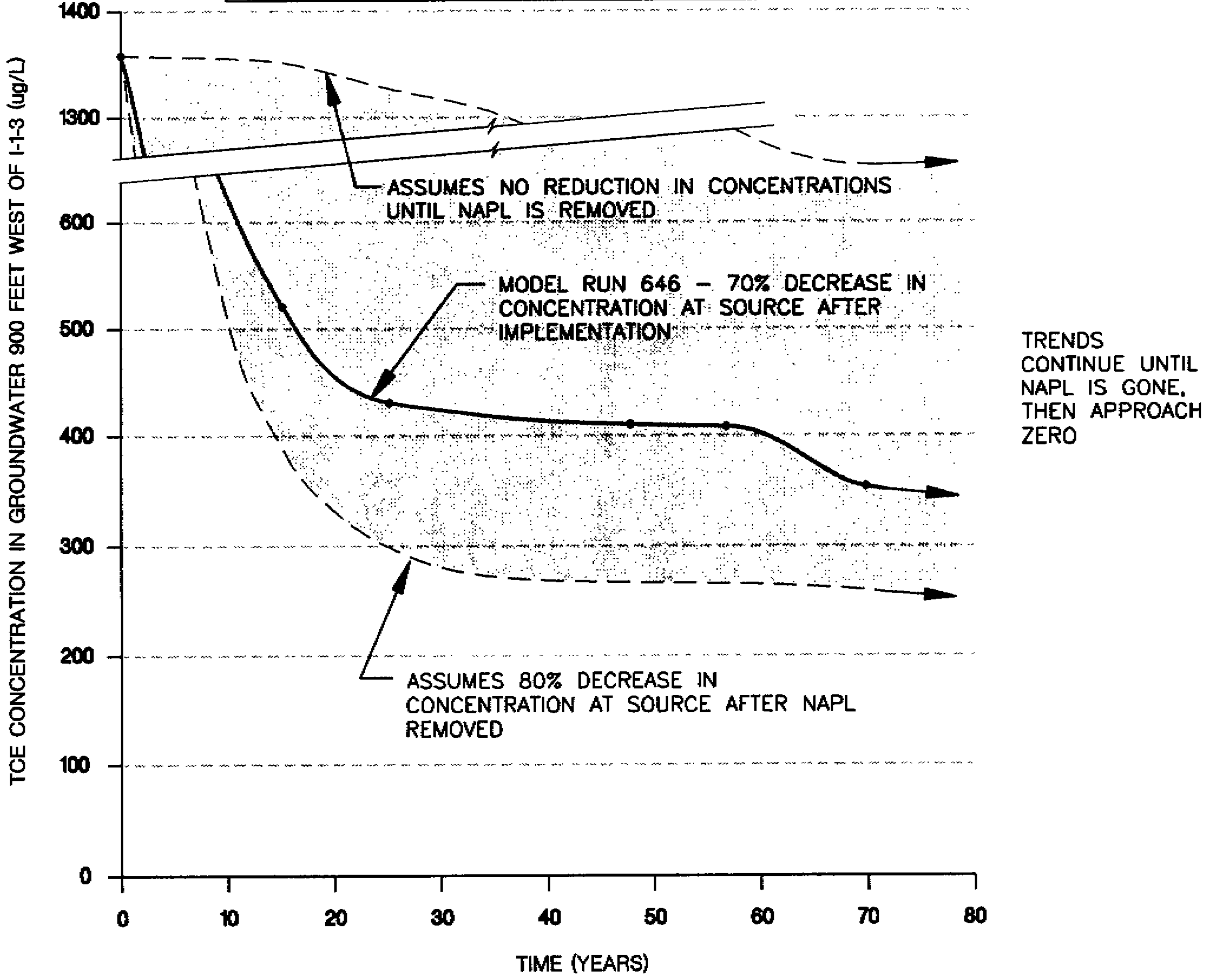
BUILDINGS I-1-2/I-1-3 - ALTERNATIVE A MPE WITH FRACTURING AND EXCAVATION



ASSUMES NO REDUCTION IN CONCENTRATIONS UNTIL NAPL IS REMOVED

MODEL RUN 646 – 70% DECREASE IN CONCENTRATION AT SOURCE AFTER IMPLEMENTATION

TRENDS CONTINUE UNTIL NAPL IS GONE, THEN APPROACH ZERO

ASSUMES 80% DECREASE IN CONCENTRATION AT SOURCE AFTER NAPL REMOVED

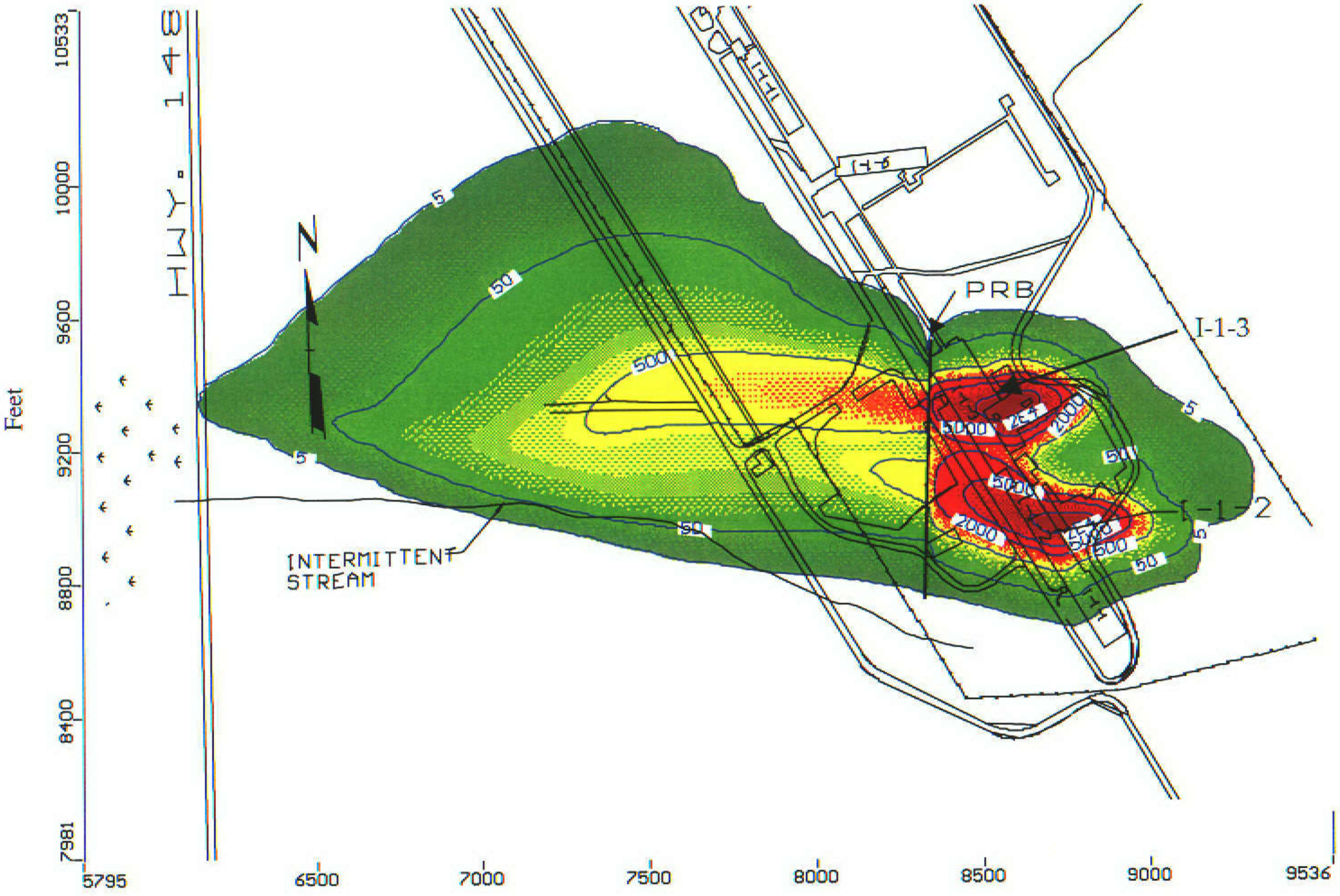
RMT

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER 900 FEET WEST OF I-1-3 OVER TIME

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811222.DWG
DATE:	AUGUST 2004

FIGURE 7-40



Buildings I-1-2/I-1-3 - Alternative B
PRB – Year 5; TCE (µg/L)

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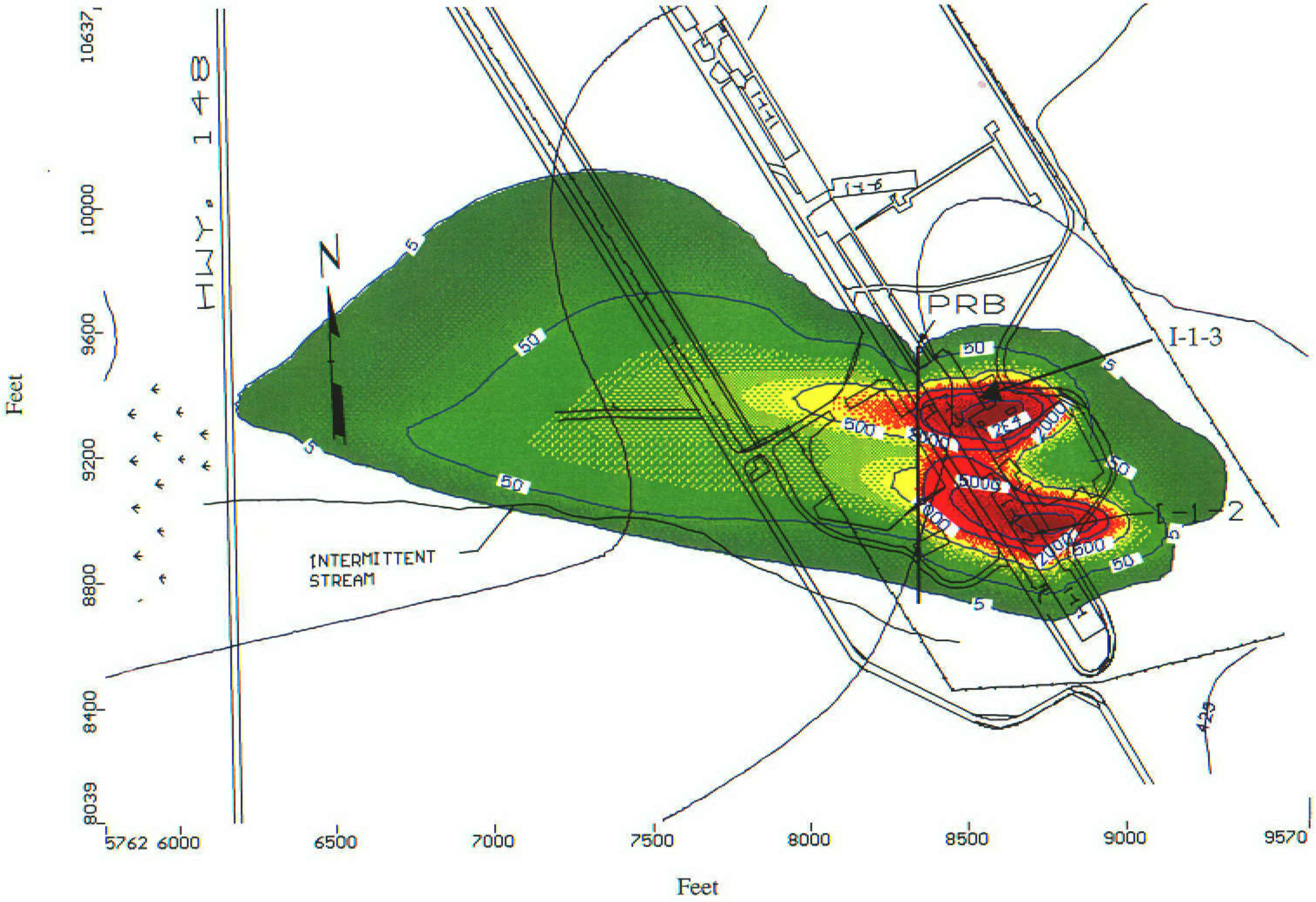
Figure 7-41



Buildings I-1-2/I-1-3 - Alternative B
PRB – Year 15; TCE (µg/L)

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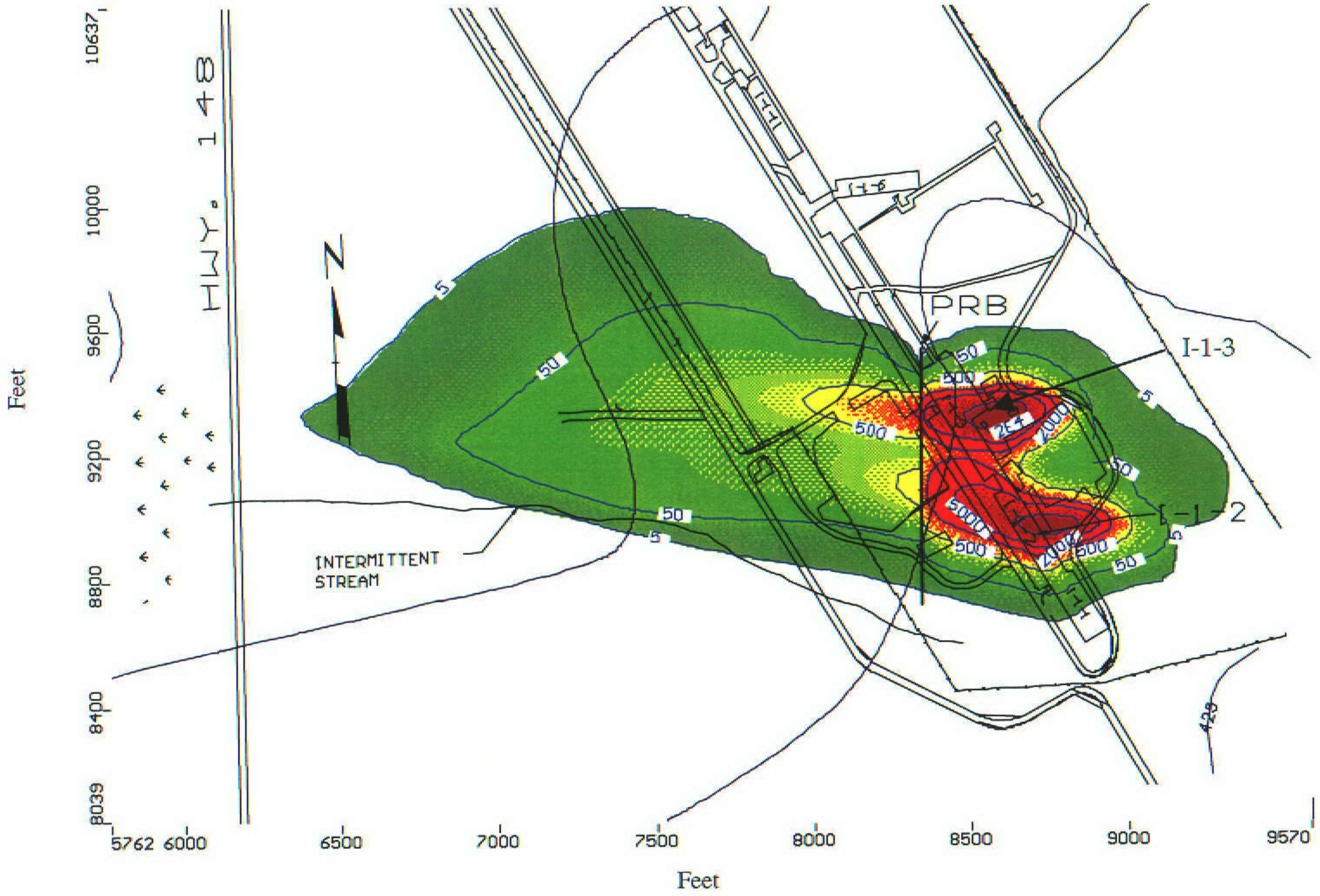
Figure 7-42



Buildings I-1-2/I-1-3 - Alternative B
PRB – Year 50; TCE (µg/L)

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Figure 7-43

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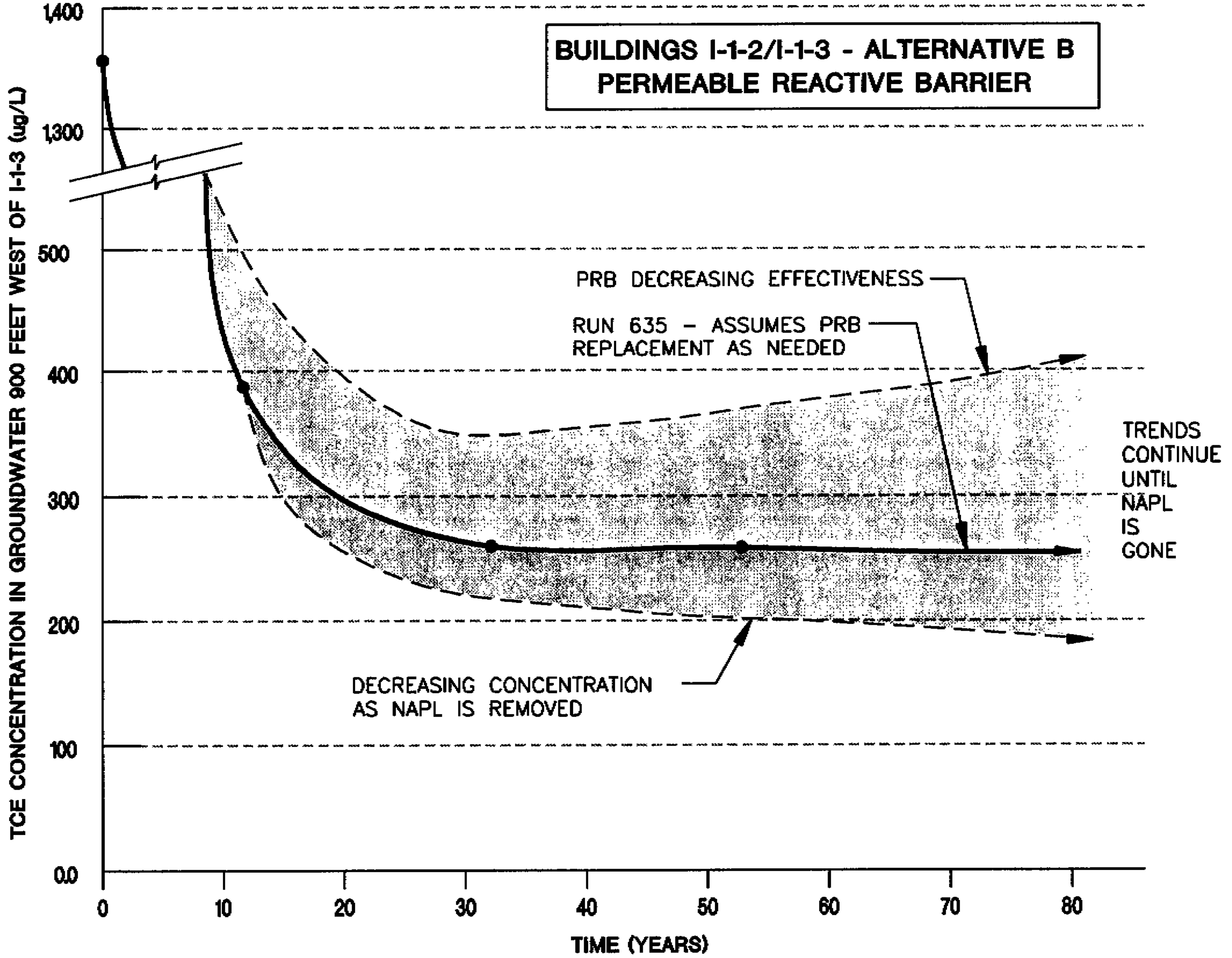

BUILDINGS I-1-2/I-1-3 - ALTERNATIVE B PERMEABLE REACTIVE BARRIER

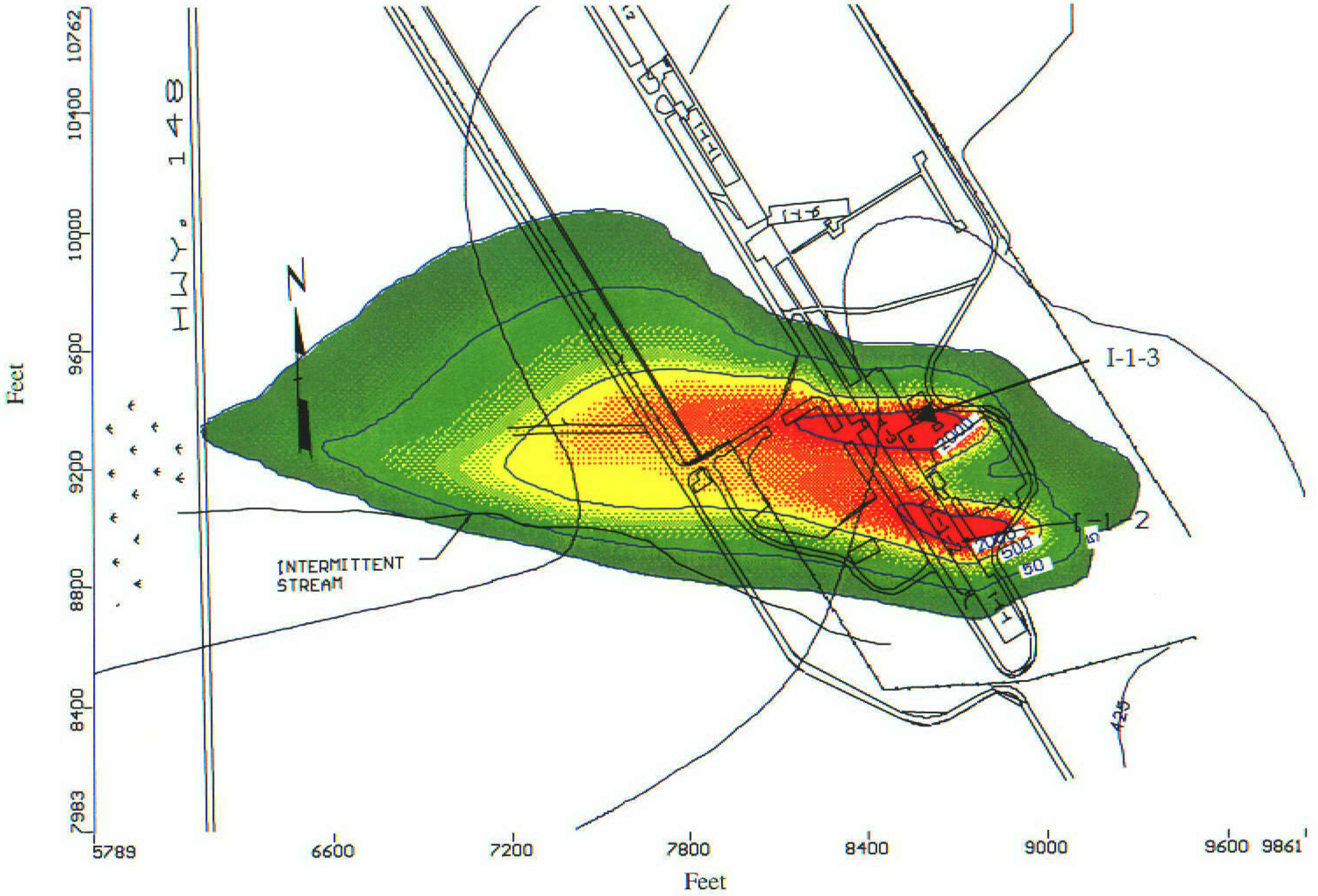
RMT INC.

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER 900 FEET WEST OF I-1-3 OVER TIME

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811225.DWG
DATE:	AUGUST 2004

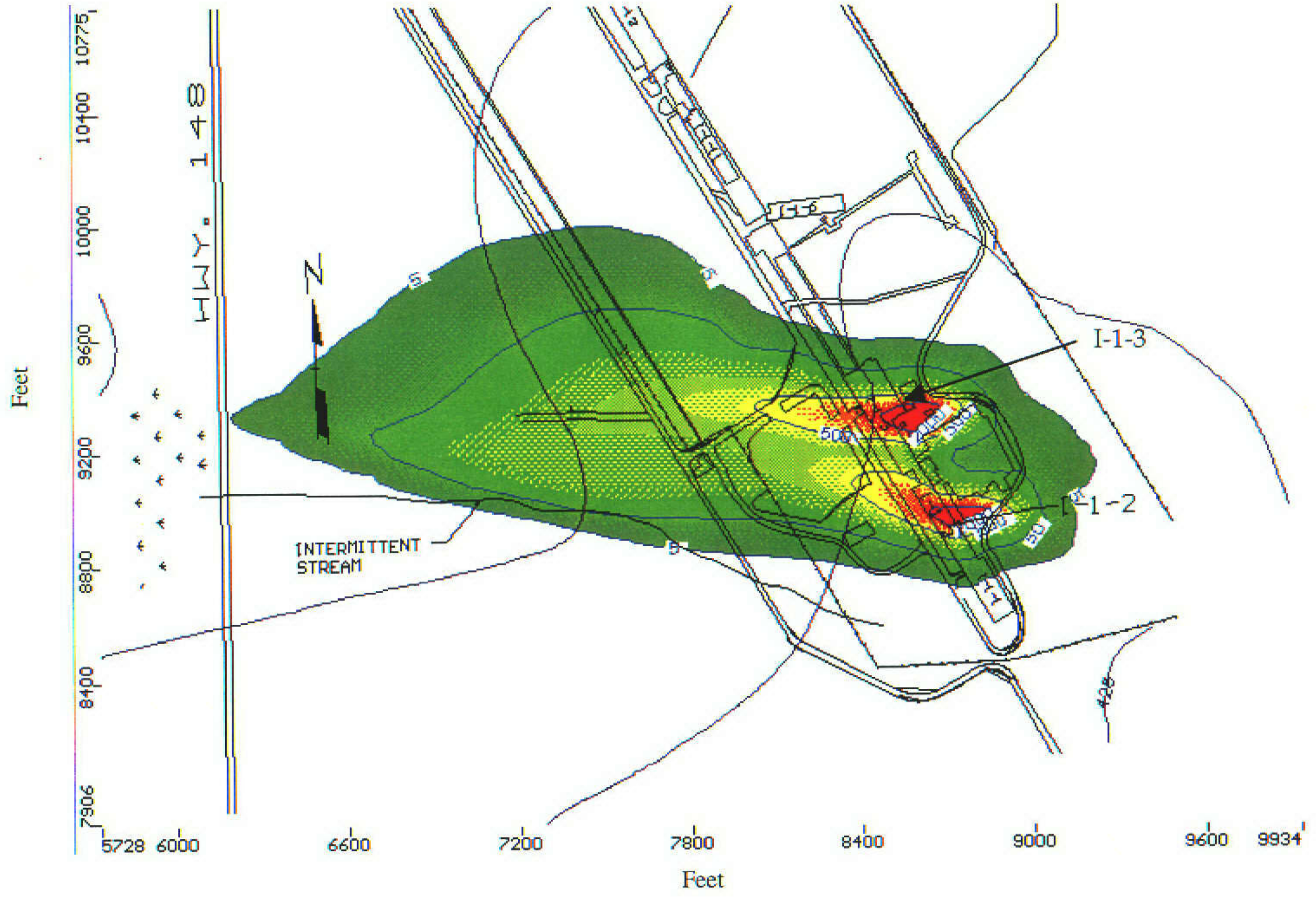
FIGURE 7-44



Buildings I-1-2/I-1-3 - Alternative E

Excavation and Reductive Dechlorination – Year 5; TCE (μg/L)

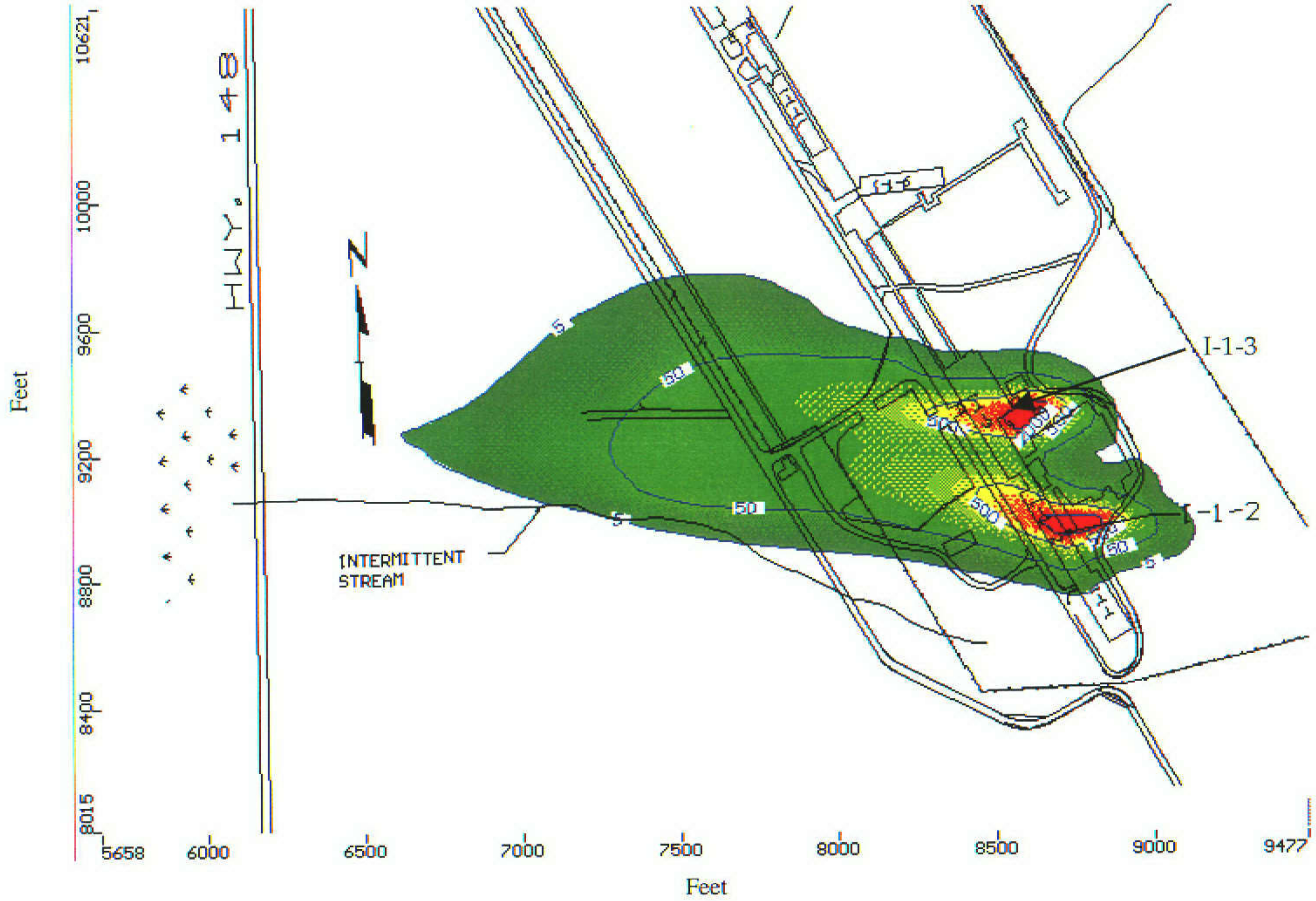
Figure 7-45



Buildings I-1-2/I-1-3 - Alternative E

Excavation and Reductive Dechlorination – Year 15; TCE (µg/L)

Figure 7-46



Buildings I-1-2/I-1-3 - Alternative E
Excavation and Reductive Dechlorination – Year 47; TCE (µg/L)

Figure 7-47

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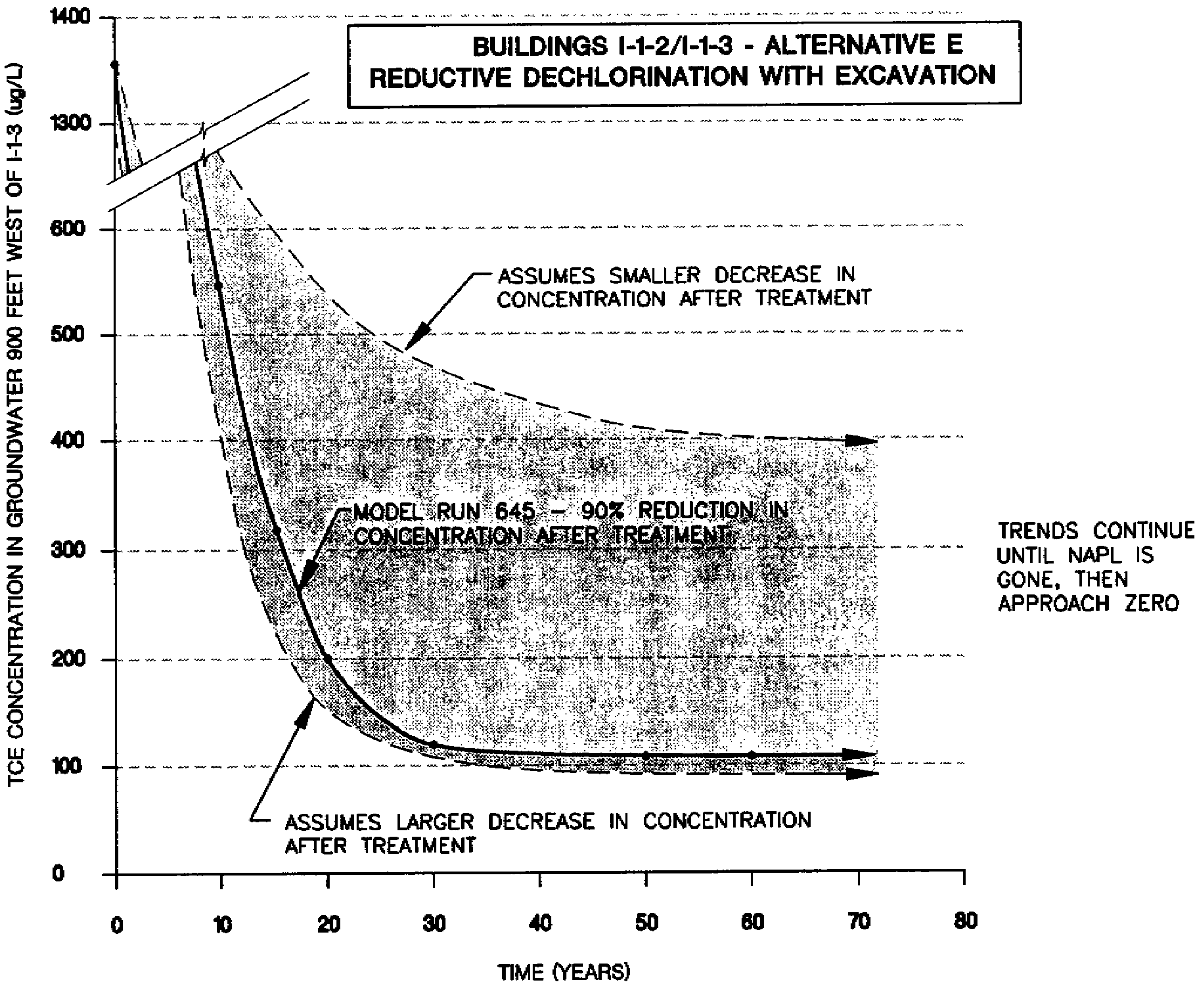
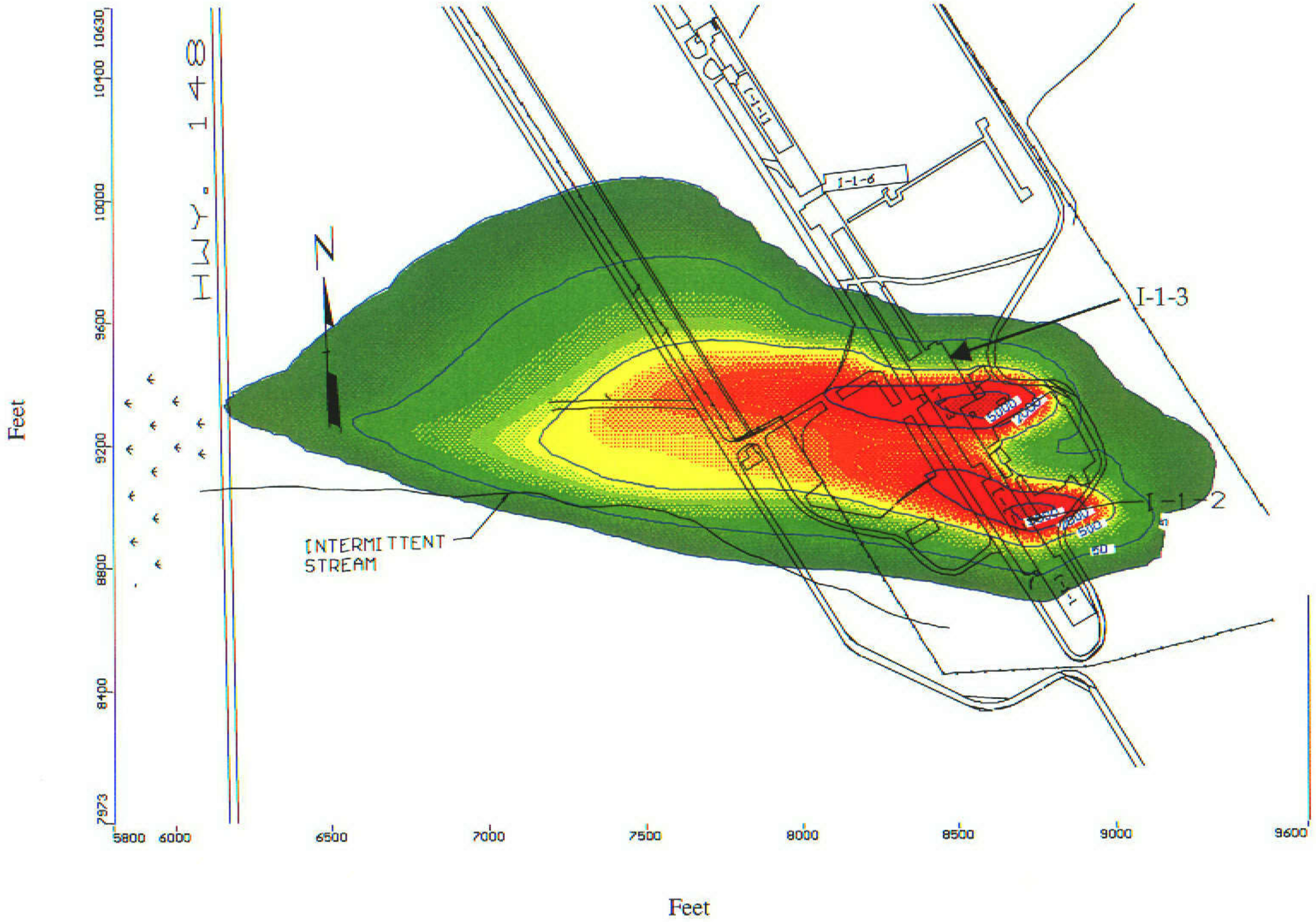


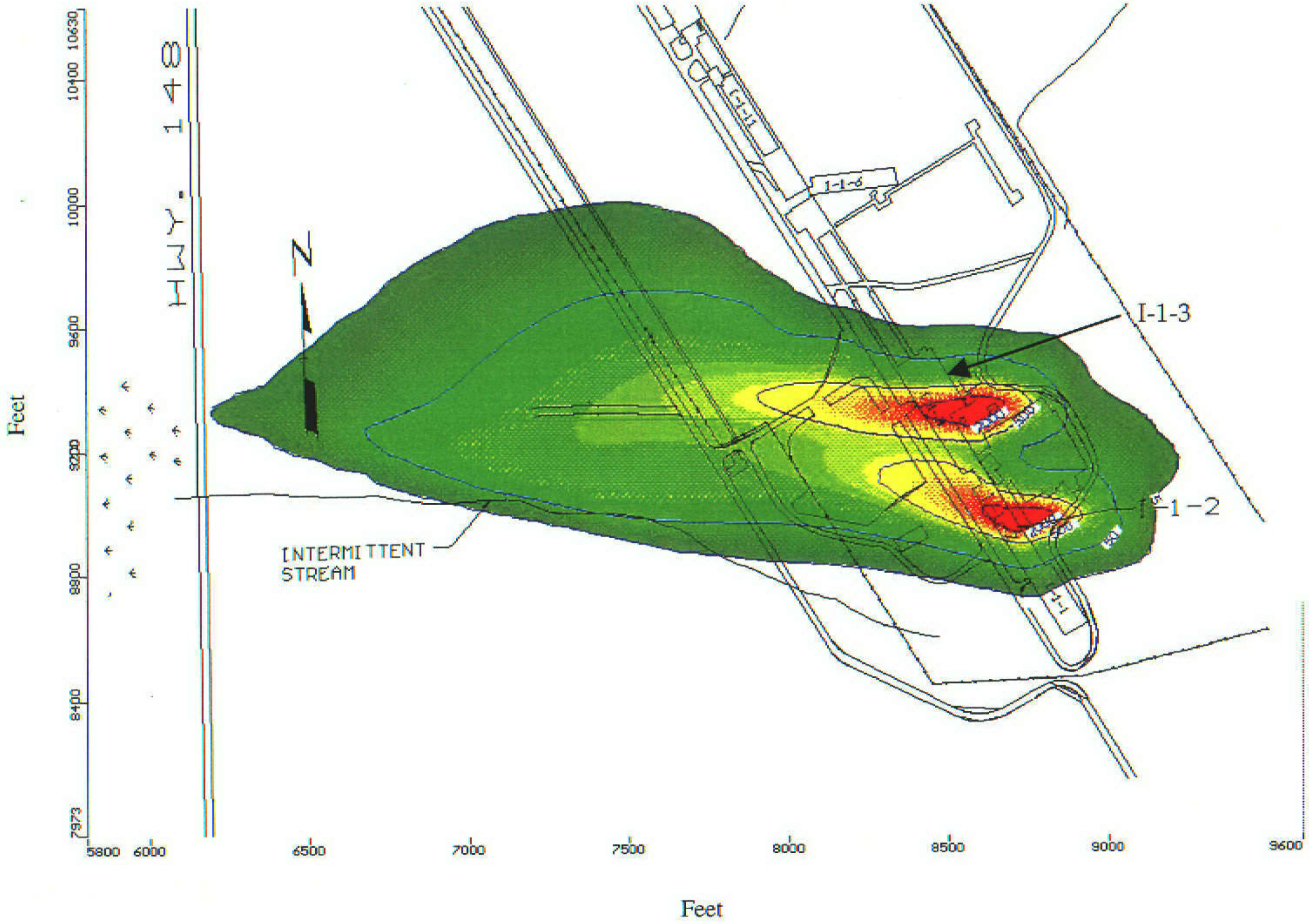
RMT	CRAB ORCHARD NWR PCBOU MARION, ILLINOIS FOCUSED FEASIBILITY STUDY REV. 3	DRAWN BY: SIEWERTD APPROVED BY: TEG PROJECT NO. 04781.12
	TCE CONCENTRATION IN GROUNDWATER 900 FEET WEST OF I-1-3 OVER TIME	FILE NO. 47811223.DWG DATE: AUGUST 2004

FIGURE 7-48



Buildings I-1-2/I-1-3 - Alternative F
Electrical Resistive Heating – Year 5; TCE (µg/L)

Figure 7-49



Buildings I-1-2/I-1-3 - Alternative F
Electrical Resistive Heating – Year 15; TCE (µg/L)

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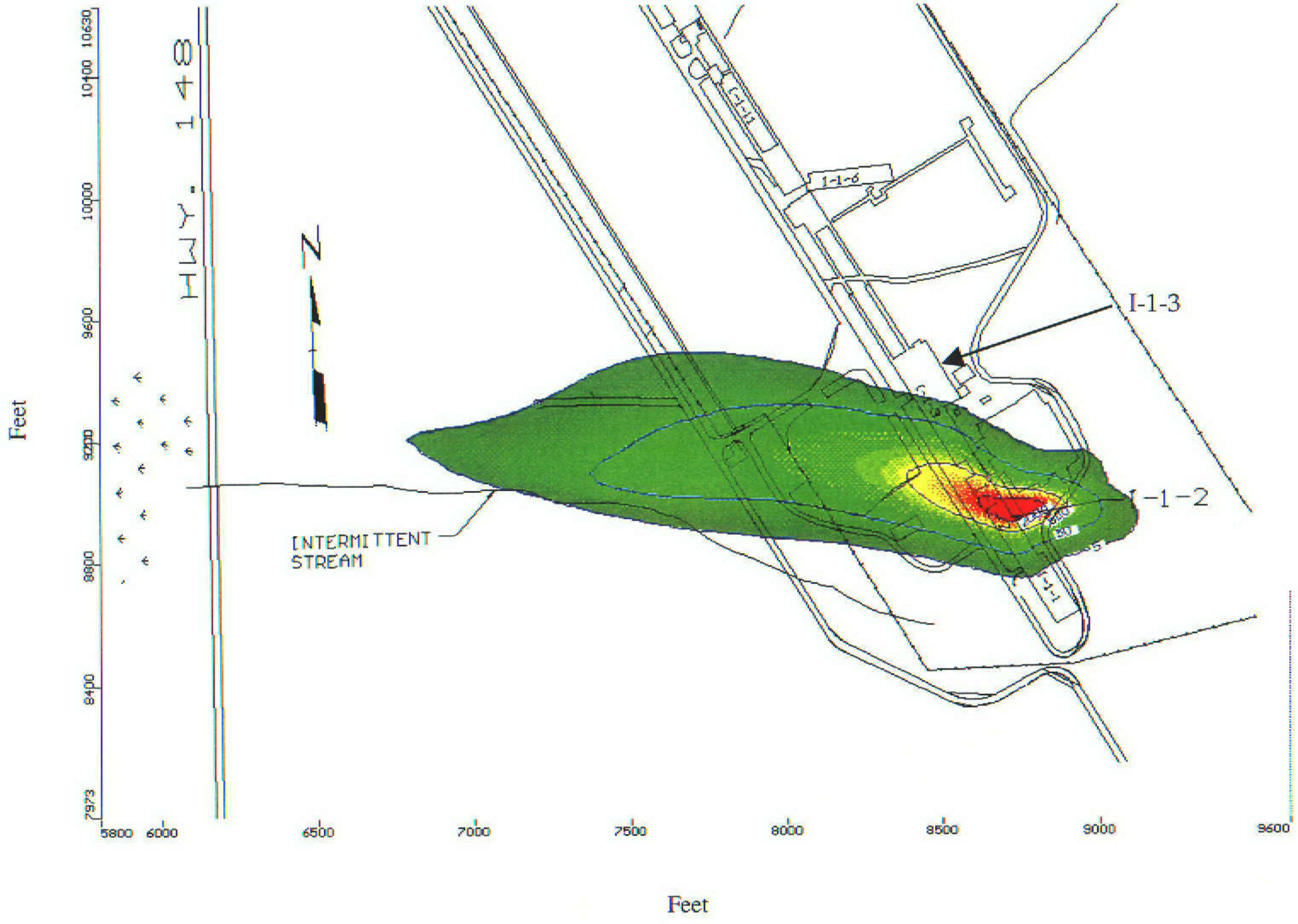
Figure 7-50



Buildings I-1-2/I-1-3 - Alternative F
Electrical Resistive Heating – Year 50; TCE (µg/L)

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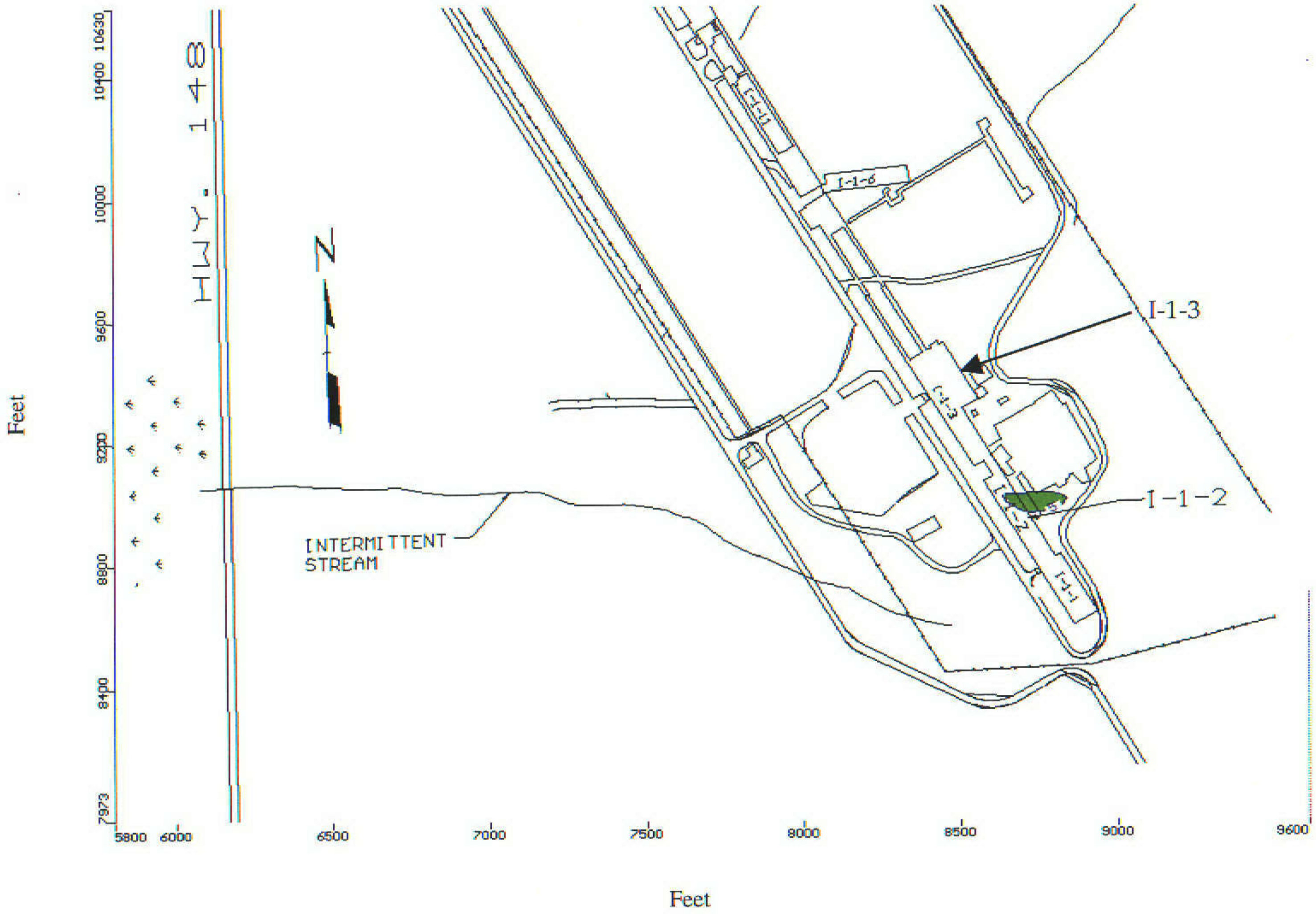
Figure 7-51



Buildings I-1-2/I-1-3 - Alternative F
Electrical Resistive Heating – Year 87; TCE (µg/L)

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Figure 7-52

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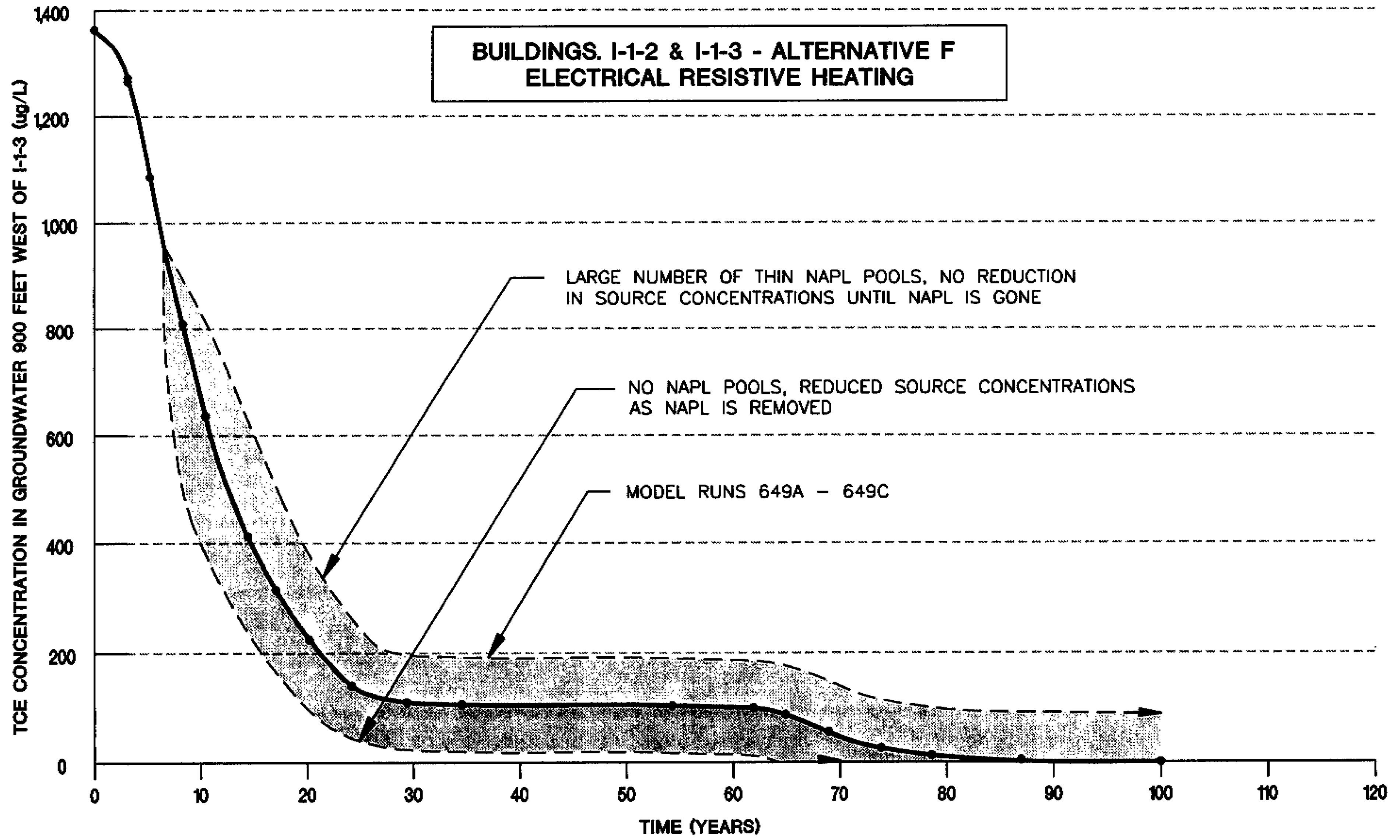

BUILDINGS. I-1-2 & I-1-3 - ALTERNATIVE F
ELECTRICAL RESISTIVE HEATING

LARGE NUMBER OF THIN NAPL POOLS, NO REDUCTION IN SOURCE CONCENTRATIONS UNTIL NAPL IS GONE

NO NAPL POOLS, REDUCED SOURCE CONCENTRATIONS AS NAPL IS REMOVED

MODEL RUNS 649A – 649C

CRAB ORCHARD NWR PCBOU
MARION, ILLINOIS
FOCUSED FEASIBILITY STUDY - REV. 3

TCE CONCENTRATION IN GROUNDWATER 900 FEET WEST OF I-1-3 OVER TIME

RMT INC.

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.12
FILE NO.	47811205.DWG
DATE:	AUGUST 2004

FIGURE 7-53

Appendix A
Cost Estimates for Remedial Alternatives - Cost Breakdown Tables

Building I-1-23

Crab Orchard National Wildlife Refuge
PCB Operable Unit - Sites 32/33
Area I-1-23 Cost Estimate Summary

Alternative	Description	Total Capital Cost ($)	Total Cost ($)	Total Present Value ($)
A1	Soil Excavation to 10 mg/kg, Long-Term Groundwater Extraction and Treatment, and Phytoremediation	830,000	5,182,000	3,719,000
	Soil Excavation to 10 mg/kg, 11 Years of Groundwater Extraction and Treatment, and Phytoremediation	830,000	3,757,000	2,984,000
A2	Soil Excavation to 1 mg/kg, 11 Years of Groundwater Extraction and Treatment, and Phytoremediation	2,747,000	5,688,000	4,914,000
B	Soil Excavation to 10 mg/kg, Permeable Reactive Barrier, and Phytoremediation	2,276,000	5,836,000	4,415,000
C	Multi-phase Extraction with Pneumatic Fracturing followed by Groundwater Extraction and Treatment and Phytoremediation	1,319,000	5,809,000	4,352,000
D	Soil Excavation to 10 mg/kg, Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits	1,074,000	3,062,000	2,391,000
E	Phytoremediation Including Engineered Wetland and Alternate Concentration Limits	706,000	2,740,000	2,046,000
F	Soil Excavation to 10 mg/kg, In-Situ Reductive Dechlorination, Phytoremediation Including Engineered Wetland, and ACLs	1,410,000	3,564,000	2,908,000
G	In-situ Electrical Resistive Heating (ERH) to 1 mg/kg and Phytoremediation	2,930,000	4,322,000	3,837,000

Note:

Total present value is for a 30-year period and annual discount rate of 3.2 percent.

Total cost is total realized dollars (sum of capital, operation, maintenance, and monitoring costs) over the common 30-year estimating period for all alternatives, not adjusted for inflation or discounting rates.

Present Value Analysis
Alternative A1 - Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, Long-Term Groundwater Extraction and Treatment, and Phytoremediation

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$830,340	$0	$14,000	$844,340	1	$844,340	Construct system. No OM&M costs in Year 0.
1	$0	$201,600	$0	$201,600	0.969	$195,300	
2	$0	$201,600	$0	$201,600	0.939	$189,300	
3	$0	$201,600	$0	$201,600	0.910	$183,400	
4	$0	$201,600	$0	$201,600	0.881	$177,700	
5	$0	$158,200	$14,000	$172,200	0.854	$147,100	Assumes monthly monitoring for treatment system, annual sampling for MW network, and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
6	$0	$158,200	$0	$158,200	0.828	$131,000	
7	$0	$158,200	$0	$158,200	0.802	$126,900	
8	$0	$158,200	$0	$158,200	0.777	$123,000	
9	$0	$158,200	$0	$158,200	0.753	$119,100	
10	$0	$129,100	$14,000	$143,100	0.730	$104,400	Assumes monitoring reduced to bimonthly for treatment system and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision, and bid & contract lab assumed.
11	$0	$129,100	$0	$129,100	0.707	$91,300	
12	$0	$129,100	$0	$129,100	0.686	$88,500	
13	$0	$129,100	$0	$129,100	0.664	$85,700	
14	$0	$129,100	$0	$129,100	0.644	$83,100	
15	$0	$125,700	$14,000	$139,700	0.623	$87,100	Assumes monitoring reduced to quarterly for treatment system and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
16	$0	$125,700	$0	$125,700	0.604	$75,900	
17	$0	$125,700	$0	$125,700	0.586	$73,600	
18	$0	$125,700	$0	$125,700	0.567	$71,300	
19	$0	$125,700	$0	$125,700	0.550	$69,100	
20	$0	$125,700	$14,000	$139,700	0.533	$74,400	Discharge permit update, QAPP/FSP revision anf bid/contract lab assumed.
21	$0	$125,700	$0	$125,700	0.516	$64,900	
22	$0	$125,700	$0	$125,700	0.500	$62,900	
23	$0	$125,700	$0	$125,700	0.484	$60,900	
24	$0	$125,700	$0	$125,700	0.469	$59,000	
25	$0	$125,700	$14,000	$139,700	0.455	$63,600	Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
26	$0	$125,700	$0	$125,700	0.441	$55,400	
27	$0	$125,700	$0	$125,700	0.427	$53,700	
28	$0	$125,700	$0	$125,700	0.414	$52,000	
29	$0	$125,700	$0	$125,700	0.401	$50,400	
30	$0	$125,700	$14,000	$139,700	0.389	$54,309	Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
TOTALS		**$4,254,000**	**$98,000**	**$5,182,000**		**$3,719,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative A1, Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, Long-Term Groundwater Extraction and Treatment, and Phytoremediation

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/28/04

Description: Alternative A1 consists of target soil (≥10 mg/kg VOC target in soil ≤12 feet deep) excavation followed by long-term groundwater extraction and treatment via liquid-phase carbon adsorption. A portion of the site would also utilize phytoremediation with cultivated cottonwood trees.

	COST ESTIMATES					
ITEM OF WORK	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Soil Excavation; Offsite Disposal						Excavation of soil ≥ 10 mg/kg, ≤ 12 feet bgs
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment.
Clearing and Grubbing	0	Acre	$4,000	$0		Assumes no clearing or grubbing needed.
Soil Excavation	620	CY	$15	$9,300		520 CY of soil is contaminated; 100 CY must be removed to access it. Includes excavation Area 201 only.
Soil Transport - Non Haz	442	Ton	$50	$22,100		Transport R/T to Peoria, IL. (520 CY * 50% @ 1.7 ton/CY). assumes 50% material >10 mg/kg total VOCs is hazardous.
Soil Transport - Haz	442	Ton	$70	$30,940		Transport R/T to Alabama; assumes 50% material >10 mg/kg total VOCs is hazardous.
Backfill & Site restoration	520	CY	$20	$10,400		Re-use 100 CY of uncontaminated soil, formerly above contaminated areas.
Soil Disposal - Non Haz	442	Ton	$70	$30,940		Assumes disposal at Peoria, IL. PCB conc. <50 ppm.
Soil Disposal - Haz	442	Ton	$130	$57,460		Assumes disposal at Emille, Alabama. PCB conc. <50 ppm.
Monitoring Well Abandonment and Replacement	126	VF	$70	$8,800		Abandonment and replacement of 33MWC-07 and 33MWC-23.
Demobilize	1	LS	$5,000	$5,000		
Level "C" contingency	10%	%	$184,940	$18,500		10% of contractor costs due to slower pace of work & PPE costs.
Subtotal					$203,440	
Groundwater Extraction and Treatment						
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight personnel, contractor personnel, and equipment.
Extraction Well Installation	1	Well	$7,500	$7,500		Assumes one 45-foot deep extraction well to pump at 10 to 20 gpm at an average of 1 ppm CVOCs.
Extraction Well Pump	1	Pump	$3,000	$3,000		From other project experience.
Access Road to Treatment Building	1	LS	$10,000	$10,000		From other project experience. Asphalt pavement.
Treatment Building	1	LS	$50,000	$50,000		Located at I-1-23 area. Includes heating and ventilating.
Electrical Power	1	LS	$20,000	$20,000		From other project experience. Nominal auto controls.
Mechanical Installation	1	LS	$20,000	$20,000		From other project experience.
Holding Tanks	2	Tank	$2,500	$5,000		From other project experience.
Control Panel and PLC Programming	1	LS	$20,000	$20,000		From other project experience. Conventional PLC-based panel. No SCADA system.
Upgraded instrumentation and telemetry system	0	LS	$115,000	$0		Remote system monitoring and control capabilities; SCADA system. Includes hardware and labor for installation.
Carbon Treatment System	1	Each	$18,500	$18,500		Assumes two, 1,500 lb carbon vessels, filled.
Filters, Flow Meter	1	LS	$5,000	$5,000		From other project experience.
Trenching/Conveyance and Discharge Piping	1,000	LF	$35	$35,000		Assuming 4 ft deep trench and 2-inch PVC piping.
Outfall	1	LS	$2,500	$2,500		From other project experience.
Misc. Equipment	1	LS	$15,000	$15,000		From other project experience; possible additional piping, valving, transfer pumps, influent pretreatment, etc.
Startup/System Shakedown	100	Hours	$75	$7,500		From other project experience.
Subtotal					$229,000	
Phytoremediation						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Cottonwood Trees; Procure and Install	0.5	Acre	$15,000	$7,600		Assumes a 100' x 220' area to be planted with cottonwoods. Approximately 440 trees.
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey.
Subtotal					$64,600	
INDIRECT CAPITAL COSTS						
Soil Excavation at Building I-1-23; Offsite Disposal						
Preliminary Design/Regulatory Approval	8%	LS	$203,440	$16,300		8% of direct soil excavation capital costs.
Final Design/Planning	7%	LS	$203,440	$14,200		7% of direct soil excavation capital costs.
Project Management	8%	LS	$203,440	$16,300		8% of direct soil excavation capital costs.
Bidding & Contracting	5%	LS	$203,440	$10,200		5% of direct soil excavation capital costs.
Permitting	1	LS	$5,000	$5,000		Disposal facility profile.
Construction Observation & Documentation	10%	LS	$203,440	$20,300		10% of direct soil excavation capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$98,300	
Groundwater Extraction and Treatment						
Workplan/Regulatory Approval	5%	LS	$229,000	$11,500		5% of direct extraction and treatment system capital costs.
Design/Planning	10%	LS	$229,000	$22,900		10% of direct extraction and treatment system capital costs.
Project Management	8%	LS	$229,000	$18,300		8% of direct extraction and treatment system capital costs.
Permit Application	1	LS	$5,000	$5,000		Treated groundwater discharge permit application.
Construction Observation & Documentation	10%	LS	$229,000	$22,900		10% of direct extraction and treatment system capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$96,600	
SUB-TOTAL					$691,940	
CONTINGENCY (20%)					$138,400	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$830,340	

Detailed Cost Estimate - Alternative A1, Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, Groundwater Extraction and Treatment, and Phytoremediation (Continued)

ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years of system operation.
Site Visits	24	Visit	$1,700	$40,800		Assumes inspections 2x/month. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	36	Sample	$100	$3,600		Assumes initial monthly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	36	Sample	$250	$9,000		Assumes initial monthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,800	$33,600		Includes 24 hr/mo labor, equipment
Electric Power	12	Month	$196	$2,352		Assumes 5 hp consumption at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$600	$7,200		Assumes 10 lb/day carbon usage at $2.00/lb carbon, includes carbon disposal off-site.
Monitoring Well Network Sampling labor & expenses	2	Events	$7,500	$15,000		Semiannual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	22	Sample	$250	$5,500		Assumes semiannual sampling of 10 monitoring wells with 1 QA/QC duplicate sample.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes initial semiannual reporting.
O&M Contingency	20%	LS	-	$33,600		20% of O&M items
Subtotal					$201,600	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
Permit Renewal Application	1	Applic.	$5,000	$5,000		Assumes discharge permit renewal required every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for second 5 years of system operation.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	36	Sample	$100	$3,600		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	36	Sample	$250	$9,000		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,800	$33,600		Includes 24 hr/mo labor, equipment.
Electric Power	12	Month	$196	$2,352		Assumes 5 hp consumption at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$540	$6,480		Assumes 9 lb/day carbon usage at $2.00/lb carbon, includes carbon disposal off-site.
Monitoring Well Network Sampling labor & expenses	1	Event	$7,500	$7,500		Annual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 10 monitoring wells with 1 QA/QC duplicate sample.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS	-	$26,366		20% of O&M items
Subtotal					$158,200	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 11-15						Estimated annual operation, maintenance, and monitoring costs for third 5 years of system operation.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	18	Sample	$100	$1,800		Assumes bimonthly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	18	Sample	$250	$4,500		Assumes bimonthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,200	$26,400		Includes 16 hr/mo labor, equipment
Power Consumption	12	Month	$196	$2,352		Assumes 5 hp consumption at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$480	$5,760		Assumes 8 lb/day carbon usage at $2.00/lb carbon, includes carbon disposal off-site.
Miscellaneous Equipment Replacement Allowance	1	LS	$5,000	$5,000		Placeholder for potential equipment replacement requirements.
Monitoring Well Network Sampling labor & expenses	1	Event	$7,500	$7,500		Assumes annual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 10 monitoring wells with 1 QA/QC duplicate sample.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$21,522		20% of O&M items
Subtotal					$129,100	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 16-30						Estimated annual operation, maintenance, and monitoring costs for years 16-30 of system operation.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	12	Sample	$100	$1,200		Assumes quarterly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	12	Sample	$250	$3,000		Assumes quarterly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,200	$26,400		Includes 16 hr/mo labor, equipment
Electric Power	12	Month	$196	$2,352		Assumes 5 hp consumption at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$420	$5,040		Assumes 7 lb/day carbon usage at $2.00/lb carbon, includes carbon disposal off-site.
Miscellaneous Equipment Replacement Allowance	1	LS	$5,000	$5,000		Placeholder for potential equipment replacement requirements.
Monitoring Well Network Sampling labor & expenses	1	Event	$7,500	$7,500		Assumes annual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 10 monitoring wells with 1 QA/QC duplicate sample.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$20,958		20% of O&M items
Subtotal					$125,700	

Present Value Analysis
Alternative A1 - Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, 11 Years of Groundwater Extraction and Treatment, and Phytoremediation

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$830,340	$0	$14,000	$844,340	1	$844,340	Construct system. No OM&M costs in Year 0.
1	$0	$201,600	$0	$201,600	0.969	$195,300	
2	$0	$201,600	$0	$201,600	0.939	$189,300	
3	$0	$201,600	$0	$201,600	0.910	$183,400	
4	$0	$201,600	$0	$201,600	0.881	$177,700	
5	$0	$158,200	$14,000	$172,200	0.854	$147,100	Assumes monthly monitoring for treatment system, annual sampling for MW network, and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
6	$0	$158,200	$0	$158,200	0.828	$131,000	
7	$0	$158,200	$0	$158,200	0.802	$126,900	
8	$0	$158,200	$0	$158,200	0.777	$123,000	
9	$0	$158,200	$0	$158,200	0.753	$119,100	
10	$0	$158,200	$14,000	$172,200	0.730	$125,700	
11	$0	$158,200	$0	$158,200	0.707	$111,900	
12	$0	$49,700	$0	$49,700	0.686	$34,100	Assumes treatment system turned off, only groundwater monitoring.
13	$0	$49,700	$0	$49,700	0.664	$33,000	
14	$0	$49,700	$0	$49,700	0.644	$32,000	
15	$0	$49,700	$9,000	$58,700	0.624	$36,600	
16	$0	$49,700	$0	$49,700	0.604	$30,000	
17	$0	$49,700	$0	$49,700	0.586	$29,100	
18	$0	$49,700	$0	$49,700	0.567	$28,200	
19	$0	$49,700	$0	$49,700	0.549	$27,300	
20	$0	$49,700	$9,000	$58,700	0.533	$31,300	
21	$0	$49,700	$0	$49,700	0.515	$25,600	
22	$0	$49,700	$0	$49,700	0.501	$24,900	
23	$0	$49,700	$0	$49,700	0.485	$24,100	
24	$0	$49,700	$0	$49,700	0.469	$23,300	
25	$0	$49,700	$9,000	$58,700	0.455	$26,700	
26	$0	$49,700	$0	$49,700	0.441	$21,900	
27	$0	$49,700	$0	$49,700	0.427	$21,200	
28	$0	$49,700	$0	$49,700	0.414	$20,600	
29	$0	$49,700	$0	$49,700	0.400	$19,900	
30	$0	$49,700	$0	$49,700	0.389	$19,321	
TOTALS		**$2,858,100**	**$69,000**	**$3,757,440**		**$2,984,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative A1, Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, 11 Years of Groundwater Extraction and Treatment, and Phytoremediation

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/28/04

Description: Alternative A1 consists of target soil (≥10 mg/kg VOC target in soil ≤12 feet deep) excavation followed by 11 years of groundwater extraction and treatment via liquid-phase carbon adsorption. A portion of the site would also utilize phytoremediation with cultivated cottonwood trees.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT CAPITAL COSTS						
Soil Excavation; Offsite Disposal						Excavation of soil ≥ 10 mg/kg, ≤ 12 feet bgs
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment.
Clearing and Grubbing	0	Acre	$4,000	$0		Assumes no clearing or grubbing needed.
Soil Excavation	620	CY	$15	$9,300		520 CY of soil is contaminated; 100 CY must be removed to access it. Includes excavation Area 201 only.
Soil Transport - Non Haz	442	Ton	$50	$22,100		Transport R/T to Peoria, IL. (520 CY * 50% @ 1.7 ton/CY). assumes 50% material >10 mg/kg total VOCs is hazardous.
Soil Transport - Haz	442	Ton	$70	$30,940		Transport R/T to Alabama; assumes 50% material >10 mg/kg total VOCs is hazardous.
Backfill & Site restoration	520	CY	$20	$10,400		Re-use 100 CY of uncontaminated soil, formerly above contaminated areas.
Soil Disposal - Non Haz	442	Ton	$70	$30,940		Assumes disposal at Peoria, IL. PCB conc. <50 ppm.
Soil Disposal - Haz	442	Ton	$130	$57,460		Assumes disposal at Emille, Alabama. PCB conc. <50 ppm.
Monitoring Well Abandonment and Replacement	126	VF	$70	$8,800		Abandonment and replacement of 33MWC-07 and 33MWC-23.
Demobilize	1	LS	$5,000	$5,000		
Level "C" contingency	10%	%	$184,940	$18,500		10% of contractor costs due to slower pace of work & PPE costs.
Subtotal					$203,440	
Groundwater Extraction and Treatment						
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight personnel, contractor personnel, and equipment.
Extraction Well Installation	1	Well	$7,500	$7,500		Assumes one 45-foot deep extraction well to pump at 10 to 20 gpm at an average of 1 ppm CVOCs.
Extraction Well Pump	1	Pump	$3,000	$3,000		From other project experience.
Access Road to Treatment Building	1	LS	$10,000	$10,000		From other project experience. Asphalt pavement.
Treatment Building	1	LS	$50,000	$50,000		Located at I-1-23 area. Includes heating and ventilating.
Electrical Power	1	LS	$20,000	$20,000		From other project experience. Nominal auto controls.
Mechanical Installation	1	LS	$20,000	$20,000		From other project experience.
Holding Tanks	2	Tank	$2,500	$5,000		From other project experience.
Control Panel and PLC Programming	1	LS	$20,000	$20,000		From other project experience. Conventional PLC-based panel. No SCADA system.
Upgraded instrumentation and telemetry system	0	LS	$115,000	$0		Remote system monitoring and control capabilities; SCADA system. Includes hardware and labor for installation.
Carbon Treatment System	1	Each	$18,500	$18,500		Assumes two, 1,500 lb carbon vessels, filled.
Filters, Flow Meter	1	LS	$5,000	$5,000		From other project experience.
Trenching/Conveyance and Discharge Piping	1,000	LF	$35	$35,000		Assuming 4 ft deep trench and 2-inch PVC piping.
Outfall	1	LS	$2,500	$2,500		From other project experience.
Misc. Equipment	1	LS	$15,000	$15,000		From other project experience; possible additional piping, valving, transfer pumps, influent pretreatment, etc.
Startup/System Shakedown	100	Hours	$75	$7,500		From other project experience.
Subtotal					$229,000	
Phytoremediation						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Cottonwood Trees; Procure and Install	0.5	Acre	$15,000	$7,600		Assumes a 100' x 220' area to be planted with cottonwoods. Approximately 440 trees.
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey.
Subtotal					$64,600	
INDIRECT CAPITAL COSTS						
Soil Excavation at Building I-1-23; Offsite Disposal						
Preliminary Design/Regulatory Approval	8%	LS	$203,440	$16,300		8% of direct soil excavation capital costs.
Final Design/Planning	7%	LS	$203,440	$14,200		7% of direct soil excavation capital costs.
Project Management	8%	LS	$203,440	$16,300		8% of direct soil excavation capital costs.
Bidding & Contracting	5%	LS	$203,440	$10,200		5% of direct soil excavation capital costs.
Permitting	1	LS	$5,000	$5,000		Disposal facility profile.
Construction Observation & Documentation	10%	LS	$203,440	$20,300		10% of direct soil excavation capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$98,300	
Groundwater Extraction and Treatment						
Workplan/Regulatory Approval	5%	LS	$229,000	$11,500		5% of direct extraction and treatment system capital costs.
Design/Planning	10%	LS	$229,000	$22,900		10% of direct extraction and treatment system capital costs.
Project Management	8%	LS	$229,000	$18,300		8% of direct extraction and treatment system capital costs.
Permit Application	1	LS	$5,000	$5,000		Treated groundwater discharge permit application.
Construction Observation & Documentation	10%	LS	$229,000	$22,900		10% of direct extraction and treatment system capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$96,600	
SUB-TOTAL					$691,940	
CONTINGENCY (20%)					$138,400	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$830,340	

Detailed Cost Estimate - Alternative A1, Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, 11 Years of Groundwater Extraction and Treatment, and Phytoremediation

ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years of system operation.
Site Visits	24	Visit	$1,700	$40,800		Assumes inspections 2x/month. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	36	Sample	$100	$3,600		Assumes initial monthly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	36	Sample	$250	$9,000		Assumes initial monthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,800	$33,600		Includes 24 hr/mo labor, equipment
Electric Power	12	Month	$196	$2,352		Assumes 5 hp consumption at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$600	$7,200		Assumes 10 lb/day carbon usage at $2.00/lb carbon, includes carbon disposal off-site.
Monitoring Well Network Sampling labor & expenses	2	Events	$7,500	$15,000		Semiannual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	22	Sample	$250	$5,500		Assumes semiannual sampling of 10 monitoring wells with 1 QA/QC duplicate sample.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes initial semiannual reporting.
O&M Contingency	20%	LS	-	$33,600		20% of O&M items
Subtotal					$201,600	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
Permit Renewal Application	1	Applic.	$5,000	$5,000		Assumes discharge permit renewal required every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 6-11						Estimated annual operation, maintenance, and monitoring costs for second 5 years of system operation.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	36	Sample	$100	$3,600		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	36	Sample	$250	$9,000		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,800	$33,600		Includes 24 hr/mo labor, equipment.
Electric Power	12	Month	$196	$2,352		Assumes 5 hp consumption at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$540	$6,480		Assumes 9 lb/day carbon usage at $2.00/lb carbon, includes carbon disposal off-site.
Monitoring Well Network Sampling labor & expenses	1	Event	$7,500	$7,500		Annual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 10 monitoring wells with 1 QA/QC duplicate sample.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS	-	$26,366		20% of O&M items
Subtotal					$158,200	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 12-30						Assumes system turned off in year 12.
Site Visits	0	Visit	$1,700	$0		
Treatment System Performance Sampling	0	Sample	$100	$0		
Analytical Testing (Performance Sampling)	0	Sample	$250	$0		
Treatment System Operation	0	Month	$2,200	$0		
Power Consumption	0	Month	$196	$0		
Carbon Replacement	0	Month	$480	$0		
Miscellaneous Equipment Replacement Allowance	0	LS	$5,000	$0		
Monitoring Well Network Sampling labor & expenses	1	Event	$7,500	$7,500		Assumes annual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 10 monitoring wells with 1 QA/QC duplicate sample.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$8,280		20% of O&M items
Subtotal					$49,700	

Present Value Analysis
Alternative A2 - Building I-1-23 VOC Source Area
Soil Excavation to 1 mg/kg, 11 Years of Groundwater Extraction and Treatment, and Phytoremediation

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$2,746,951	$14,000	$14,000	$2,774,951	1	$2,774,951	Construct system. No OM&M costs in Year 0.
1	$0	$201,600	$0	$201,600	0.969	$195,300	
2	$0	$201,600	$0	$201,600	0.939	$189,300	
3	$0	$201,600	$0	$201,600	0.910	$183,400	
4	$0	$201,600	$0	$201,600	0.881	$177,700	
5	$0	$158,200	$14,000	$172,200	0.854	$147,100	Assumes monthly monitoring for treatment system, annual sampling for MW network, and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
6	$0	$158,200	$0	$158,200	0.828	$131,000	
7	$0	$158,200	$0	$158,200	0.802	$126,900	
8	$0	$158,200	$0	$158,200	0.777	$123,000	
9	$0	$158,200	$0	$158,200	0.753	$119,100	
10	$0	$158,200	$14,000	$172,200	0.730	$125,700	
11	$0	$158,200	$0	$158,200	0.707	$111,900	
12	$0	$49,700	$0	$49,700	0.686	$34,100	Assumes treatment system turned off, only groundwater monitoring.
13	$0	$49,700	$0	$49,700	0.664	$33,000	
14	$0	$49,700	$0	$49,700	0.644	$32,000	
15	$0	$49,700	$9,000	$58,700	0.624	$36,600	
16	$0	$49,700	$0	$49,700	0.604	$30,000	
17	$0	$49,700	$0	$49,700	0.586	$29,100	
18	$0	$49,700	$0	$49,700	0.567	$28,200	
19	$0	$49,700	$0	$49,700	0.549	$27,300	
20	$0	$49,700	$9,000	$58,700	0.533	$31,300	
21	$0	$49,700	$0	$49,700	0.515	$25,600	
22	$0	$49,700	$0	$49,700	0.501	$24,900	
23	$0	$49,700	$0	$49,700	0.485	$24,100	
24	$0	$49,700	$0	$49,700	0.469	$23,300	
25	$0	$49,700	$9,000	$58,700	0.455	$26,700	
26	$0	$49,700	$0	$49,700	0.441	$21,900	
27	$0	$49,700	$0	$49,700	0.427	$21,200	
28	$0	$49,700	$0	$49,700	0.414	$20,600	
29	$0	$49,700	$0	$49,700	0.400	$19,900	
30	$0	$49,700	$0	$49,700	0.389	$19,321	
TOTALS		$2,872,100	$69,000	$5,688,051		$4,914,000	30 year total (linked to Summary sheet)

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Detailed Cost Estimate - Alternative A2, Building I-1-23 VOC Source Area
Soil Excavation to 1 mg/kg, Groundwater Extraction and Treatment, and Phytoremediation

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/28/04

Description: Alternative A2 consists of target soil (≥1 mg/kg VOC target in the Upper Clay in Areas 201, 212, and 208) excavation followed by long-term groundwater extraction within the Upper Sand and treatment via liquid-phase carbon adsorption. A portion of the site would also utilize phytoremediation with cultivated cottonwood trees.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT CAPITAL COSTS						
Soil Excavation; Offsite Disposal						Excavation of soil ≥ 1 mg/kg
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment.
Clearing and Grubbing	0	Acre	$4,000	$0		Assumes no clearing or grubbing needed.
Excavation Support	1	LS	$50,000	$50,000		Placeholder for engineering controls for excavation support - deep excavation
Soil Excavation - Area 201	3,020	CY	$15	$45,300		350 cy must be removed to access soil that requires disposal (2,670 cy).
Soil Excavation - Area 208	450	CY	$15	$6,750		250 cy must be removed to access soil that requires disposal (200 cy).
Soil Excavation - Area 212	2,180	CY	$25	$54,500		630 cy must be removed to access soil that requires disposal (1,550 cy), unit price higher due to deep Upper Sand excavation.
Soil Transport - Non Haz	6,763	Ton	$50	$338,130		Transport R/T to Peoria, IL. (3,580 - 442 CY @ 1.7 ton/CY). Assumes all saturated soil will require disposal.
Soil Transport - Haz	751	Ton	$70	$52,600		Transport R/T to Emelle, Alabama. (442 CY @ 1.7 ton/CY); assumes 50% material >10 mg/kg total VOCs is hazardous
Backfill & Site restoration	4,440	CY	$20	$88,800		Backfill, placed and compacted. Re-use 1,230 CY of clean matl for backfill
Soil Disposal - Non Haz	6,763	Ton	$70	$473,382		Assumes disposal at Peoria, IL. PCB conc. <50 ppm.
Soil Disposal - Haz	751	Ton	$130	$97,682		Assumes disposal at Emille, Alabama. PCB conc. <50 ppm.
Monitoring Well Abandonment and Replacement	213	VF	$70	$14,900		Abandonment and replacement of 33MWC-07, 33MWC-21, 33MWC-22, and 33MWC-23.
Demobilize	1	LS	$5,000	$5,000		
Level "C" contingency	10%	LS	$1,237,044	$123,700		10% of contractor costs due to slower pace of work & PPE costs.
Subtotal					$1,360,744	
Groundwater Extraction and Treatment						
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight personnel, contractor personnel, and equipment.
Extraction Well Installation	1	Well	$7,500	$7,500		Assumes one 45-foot deep extraction well to pump at 10 to 20 gpm at an average of 1 ppm CVOCs.
Extraction Well Pump	1	Pump	$3,000	$3,000		From other project experience.
Access Road to Treatment Building	1	LS	$10,000	$10,000		From other project experience. Asphalt pavement.
Treatment Building	1	LS	$50,000	$50,000		Located at I-1-23 area. Includes heating and ventilating.
Electrical Power	1	LS	$20,000	$20,000		From other project experience. Nominal auto controls.
Mechanical Installation	1	LS	$20,000	$20,000		From other project experience.
Holding Tanks	2	Tank	$2,500	$5,000		From other project experience.
Control Panel and PLC Programming	1	LS	$20,000	$20,000		From other project experience. Conventional PLC-based panel. No SCADA system.
Upgraded instrumentation and telemetry system	0	LS	$115,000	$0		Remote system monitoring and control capabilities; SCADA system. Includes hardware and labor for installation.
Carbon Treatment System	1	Each	$18,500	$18,500		Assumes two, 1,500 lb carbon vessels, filled.
Filters, Flow Meter	1	LS	$5,000	$5,000		From other project experience.
Trenching/Conveyance and Discharge Piping	1,000	LF	$35	$35,000		Assuming 4 ft deep trench and 2-inch PVC piping.
Outfall	1	LS	$2,500	$2,500		From other project experience.
Misc. Equipment	1	LS	$15,000	$15,000		From other project experience; possible additional piping, valving, transfer pumps, influent pretreatment, etc.
Startup/System Shakedown	100	Hours	$75	$7,500		From other project experience.
Subtotal					$229,000	
Phytoremediation						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Cottonwood Trees; Procure and Install	0.5	Acre	$15,000	$7,600		Assumes a 100' x 220' area to be planted with cottonwoods. Approximately 440 trees.
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey.
Subtotal					$64,600	
INDIRECT CAPITAL COSTS						
Soil Excavation at Building I-1-23; Offsite Disposal						
Preliminary Design/Regulatory Approval	8%	LS	$1,360,744	$108,900		8% of direct soil excavation capital costs.
Final Design/Planning	7%	LS	$1,360,744	$95,300		7% of direct soil excavation capital costs.
Project Management	8%	LS	$1,360,744	$108,900		8% of direct soil excavation capital costs.
Bidding & Contracting	5%	LS	$1,360,744	$68,037		5% of direct soil excavation capital costs.
Permitting	1	LS	$5,000	$5,000		Disposal facility profile.
Construction Observation & Documentation	10%	LS	$1,360,744	$136,100		10% of direct soil excavation capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$538,237	
Groundwater Extraction and Treatment						
Workplan/Regulatory Approval	5%	LS	$229,000	$11,450		5% of direct extraction and treatment system capital costs.
Design/Planning	10%	LS	$229,000	$22,900		10% of direct extraction and treatment system capital costs.
Project Management	8%	LS	$229,000	$18,320		8% of direct extraction and treatment system capital costs.
Permit Application	1	LS	$5,000	$5,000		Treated groundwater discharge permit application.
Construction Observation & Documentation	10%	LS	$229,000	$22,900		10% of direct extraction and treatment system capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$96,570	
SUB-TOTAL					$2,289,151	
CONTINGENCY (20%)					$457,800	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$2,746,951	

Detailed Cost Estimate - Alternative A2, Building I-1-23 VOC Source Area
Soil Excavation to 1 mg/kg, Groundwater Extraction and Treatment, and Phytoremediation (Continued)

ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years of system operation.
Site Visits	24	Visit	$1,700	$40,800		Assumes inspections 2x/month. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	36	Sample	$100	$3,600		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	36	Sample	$250	$9,000		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,800	$33,600		Includes 24 hr/mo labor, equipment
Electric Power	12	Month	$196	$2,352		Assumes 5 hp consumption at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$600	$7,200		Assumes 10 lb/day carbon usage at $2.00/lb carbon, includes carbon disposal off-site.
Monitoring Well Network Sampling labor & expenses	2	Events	$7,500	$15,000		Semiannual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	22	Sample	$250	$5,500		Assumes semiannual sampling of 10 monitoring wells with 1 QA/QC duplicate sample per quarter.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes initial semiannual reporting.
O&M Contingency	20%	LS	-	$33,600		20% of O&M items
Subtotal					$201,600	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
Permit Renewal Application	1	Applic.	$5,000	$5,000		Assumes discharge permit renewal required every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 6-11						Estimated annual operation, maintenance, and monitoring costs for years 6-11 of system operation.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	36	Sample	$100	$3,600		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	36	Sample	$250	$9,000		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,800	$33,600		Includes 24 hr/mo labor, equipment.
Electric Power	12	Month	$196	$2,352		Assumes 5 hp consumption at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$540	$6,480		Assumes 9 lb/day carbon usage at $2.00/lb carbon, includes carbon disposal off-site.
Monitoring Well Network Sampling labor & expenses	1	Event	$7,500	$7,500		Assumes annual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 10 monitoring wells with 1 QA/QC duplicate sample per event.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS	-	$26,366		20% of O&M items
Subtotal					$158,200	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 12-30						Assumes system turned off in year 12.
Site Visits	0	Visit	$1,700	$0		
Treatment System Performance Sampling	0	Sample	$100	$0		
Analytical Testing (Performance Sampling)	0	Sample	$250	$0		
Treatment System Operation	0	Month	$2,200	$0		
Power Consumption	0	Month	$196	$0		
Carbon Replacement	0	Month	$480	$0		
Miscellaneous Equipment Replacement Allowance	0	LS	$5,000	$0		
Monitoring Well Network Sampling labor & expenses	1	Event	$7,500	$7,500		Assumes annual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 10 monitoring wells with 1 QA/QC duplicate sample per event.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$8,280		20% of O&M items
Subtotal					$49,700	

Present Value Analysis
Alternative B - Building I-1-23 VOC Source Area
Soil Excavation, Permeable Reactive Barrier, and Phytoremediation

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$2,276,375	$0	$9,000	$2,285,375	1	$2,285,375	PRB Construction.
1	$0	$94,300	$0	$94,300	0.969	$91,400	Assumes quarterly monitoring for PRB and semi-annual GW monitoring.
2	$0	$94,300	$0	$94,300	0.938	$88,500	
3	$0	$94,300	$0	$94,300	0.910	$85,800	
4	$0	$94,300	$0	$94,300	0.881	$83,100	
5	$0	$94,300	$9,000	$103,300	0.854	$88,200	QAPP/FSP revision and lab bid/contract assumed.
6	$0	$46,500	$0	$46,500	0.828	$38,500	Assumes monitoring reduced to annually for GW and PRB, semi-annual site visits included.
7	$0	$46,500	$0	$46,500	0.802	$37,300	
8	$0	$46,500	$0	$46,500	0.776	$36,100	
9	$0	$46,500	$0	$46,500	0.753	$35,000	
10	$0	$46,500	$9,000	$55,500	0.730	$40,500	
11	$0	$44,500	$0	$44,500	0.708	$31,500	Assumes annual monitoring for GW and PRB, with annual site visit.
12	$0	$44,500	$0	$44,500	0.685	$30,500	
13	$0	$44,500	$0	$44,500	0.663	$29,500	
14	$0	$44,500	$0	$44,500	0.643	$28,600	
15	$0	$44,500	$9,000	$53,500	0.624	$33,400	
16	$0	$44,500	$0	$44,500	0.604	$26,900	
17	$0	$44,500	$0	$44,500	0.584	$26,000	
18	$0	$44,500	$0	$44,500	0.566	$25,200	
19	$0	$44,500	$0	$44,500	0.551	$24,500	
20	$0	$44,500	$1,911,300	$1,955,800	0.533	$1,041,700	Replacement of PRB in year 20.
21	$0	$44,500	$0	$44,500	0.517	$23,000	
22	$0	$44,500	$0	$44,500	0.501	$22,300	
23	$0	$44,500	$0	$44,500	0.485	$21,600	
24	$0	$44,500	$0	$44,500	0.470	$20,900	
25	$0	$44,500	$9,000	$53,500	0.454	$24,300	
26	$0	$44,500	$0	$44,500	0.440	$19,600	
27	$0	$44,500	$0	$44,500	0.427	$19,000	
28	$0	$44,500	$0	$44,500	0.413	$18,400	
29	$0	$44,500	$0	$44,500	0.402	$17,900	
30	$0	$44,500	$9,000	$53,500	0.389	$20,799	
TOTALS		**$1,594,000**	**$1,965,300**	**$5,836,000**		**$4,415,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative B - Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, Permeable Reactive Barrier, and Phytoremediation

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/28/04

Description: Alternative B consists of target soil (>10 mg/kg VOC target in soil <12 feet deep) excavation followed by installation of a permeable reactive barrier containing zero-valent iron. A portion of the site would also utilize phytoremediation with cultivated cottonwood trees.

	COST ESTIMATES					
ITEM OF WORK	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Permeable Reactive Barrier						
Mobilization	1	Estimate	$50,000	$50,000		Oversight personnel, contractor personnel, and equipment.
Utility Relocation	1	LS	$22,000	$22,000		Assumes utilities in the area of soil to be excavated.
Trenching	15,750	SF	$20	$315,000		Assuming 350 ft long, 45 ft deep, 2.5 ft wide.
Soil Reuse-Backfill Above Iron/Sand Mixture	826	Ton	$10	$8,264		Assumes top 15 ft excavated soil can be replaced into the top of the trench.
Soil Transportation	1,653	Ton	$50	$82,639		Assumes bottom 30 ft excavated soil will require off-site disposal; 1.7t/cy. Includes transportation.
Soil Disposal	1,653	Ton	$70	$115,694		Assumes bottom 30 ft excavated soil will require off-site disposal; 1.7t/cy. Includes transportation.
Iron Material	984	Ton	$450	$442,969		Assumes bulk density of 0.08 tons/cubic foot, bottom 30' of trench filled with 1:1 iron/sand-mixture. Delivered.
Sand Material	1,458	Ton	$15	$21,880		Assumes bottom 30' of trench filled with 1:1 iron/sand-mixture. Delivered.
Monitoring Well Installation	260	VF	$77	$20,020		Assumes installation of 8 new wells; 5 in US unit and 3 water table wells. Includes soil disposal and survey.
Subtotal					$1,078,500	
Soil Excavation; Offsite Disposal						Excavation of soil ≥ 10 mg/kg
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment.
Clearing and Grubbing	0	Acre	$4,000	$0		Assumes no clearing or grubbing needed.
Soil Excavation	620	CY	$15	$9,300		520 CY of soil is contaminated; 100 CY must be removed to access it. Includes excavation Area 201 only
Soil Transport	884	Ton	$50	$44,200		Transport R/T from CONWR to Peoria, IL. (520 CY @ 1.7ton/CY).
Backfill & Site restoration	520	CY	$20	$10,400		Re-use 100 CY of uncontaminated soil, formerly above contaminated areas.
Soil Disposal	884	Ton	$70	$61,880		Assumes disposal at Peoria, IL. PCB conc. <50 ppm.
Monitoring Well Abandonment and Replacement	126	VF	$70	$8,800		Abandonment and replacement of 33MWC-07 and 33MWC-23.
Demobilize	1	LS	$5,000	$5,000		
Level "C" contingency	10%	%	$149,580	$15,000		10% of contractor costs due to slower pace of work & PPE costs.
Subtotal					$164,580	
Phytoremediation						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Cottonwood Trees; Procure and Install	0.5	Acre	$15,000	$7,600		Assumes a 100' x 220' area to be planted with cottonwoods. Approximately 440 trees.
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey.
Subtotal					$64,600	
INDIRECT CAPITAL COSTS						
Permeable Reactive Barrier						
Bench-scale Testing	1	LS	$15,000	$15,000		Per vendor estimate.
Data Review	1	LS	$2,500	$2,500		
Preliminary Design/Regulatory Approval	2%	LS	$1,078,500	$21,570		2% of direct PRB system capital costs.
Final Design/Planning	12%	LS	$1,078,500	$129,420		12% of direct PRB capital cost.
Project Management	6%	LS	$1,078,500	$64,710		6% of direct PRB capital cost.
Field Design/Implementation Assistance	1	LS	$7,500	$7,500		EnviroMetal.
Site License Fee for Use of Zero-Valent Iron PRB	15%	LS	$1,078,500	$161,775		15% of direct PRB capital costs to EnviroMetal.
Construction Observation & Documentation	8%	LS	$1,078,500	$86,280		8% of direct PRB capital cost.
Health and Safety Monitoring	1	LS	$3,000	$3,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$506,755	
Soil Excavation at Building I-1-23; Offsite Disposal						
Workplan/Regulatory Approval	8%	LS	$164,580	$13,166		8% of direct soil excavation capital costs.
Design/Planning	7%	LS	$164,580	$11,521		7% of direct soil excavation capital costs.
Project Management	8%	LS	$164,580	$13,166		8% of direct soil excavation capital costs.
Bidding & Contracting	5%	LS	$164,580	$8,229		5% of direct soil excavation capital costs.
Permitting	1	LS	$5,000	$5,000		
Construction Observation & Documentation	10%	LS	$164,580	$16,458		10% of direct soil excavation capital costs.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$82,540	
SUB-TOTAL					$1,896,975	
CONTINGENCY (20%)					$379,400	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$2,276,375	

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Detailed Cost Estimate - Alternative B - Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, Permeable Reactive Barrier, and Phytoremediation (Continued)

ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years of system operation.
Site Inspection	4	Visit	$1,700	$6,800		Assumes quarterly inspections for water level evaluation. 16 hours labor and $500 expenses.
PRB Monitoring Network Well Sampling	2	Event	$3,700	$7,400		Assumes 2 quarterly sampling events of 8 PRB wells (2 other events included w/SA GW monitoring- costs incl. below).
Analytical Testing (PRB Network)	18	Sample	$250	$4,500		Assumes 2 quarterly sampling events of 8 PRB wells with 1 QA/QC duplicate sample per quarter.
Monitoring Well Network Sampling	2	Event	$9,500	$19,000		Assumes semiannual sampling of 10 monitoring wells and 8 PRB wells.
Analytical Testing (MW Network)	40	Sample	$250	$10,000		Assumes semiannual sampling of 10 monitoring wells and 8 PRB wells with 2 QA/QC dup. sample per event.
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	2	Report	$10,000	$20,000		Assumes semiannual reporting.
O&M Contingency	20%	LS	-	$15,710		20% of O&M items
Subtotal					$94,300	

PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5
REPLACEMENT OF PRB IN YEAR 20*						Cost for complete replacement of PRB in year 20.
Direct Capital Cost	1	LS	$1,078,500	$1,078,500		Assumes same cost as original construction.
Indirect Capital Cost	1	LS	$506,755	$506,755		Assumes same cost as original construction.
Contingency	20%	LS	$1,585,255	$317,051		20% of direct and indirect costs.
Subtotal					$1,902,300	

ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for second 5 years of system operation.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 16 hours labor and $500 expenses.
PRB Monitoring Network Well Sampling	0	Event	$3,700	$0		Included with GW monitoring below.
Analytical Testing (PRB Network)	0	Sample	$250	$0		Included with GW monitoring below.
GW+ PRB Monitoring Well Network Sampling	1	Event	$9,500	$9,500		Assumes annual sampling of 10 monitoring wells and 8 PRB wells.
Analytical Testing (MW Network)	20	Sample	$250	$5,000		Assumes annual sampling of 10 monitoring wells and 8 PRB wells with 2 QA/QC duplicate sample per event.
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	1	Report	$10,000	$10,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$7,750		20% of O&M items
Subtotal					$46,500	

ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 11-30						Estimated annual operation, maintenance, and monitoring costs for years 11-30 of system operation.
Site Visits	1	Visit	$1,700	$1,700		Assumes annual inspections. 16 hours labor and $500 expenses.
PRB Monitoring Network Well Sampling	0	Event	$3,700	$0		Included with GW monitoring below.
Analytical Testing (PRB Network)	0	Sample	$250	$0		Included with GW monitoring below.
GW+ PRB Monitoring Well Network Sampling	1	Event	$9,500	$9,500		Assumes annual sampling of 10 monitoring wells and 8 PRB wells.
Analytical Testing (MW Network)	20	Sample	$250	$5,000		Assumes annual sampling of 10 monitoring wells and 8 PRB wells with 2 QA/QC duplicate sample per event.
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	1	Report	$10,000	$10,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$7,410		20% of O&M items
Subtotal					$44,500	

* Assumes PRB bed will require replacement in year 20.

Present Value Analysis
Alternative C - Building I-1-23 VOC Source Area
Multi-phase Extraction with Pneumatic Fracturing followed by Groundwater Extraction and Treatment and Phytoremediation

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$1,318,900	$0	$14,000	$1,332,900	1	$1,332,900	Construct system. No O&M costs in Year 0. Horizontal wells at 100 gpm total.
1	$0	$298,300	$0	$298,300	0.969	$289,100	MPE /SVE system and P&T system active.
2	$0	$298,300	$0	$298,300	0.939	$280,100	MPE /SVE system and P&T system active.
3	$0	$178,800	$0	$178,800	0.910	$162,700	Long-term P&T @ 10 to 20 gpm remains active (through 30 years), MPE /SVE system shut down.
4	$0	$178,800	$0	$178,800	0.881	$157,600	
5	$0	$162,600	$14,000	$176,600	0.854	$150,900	Assumes monthly monitoring for treatment system, annual sampling for MW network, and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
6	$0	$162,600	$0	$162,600	0.828	$134,600	
7	$0	$162,600	$0	$162,600	0.802	$130,400	
8	$0	$162,600	$0	$162,600	0.777	$126,400	
9	$0	$162,600	$0	$162,600	0.753	$122,500	
10	$0	$127,600	$14,000	$141,600	0.730	$103,300	Assumes monitoring reduced to bimonthly for treatment system and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision, and bid & contract lab assumed.
11	$0	$127,600	$0	$127,600	0.707	$90,200	
12	$0	$127,600	$0	$127,600	0.685	$87,400	
13	$0	$127,600	$0	$127,600	0.664	$84,700	
14	$0	$127,600	$0	$127,600	0.643	$82,100	
15	$0	$124,200	$14,000	$138,200	0.624	$86,200	Assumes monitoring reduced to quarterly for treatment system and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
16	$0	$124,200	$0	$124,200	0.604	$75,000	
17	$0	$124,200	$0	$124,200	0.585	$72,700	
18	$0	$124,200	$0	$124,200	0.568	$70,500	
19	$0	$124,200	$0	$124,200	0.550	$68,300	
20	$0	$124,200	$14,000	$138,200	0.533	$73,600	Discharge permit update assumed.
21	$0	$124,200	$0	$124,200	0.516	$64,100	
22	$0	$124,200	$0	$124,200	0.500	$62,100	
23	$0	$124,200	$0	$124,200	0.485	$60,200	
24	$0	$124,200	$0	$124,200	0.469	$58,300	
25	$0	$124,200	$14,000	$138,200	0.455	$62,900	Discharge permit update assumed.
26	$0	$124,200	$0	$124,200	0.441	$54,800	
27	$0	$124,200	$0	$124,200	0.428	$53,100	
28	$0	$124,200	$0	$124,200	0.414	$51,400	
29	$0	$124,200	$0	$124,200	0.401	$49,800	
30	$0	$124,200	$14,000	$138,200	0.389	$53,726	Discharge permit update assumed.
TOTALS		**$4,392,000**	**$98,000**	**$5,809,000**		**$4,352,000**	30 year total (linked to Summary sheet)

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Detailed Cost Estimate - Alternative C - Building I-1-23 VOC Source Area
Multi-phase Extraction with Pneumatic Fracturing followed by Groundwater Extraction and Treatment and Phytoremediation

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/28/04

Description: Alternative C consists of groundwater and soil treatment for two years by multi-phase extraction and SVE, enhanced via pneumatic fracturing, followed by long-term groundwater extraction and treatment via liquid-phase carbon adsorption. A portion of the site would also utilize phytoremediation with cultivated cottonwood trees.

	COST ESTIMATES					
ITEM OF WORK	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Multi-Phase Extraction System (used during years 1-2) *	1	LS	$50,000	$50,000		Placeholder for pneumatic fracturing pilot study.
Pilot Study	1	LS	$20,000	$20,000		Oversight and construction personnel and equipment for both systems.
Mobilization/Site Preparation	1	LS	$20,000	$20,000		Oversight and construction personnel and equipment for both systems.
Access Road to Treatment Building	1	LS	$10,000	$10,000		
Treatment Building	1	LS	$75,000	$75,000		Assumes new building will house both MPE and groundwater treatment systems.
Electrical Power Installation	1	LS	$25,000	$25,000		
Mechanical Installation	1	LS	$50,000	$50,000		
MPE/SVE Well Installation - Vertical Wells	380	VF	$50	$19,000		Assumes 12 wells (8 in Upper Sand (35' to 45' deep) and 4 in Upper Clay (average 20' deep)).
Fracturing Borehole Installation	80	VF	$35	$2,800		Assumes 4 boreholes with average depth of 20 feet bgs. Three in 201 area and one in 212 area.
Groundwater Extraction Wells - Horizontal	750	LF	$200	$150,000		Assumes 3 horizontal extraction wells with pumps.
Well Heads	15	Each	$500	$7,500		
Extraction Line Piping - 1-inch	300	LF	$5	$1,500		
Extraction Line Piping - 2-inch	400	LF	$8	$3,200		
Discharge Line Piping - 3-inch	650	LF	$10	$6,500		
Trenching	1,350	LF	$35	$47,250		Conveyance, discharge, and utility line trenching.
Soil Disposal	850	Ton	$70	$59,500		Assumes 500 cy to be disposed at 1.7 t/cy; offsite, non-hazardous disposal. Incl transport.
MPE Skid	2	Each	$25,000	$50,000		
Settling Tank Relocation	1	LS	$2,000	$2,000		Relocation of settling tank from existing WWT building to new treatment building.
Carbon Treatment System - Liquid Phase	1	LS	$35,000	$35,000		Assumes two 5,000 lb vessels and initial carbon supply.
Carbon Treatment System - Vapor Phase	1	LS	$10,000	$10,000		Assumes two 2,000 lb vessels and initial carbon supply.
Pneumatic Fracturing	12	Point	$3,000	$36,000		Fracturing zones targeted from 10 to 20 feet bgs (in four Upper Clay MPE wells).
Control Panel and PLC Programming	1	LS	$25,000	$25,000		Conventional PLC-based panel; no SCADA.
Holding Tank	1	Tank	$5,000	$5,000		
Outfall	1	LS	$10,000	$10,000		For 100 gpm flow.
Misc. Equipment	1	LS	$15,000	$15,000		From other project experience; possible additional piping, valving, pumps, influent pretreat.
Startup/ System Shakedown	200	Hours	$75	$15,000		
Subtotal					$750,250	
Pump-and-Treat System (used during years 3-30)						
Extraction Well Installation	1	Well	$7,500	$7,500		Assumes one 45-foot deep extraction well to pump at 10 to 20 gpm at an avg. of 1 ppm CVOCs.
Extraction Well Pump	1	Pump	$3,000	$3,000		From other project experience.
Holding Tank	0	Tank	$0	$0		Assumes MPE system component can be utilized.
Product Separator and Tank	0	LS	$0	$0		Assumes MPE system component can be utilized.
Control Panel and PLC Programming	1	LS	$5,000	$5,000		Assumes some adjustments to system installed for MPE will be required.
Carbon Treatment System	0	Each	$0	$0		Assumes treatment system installed for MPE system can be utilized.
Instrumentation	1	LS	$5,000	$5,000		
Trenching - Conveyance and Discharge Piping	0	LF	$0	$0		Assumes piping installed for MPE system can be utilized.
Outfall	0	LS	$0	$0		Assumes outfall installed for MPE system can be utilized.
Misc. Equipment	1	LS	$15,000	$15,000		Assumes alternate items such as flow meters, transfer pumps required for downsizing.
Startup/System Shakedown	100	Hours	$75	$7,500		
Subtotal					$43,000	
Phytoremediation						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Cottonwood Trees; Procure and Install	0.5	Acre	$15,000	$7,600		Assumes a 100' x 220' area to be planted with cottonwoods.
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey
Subtotal					$64,600	
INDIRECT CAPITAL COSTS						
Multi-Phase Extraction and Groundwater Extraction and Treatment Systems						
Preliminary Design/Regulatory Approval	4%	LS	$793,250	$31,730		4% of direct MPE and P&T capital costs.
Final Design/Planning	8%	LS	$793,250	$63,460		8% of direct MPE and GW extraction and treatment system capital costs.
Project Management	6%	LS	$793,250	$47,595		6% of direct MPE and GW extraction and treatment system capital costs.
Permit Application	1	LS	$5,000	$5,000		Treated groundwater discharge permit application.
Construction Observation & Documentation	8%	LS	$793,250	$63,460		8% of direct MPE and GW extraction and treatment system capital costs.
Health and Safety Monitoring	1	LS	$5,000	$5,000		Health and Safety Plan preparation, field monitoring equipment, documentation.
Documentation Report	1	LS	$25,000	$25,000		
Subtotal					$241,245	
SUB-TOTAL					$1,099,095	
CONTINGENCY (20%)					$219,800	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$1,318,900	

* Includes treatment of Upper Clay and Upper Sand units.

Detailed Cost Estimate - Alternative C - Building I-1-23 VOC Source Area
Multi-phase Extraction followed by Groundwater Extraction and Treatment

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2001
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 9/23/03

Description: Alternative C consists of groundwater and soil treatment for two years by multi-phase extraction and SVE, enhanced via pneumatic fracturing, followed by long-term groundwater extraction and treatment via liquid-phase carbon adsorption. A portion of the site would also utilize phytoremediation with cultivated cottonwood trees.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 1-2						Estimated annual operation, maintenance, and monitoring costs for initial 2 years of system operation.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	72	Sample	$100	$7,200		Assumes monthly sampling of treatment system vapor and fluid influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	72	Sample	$250	$18,000		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$4,000	$48,000		Includes 40 hr/mo labor, equipment.
Electric Power	12	Month	$1,960	$23,515		Assumes 50 hp at 90% run time and $0.08/kWhr.
Carbon Replacement - Liquid Phase	12	Month	$3,000	$36,000		Assuming 50 lb/day carbon usage at $2.00/lb carbon.
Carbon Replacement - Vapor Phase	12	Month	$1,800	$21,600		Assuming 30 lb/day carbon usage at $2.00/lb carbon.
Miscellaneous Equipment Replacement Allowance	1	LS	$5,000	$5,000		Contingency for equipment replacement.
Monitoring Well Network Sampling labor & expenses	2	Events	$6,200	$12,400		Semiannual sampling of 10 monitoring wells
Analytical Testing (MW Network)	22	Sample	$250	$5,500		Assumes semiannual sampling of 10 monitoring wells with 1 QA/QC duplicate sample per event.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS	-	$49,713		20% of O&M items
Subtotal					$298,300	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 3-5						Estimated annual operation, maintenance, and monitoring costs for years 3-5 of system operation.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	36	Sample	$100	$3,600		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	36	Sample	$250	$9,000		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,800	$33,600		Includes 24 hr/mo labor, equipment
Electric Power	12	Month	$196	$2,352		Assumes 5 hp at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$600	$7,200		Assumes 10 lb/day carbon usage at $2.00/lb carbon.
Miscellaneous Equipment Replacement Allowance	1	LS	$5,000	$5,000		Contingency for equipment replacement.
Monitoring Well Network Sampling labor & expenses	2	Events	$5,700	$11,400		Semiannual sampling of 10 monitoring wells
Analytical Testing (MW Network)	22	Sample	$250	$5,500		Assumes semiannual sampling of 10 monitoring wells with 1 QA/QC duplicate sample per event.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes initial semiannual reporting.
O&M Contingency	20%	LS	-	$29,800		20% of O&M items
Subtotal					$178,800	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5
Permit Renewal Application	1	Applic.	$5,000	$5,000		Assumes discharge permit renewal required every 5 years.

Detailed Cost Estimate - Alternative C - Building I-1-23 VOC Source Area
Multi-phase Extraction followed by Groundwater Extraction and Treatment (Continued)

ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for years 6-10 of system operation.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	36	Sample	$100	$3,600		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	36	Sample	$250	$9,000		Assumes monthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,800	$33,600		Includes 24 hr/mo labor, equipment
Electric Power	12	Month	$196	$2,352		Assumes 5 hp at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$540	$6,480		Assumes 9 lb/day carbon usage at $2.00/lb carbon.
Miscellaneous Equipment Replacement Allowance	1	LS	$5,000	$5,000		Contingency for equipment replacement.
Monitoring Well Network Sampling labor & expenses	1	Event	$6,200	$6,200		Annual sampling of 10 monitoring wells with 1 QA/QC duplicate. Water levels at wells & 1 staff gauge
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 7 monitoring wells with 1 QA/QC duplicate sample per event.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS	-	$27,106		20% of O&M items
Subtotal					$162,600	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 11-15						Estimated annual operation, maintenance, and monitoring costs for years 11-15.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	18	Sample	$100	$1,800		Assumes bimonthly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	18	Sample	$250	$4,500		Assumes bimonthly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,200	$26,400		Includes 16 hr/mo labor, equipment
Electric Power	12	Month	$196	$2,352		Assumes 5 hp at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$480	$5,760		Assumes 8 lb/day carbon usage at $2.00/lb carbon.
Miscellaneous Equipment Replacement Allowance	1	LS	$5,000	$5,000		Contingency for equipment replacement.
Monitoring Well Network Sampling labor & expenses	1	Event	$6,200	$6,200		Assumes annual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 10 monitoring wells with 1 QA/QC duplicate sample per event.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$21,262		20% of O&M items
Subtotal					$127,600	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 16-30						Estimated annual operation, maintenance, and monitoring costs for years 16-30.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	12	Sample	$100	$1,200		Assumes quarterly sampling of treatment system influent, mid-train, and effluent sampling.
Analytical Testing (Performance Sampling)	12	Sample	$250	$3,000		Assumes quarterly sampling of treatment system influent, mid-train, and effluent sampling.
Treatment System Operation	12	Month	$2,200	$26,400		Includes 16 hr/mo labor, equipment
Electric Power	12	Month	$196	$2,352		Assumes 5 hp at 90% run time and $0.08/kWhr.
Carbon Replacement	12	Month	$420	$5,040		Assumes 7 lb/day carbon usage at $2.00/lb carbon.
Miscellaneous Equipment Replacement Allowance	1	LS	$5,000	$5,000		Contingency for equipment replacement.
Monitoring Well Network Sampling labor & expenses	1	Event	$6,200	$6,200		Assumes annual sampling of 10 monitoring wells.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 10 monitoring wells with 1 QA/QC duplicate sample per event.
Outfall Inspection/Clearing	1	Year	$500	$500		
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$20,698		20% of O&M items
Subtotal					$124,200	

Present Value Analysis
Alternative D - Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$1,074,240	$0	$9,000	$1,083,240	1	$1,083,240	Construct system and perform baseline monitoring. No OM&M costs in Year 0.
1	$0	$93,600	$0	$93,600	0.969	$90,700	
2	$0	$93,600	$0	$93,600	0.939	$87,900	
3	$0	$93,600	$0	$93,600	0.910	$85,200	
4	$0	$93,600	$0	$93,600	0.881	$82,500	
5	$0	$66,100	$9,000	$75,100	0.855	$64,200	Assumes annual sampling for ACL network, discharge permit update,QAPP/FSP revision and bid/contract lab assumed.
6	$0	$66,100	$0	$66,100	0.828	$54,700	
7	$0	$66,100	$0	$66,100	0.802	$53,000	
8	$0	$66,100	$0	$66,100	0.778	$51,400	
9	$0	$66,100	$0	$66,100	0.753	$49,800	
10	$0	$60,300	$9,000	$69,300	0.730	$50,600	QAPP/FSP revision and bid/contract lab assumed.
11	$0	$60,300	$0	$60,300	0.706	$42,600	
12	$0	$60,300	$0	$60,300	0.685	$41,300	
13	$0	$60,300	$0	$60,300	0.663	$40,000	
14	$0	$60,300	$0	$60,300	0.643	$38,800	
15	$0	$57,400	$9,000	$66,400	0.623	$41,400	QAPP/FSP revision and bid/contract lab assumed.
16	$0	$57,400	$0	$57,400	0.605	$34,700	
17	$0	$57,400	$0	$57,400	0.585	$33,600	
18	$0	$57,400	$0	$57,400	0.568	$32,600	
19	$0	$57,400	$0	$57,400	0.549	$31,500	
20	$0	$57,400	$9,000	$66,400	0.533	$35,400	Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
21	$0	$57,400	$0	$57,400	0.516	$29,600	
22	$0	$57,400	$0	$57,400	0.500	$28,700	
23	$0	$57,400	$0	$57,400	0.484	$27,800	
24	$0	$57,400	$0	$57,400	0.470	$27,000	
25	$0	$57,400	$9,000	$66,400	0.455	$30,200	Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
26	$0	$57,400	$0	$57,400	0.441	$25,300	
27	$0	$57,400	$0	$57,400	0.427	$24,500	
28	$0	$57,400	$0	$57,400	0.415	$23,800	
29	$0	$57,400	$0	$57,400	0.401	$23,000	
30	$0	$57,400	$9,000	$66,400	0.389	$25,813	Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
TOTALS		**$1,925,000**	**$63,000**	**$3,062,000**		**$2,391,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative D, Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, Phytoremediation Including Engineered Wetland, and Alternate Concentration Limits

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/28/04

Description: Alternative D consists of target soil (≥10 mg/kg VOC target in soil ≤12 feet deep) excavation, phytoremediation in the West Swale and lake embayment area, and the establishment of Alternate Concentration Limits (ACLs) for shallow groundwater quality.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT CAPITAL COSTS						
Soil Excavation; Offsite Disposal						Excavation of soil ≥ 10 mg/kg, ≤ 12 feet bgs
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment.
Clearing and Grubbing	0	Acre	$4,000	$0		Assumes no clearing or grubbing needed.
Soil Excavation	620	CY	$15	$9,300		520 CY of soil is contaminated; 100 CY must be removed to access it. Includes excavation Area 201 only.
Soil Transport - Non Haz	442	Ton	$50	$22,100		Transport R/T to Peoria, IL. (520 CY * 50% @ 1.7 ton/CY). assumes 50% material >10 mg/kg total VOCs is hazardous.
Soil Transport - Haz	442	Ton	$70	$30,940		Transport R/T to Alabama; assumes 50% material >10 mg/kg total VOCs is hazardous.
Backfill & Site restoration	520	CY	$20	$10,400		Re-use 100 CY of uncontaminated soil, formerly above contaminated areas.
Soil Disposal - Non Haz	442	Ton	$70	$30,940		Assumes disposal at Peoria, IL. PCB conc. <50 ppm.
Soil Disposal - Haz	442	Ton	$130	$57,460		Assumes disposal at Emille, Alabama. PCB conc. <50 ppm.
Monitoring Well Abandonment and Replacement	126	VF	$70	$8,800		Abandonment and replacement of 33MWC-07 and 33MWC-23.
Demobilize	1	LS	$5,000	$5,000		
Level "C" contingency	10%	%	$184,940	$18,500		10% of contractor costs due to slower pace of work & PPE costs.
Subtotal					$203,440	
Establishment of ACLs						
Data Review	1	LS	$5,000	$5,000		
ACLs Development Submittal	1	LS	$20,000	$20,000		
Project Management	1	LS	$5,000	$5,000		
Subtotal					$30,000	
Enhanced Phytoremediation						
Phreatophytic Tree Stand						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Cottonwood Trees; Procure and Install	0.5	Acre	$15,000	$7,600		Assumes a 100' x 220' area to be planted with cottonwoods.
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey.
Constructed Wetland						6.5 acre constructed wetland within Crab Orchard Lake embayment.
Vendor Design Fees	1	LS	$50,000	$50,000		
Excavation/Regrading	4,000	CY	$20	$80,000		Open water cell, average target surface elevation of 400'.
Fill/Regrading	400	CY	$20	$8,000		Emergent vegetation cell, average target surface elevation of 403.5'. Assumes using the open water cut (4,000 cy) as partial fill.
Berm	3,300	CY	$25	$82,500		One berm between cells and one berm between open water cell and Crab Orchard Lake.
Rip Rap	36,000	SF	$0.50	$18,000		Protective covering of berm.
Plants	60,000	Each	$0.60	$36,000		Assumes plants 24" o.c., emergent plants.
Planting	5.5	Acre	$5,000	$27,500		Installation of rootstock.
Outfalls	2	Each	$2,000	$4,000		Interconnection of wetland and Crab Orchard Lake.
Monitoring Well Installation	50	VF	$70	$3,500		Assumes installation of 5 new wells, assumed average depth of 10 feet. Cost includes soil disposal and survey.
Subtotal					$374,100	
INDIRECT CAPITAL COSTS						
Soil Excavation at Building I-1-23; Offsite Disposal						
Preliminary Design/Regulatory Approval	8%	LS	$203,440	$16,300		8% of direct soil excavation capital costs.
Final Design/Planning	7%	LS	$203,440	$14,200		7% of direct soil excavation capital costs.
Project Management	8%	LS	$203,440	$16,300		8% of direct soil excavation capital costs.
Bidding & Contracting	5%	LS	$203,440	$10,200		5% of direct soil excavation capital costs.
Permitting	1	LS	$5,000	$5,000		Disposal facility profile.
Construction Observation & Documentation	10%	LS	$203,440	$20,300		10% of direct soil excavation capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$10,000	$15,000		
Subtotal					$98,300	
Enhanced Phytoremediation						
Workplan/Regulatory Approval	5%	LS	$374,100	$18,700		5% of direct extraction and treatment system capital costs.
Design/Planning	10%	LS	$374,100	$37,400		10% of direct extraction and treatment system capital costs.
Project Management	8%	LS	$374,100	$29,900		8% of direct extraction and treatment system capital costs.
Permit Application	1	LS	$50,000	$50,000		Construction permitting/approval.
Construction Observation & Documentation	10%	LS	$374,100	$37,400		10% of direct extraction and treatment system capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$10,000	$15,000		
Subtotal					$189,400	
SUB-TOTAL					$895,240	
CONTINGENCY (20%)					$179,000	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$1,074,240	

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Detailed Cost Estimate - Alternative D, Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, Enhanced Phytoremediation, and Alternate Concentration Limits

ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years of system operation.
Site Visits	4	Visit	$1,700	$6,800		Assumes quarterly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	2	Events	$6,200	$12,400		Semiannual sampling of 13 monitoring locations.
Analytical Testing	30	Sample	$250	$7,500		Assumes semiannual sampling of 10 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Phytoremediation Maintenance	3	Acre	$2,500	$7,500		
Administrative Costs	288	Hour	$100	$28,800		Assumes average labor rate and 24 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$15,600		20% of O&M items
Subtotal					$93,600	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for second 5 years of system operation.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	1	Event	$6,200	$6,200		Annual sampling of 13 monitoring locations.
Analytical Testing	15	Sample	$250	$3,750		Assumes annual sampling of 10 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Phytoremediation Maintenance	3	Acre	$2,500	$7,500		
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$11,010		20% of O&M items
Subtotal					$66,100	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 11-15						Estimated annual operation, maintenance, and monitoring costs for third 5 years of system operation.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	1	Event	$6,200	$6,200		Annual sampling of 13 monitoring locations.
Analytical Testing	15	Sample	$250	$3,750		Assumes annual sampling of 10 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Phytoremediation Maintenance	3	Acre	$2,500	$7,500		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$10,050		20% of O&M items
Subtotal					$60,300	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 16-30						Estimated annual operation, maintenance, and monitoring costs for years 16-30 of system operation.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	1	Event	$6,200	$6,200		Annual sampling of 13 monitoring locations.
Analytical Testing	15	Sample	$250	$3,750		Assumes annual sampling of 10 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Phytoremediation Maintenance	3	Acre	$2,500	$7,500		
Administrative Costs	120	Hour	$100	$12,000		Assumes average labor rate and 10 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$9,570		20% of O&M items
Subtotal					$57,400	

Present Value Analysis
Alternative E - Building I-1-23 VOC Source Area
Phytoremediation Including Engineered Wetland and Alternate Concentration Limits

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$706,200	$0	$9,000	$715,200	1	$715,200	No OM&M costs in Year 0.
1	$0	$93,600	$0	$93,600	0.969	$90,700	
2	$0	$93,600	$0	$93,600	0.939	$87,900	
3	$0	$93,600	$0	$93,600	0.910	$85,200	
4	$0	$93,600	$0	$93,600	0.881	$82,500	
5	$0	$66,100	$9,000	$75,100	0.855	$64,200	Assumes annual sampling for ACL network, QAPP/FSP revision and bid/contract lab assumed.
6	$0	$66,100	$0	$66,100	0.828	$54,700	
7	$0	$66,100	$0	$66,100	0.802	$53,000	
8	$0	$66,100	$0	$66,100	0.778	$51,400	
9	$0	$66,100	$0	$66,100	0.753	$49,800	
10	$0	$60,300	$9,000	$69,300	0.730	$50,600	QAPP/FSP revision and bid/contract lab assumed.
11	$0	$60,300	$0	$60,300	0.706	$42,600	
12	$0	$60,300	$0	$60,300	0.685	$41,300	
13	$0	$60,300	$0	$60,300	0.663	$40,000	
14	$0	$60,300	$0	$60,300	0.643	$38,800	
15	$0	$60,300	$9,000	$69,300	0.623	$43,200	QAPP/FSP revision and bid/contract lab assumed.
16	$0	$60,300	$0	$60,300	0.604	$36,400	
17	$0	$60,300	$0	$60,300	0.585	$35,300	
18	$0	$60,300	$0	$60,300	0.567	$34,200	
19	$0	$60,300	$0	$60,300	0.549	$33,100	
20	$0	$60,300	$9,000	$69,300	0.532	$36,900	QAPP/FSP revision and bid/contract lab assumed.
21	$0	$60,300	$0	$60,300	0.516	$31,100	
22	$0	$60,300	$0	$60,300	0.501	$30,200	
23	$0	$60,300	$0	$60,300	0.484	$29,200	
24	$0	$60,300	$0	$60,300	0.469	$28,300	
25	$0	$60,300	$9,000	$69,300	0.455	$31,500	QAPP/FSP revision and bid/contract lab assumed.
26	$0	$60,300	$0	$60,300	0.441	$26,600	
27	$0	$60,300	$0	$60,300	0.428	$25,800	
28	$0	$60,300	$0	$60,300	0.415	$25,000	
29	$0	$60,300	$0	$60,300	0.401	$24,200	
30	$0	$60,300	$9,000	$69,300	0.389	$26,941	QAPP/FSP revision and bid/contract lab assumed.
TOTALS		**$1,971,000**	**$63,000**	**$2,740,000**		**$2,046,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative E, Building I-1-23 VOC Source Area
Phytoremediation Including Engineered Wetland and Alternate Concentration Limits

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/28/04

Description: Alternative E consists of phytoremediation in the West Swale and lake embayment area, the establishment of Alternate Concentration Limits (ACLs) for shallow groundwater quality, and institutional controls.

	COST ESTIMATES					
ITEM OF WORK	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Establishment of ACLs						
Data Review	1	LS	$5,000	$5,000		
ACLs Development Submittal	1	LS	$20,000	$20,000		
Project Management	1	LS	$5,000	$5,000		
Subtotal					$30,000	
Enhanced Phytoremediation						
Phreatophytic Tree Stand						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Cottonwood Trees; Procure and Install	0.5	Acre	$15,000	$7,600		Assumes a 100' x 220' area to be planted with cottonwoods.
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey.
Constructed Wetland						6.5 acre constructed wetland within Crab Orchard Lake embayment.
Vendor Design Fees	1	LS	$50,000	$50,000		
Excavation/Regrading	4,000	CY	$20	$80,000		Open water cell, average target surface elevation of 400'.
Fill/Regrading	400	CY	$20	$8,000		Emergent vegetation cell, average target surface elevation of 403.5'. Assumes using the open water cut (4,000 cy) as partial fill.
Berm	3,300	CY	$25	$82,500		One berm between cells and one berm between open water cell and Crab Orchard Lake.
Rip Rap	36,000	SF	$0.50	$18,000		Protective covering of berm.
Plants	60,000	Each	$0.60	$36,000		Assumes plants 24" o.c., emergent plants.
Planting	5.5	Acre	$5,000	$27,500		Installation of rootstock.
Outfalls	2	Each	$2,000	$4,000		Interconnection of wetland and Crab Orchard Lake.
Monitoring Well Installation	50	VF	$70	$3,500		Assumes installation of 5 new wells, assumed average depth of 10 feet. Cost includes soil disposal and survey.
Subtotal					$374,100	
INDIRECT CAPITAL COSTS						
Workplan/Regulatory Approval	5%	LS	$374,100	$18,700		5% of direct extraction and treatment system capital costs.
Design/Planning	10%	LS	$374,100	$37,400		10% of direct extraction and treatment system capital costs.
Project Management	8%	LS	$374,100	$29,900		8% of direct extraction and treatment system capital costs.
Permit Application	1	LS	$50,000	$50,000		Construction permitting/approval.
Construction Observation & Documentation	10%	LS	$374,100	$37,400		10% of direct extraction and treatment system capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$10,000	$10,000		
Subtotal					$184,400	
SUB-TOTAL					$588,500	
CONTINGENCY (20%)					$117,700	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$706,200	

Detailed Cost Estimate - Alternative E, Building I-1-23 VOC Source Area
Phytoremediation Including Engineered Wetland and Alternate Concentration Limits

ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years of system operation.
Site Visits	4	Visit	$1,700	$6,800		Assumes quarterly inspections. 2 hrs prep., 6 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	2	Events	$6,200	$12,400		Semiannual sampling of 13 monitoring points.
Analytical Testing	30	Sample	$250	$7,500		Assumes semiannual sampling of 10 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Phytoremediation Maintenance	3	Acre	$2,500	$7,500		
Administrative Costs	288	Hour	$100	$28,800		Assumes average labor rate and 24 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$15,600		20% of O&M items
Subtotal					$93,600	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for second 5 years of system operation.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	1	Event	$6,200	$6,200		Annual sampling of 13 monitoring locations.
Analytical Testing	15	Sample	$250	$3,750		Assumes annual sampling of 10 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Phytoremediation Maintenance	3	Acre	$2,500	$7,500		
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$11,010		20% of O&M items
Subtotal					$66,100	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 11-75						Estimated annual operation, maintenance, and monitoring costs for years 11-30 of system operation.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	1	Event	$6,200	$6,200		Annual sampling of 13 monitoring locations.
Analytical Testing	15	Sample	$250	$3,750		Assumes annual sampling of 10 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Phytoremediation Maintenance	3	Acre	$2,500	$7,500		
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$10,050		20% of O&M items
Subtotal					$60,300	

Present Value Analysis
Detailed Cost Estimate - Alternative F, Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, In-Situ Reductive Dechlorination, Phytoremediation Including Engineered Wetland, and ACLs

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$1,410,040	$0	$14,000	$1,424,040	1	$1,424,040	Construct system. No OM&M costs in Year 0.
1	$0	$134,400	$0	$134,400	0.969	$130,200	
2	$0	$134,400	$0	$134,400	0.939	$126,200	
3	$0	$134,400	$0	$134,400	0.910	$122,300	
4	$0	$134,400	$0	$134,400	0.882	$118,500	
5	$0	$87,000	$14,000	$101,000	0.854	$86,300	Assumes monthly monitoring for treatment system, annual sampling for MW network, and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
6	$0	$87,000	$0	$87,000	0.828	$72,000	
7	$0	$87,000	$0	$87,000	0.802	$69,800	
8	$0	$87,000	$0	$87,000	0.777	$67,600	
9	$0	$87,000	$0	$87,000	0.753	$65,500	
10	$0	$51,600	$14,000	$65,600	0.730	$47,900	Assumes monitoring reduced to bimonthly for treatment system and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision, and bid & contract lab assumed.
11	$0	$51,600	$0	$51,600	0.707	$36,500	
12	$0	$51,600	$0	$51,600	0.686	$35,400	
13	$0	$51,600	$0	$51,600	0.665	$34,300	
14	$0	$51,600	$0	$51,600	0.643	$33,200	
15	$0	$51,600	$14,000	$65,600	0.623	$40,900	Assumes monitoring reduced to quarterly for treatment system and 10% reduction in carbon usage. Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
16	$0	$51,600	$0	$51,600	0.605	$31,200	
17	$0	$51,600	$0	$51,600	0.585	$30,200	
18	$0	$51,600	$0	$51,600	0.568	$29,300	
19	$0	$51,600	$0	$51,600	0.550	$28,400	
20	$0	$51,600	$14,000	$65,600	0.532	$34,900	Discharge permit update, QAPP/FSP revision anf bid/contract lab assumed.
21	$0	$51,600	$0	$51,600	0.516	$26,600	
22	$0	$51,600	$0	$51,600	0.500	$25,800	
23	$0	$51,600	$0	$51,600	0.484	$25,000	
24	$0	$51,600	$0	$51,600	0.469	$24,200	
25	$0	$51,600	$14,000	$65,600	0.454	$29,800	Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
26	$0	$51,600	$0	$51,600	0.440	$22,700	
27	$0	$51,600	$0	$51,600	0.426	$22,000	
28	$0	$51,600	$0	$51,600	0.415	$21,400	
29	$0	$51,600	$0	$51,600	0.401	$20,700	
30	$0	$51,600	$14,000	$65,600	0.389	$25,502	Discharge permit update, QAPP/FSP revision and bid/contract lab assumed.
TOTALS		**$2,056,000**	**$98,000**	**$3,564,000**		**$2,908,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative F, Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, In-Situ Reductive Dechlorination, Phytoremediation Including Engineered Wetland, and ACLs

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/28/04

Description: Alternative F consists of target soil (> ~10 mg/kg VOC target in soil ≤ 12 feet deep) excavation in SB-201 area followed by injection of lactate into the Upper Sand interval and placement (in bulk) of lactate into soil excavations to enhance reductive dechlorination, phytoremediation in the West Swale and lake embayment area, and the establishment of Alternate Concentration Limits (ACLs) for shallow groundwater quality

ITEM OF WORK	COST ESTIMATES QUANTITY	 UNIT	 UNIT PRICE	 COST	 SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Soil Excavation; Offsite Disposal						Excavation of soil ≥ 10 mg/kg, ≤ 12 feet bgs
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment.
Clearing and Grubbing	0	Acre	$4,000	$0		Assumes no clearing or grubbing needed.
Soil Excavation	620	CY	$15	$9,300		520 CY of soil is contaminated; 100 CY must be removed to access it. Includes excavation Area 201 only.
Soil Transport - Non Haz	442	Ton	$50	$22,100		Transport R/T to Peoria, IL. (520 CY * 50% @ 1.7 ton/CY). assumes 50% material >10 mg/kg total VOCs is hazardous.
Soil Transport - Haz	442	Ton	$70	$30,940		Transport R/T to Alabama; assumes 50% material >10 mg/kg total VOCs is hazardous.
Backfill & Site restoration	520	CY	$20	$10,400		Re-use 100 CY of uncontaminated soil, formerly above contaminated areas.
Soil Disposal - Non Haz	442	Ton	$70	$30,940		Assumes disposal at Peoria, IL. PCB conc. <50 ppm.
Soil Disposal - Haz	442	Ton	$130	$57,460		Assumes disposal at Emille, Alabama. PCB conc. <50 ppm.
Monitoring Well Abandonment and Replacement	126	VF	$70	$8,800		Abandonment and replacement of 33MWC-07 and 33MWC-23.
Demobilize	1	LS	$5,000	$5,000		
Level "C" contingency	10%	%	$184,940	$18,500		10% of contractor costs due to slower pace of work & PPE costs.
Subtotal					$203,440	
Enhanced Reductive Dechlorination - Lactate Injection						
Pilot Study	1	LS	$100,000	$100,000		Assumes limited-area, 6-month pilot study.
Mobilization/Site Preparation	1	LS	$5,000	$5,000		Oversight personnel, contractor personnel, and equipment.
Injection Well Installation	3	Well	$7,500	$22,500		Assumes three injection wells screened in the Upper Sand Unit.
Mechanical Installation	1	LS	$10,000	$10,000		From other project experience.
Holding Tanks	4	Tank	$5,000	$20,000		From other project experience.
Instrumentation (Flow Meters, sensors, etc.)	1	LS	$5,000	$5,000		From other project experience.
Electronic Control System	0	LS	$15,000	$0		Basic PLC-based panel to accommodate analog inputs for level sensors
Trenching/Conveyance Piping	200	LF	$35	$7,000		Assuming 4 ft deep trench and 2-inch PVC piping.
Misc. Equipment	1	LS	$10,000	$10,000		From other project experience; possible additional piping, valving, transfer pumps, influent pretreatment, etc.
Lactate Injection	1	EA	$5,000	$5,000		Materials only. based on 3 injection wells in US layer, ~36,000 gal./well/injection,
Lactate for Placement in Excavation Pits	1	EA	$2,500	$2,500		Materials only: based on 50,000 gal.of dilute lactate solution to be placed in excavation pits prior to backfilling
Initial Injection Labor/Startup	100	Hours	$75	$7,500		5 days/injection; 2 staff @ $75/hr x 10 hr/day
Subtotal					$194,500	
Establishment of ACLs						
Data Review	1	LS	$5,000	$5,000		
ACLs Development Submittal	1	LS	$20,000	$20,000		
Project Management	1	LS	$5,000	$5,000		
Subtotal					$30,000	
Phytoremediation						
Phreatophytic Tree Stand						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Cottonwood Trees; Procure and Install	0.5	Acre	$15,000	$7,600		Assumes a 100' x 220' area to be planted with cottonwoods. Approximately 440 trees.
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey.
Constructed Wetland						6.5 acre constructed wetland within Crab Orchard Lake embayment.
Vendor Design Fees	1	LS	$50,000	$50,000		
Excavation/Regrading	4,000	CY	$20	$80,000		Open water cell, average target surface elevation of 400'.
Fill/Regrading	400	CY	$20	$8,000		Emergent vegetation cell, average target surface elevation of 403.5'. Assumes using the open water cut (4,000 cy) as partial fill.
Berm	3,300	CY	$25	$82,500		One berm between cells and one berm between open water cell and Crab Orchard Lake.
Rip Rap	36,000	SF	$0.50	$18,000		Protective covering of berm
Plants	60,000	Each	$0.60	$36,000		Assumes plants 24" o.c., emergent plants.
Planting	5.5	Acre	$5,000	$27,500		Installation of rootstock.
Outfalls	2	Each	$2,000	$4,000		Interconnection of wetland and Crab Orchard Lake.
Monitoring Well Installation	50	VF	$70	$3,500		Assumes installation of 5 new wells, assumed average depth of 10 feet. Cost includes soil disposal and survey.
Subtotal					$374,100	
INDIRECT CAPITAL COSTS						
Soil Excavation at Building I-1-23; Offsite Disposal						
Preliminary Design/Regulatory Approval	8%	LS	$203,440	$16,300		8% of direct soil excavation capital costs.
Final Design/Planning	7%	LS	$203,440	$14,200		7% of direct soil excavation capital costs.
Project Management	8%	LS	$203,440	$16,300		8% of direct soil excavation capital costs.
Bidding & Contracting	5%	LS	$203,440	$10,200		5% of direct soil excavation capital costs.
Permitting	1	LS	$5,000	$5,000		Disposal facility profile.
Construction Observation & Documentation	10%	LS	$203,440	$20,300		10% of direct soil excavation capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$98,300	
Enhanced Reductive Dechlorination - Lactate Injection						
Workplan/Regulatory Approval	5%	LS	$194,500	$9,700		5% of direct extraction and treatment system capital costs.
Design/Planning	10%	LS	$194,500	$19,500		10% of direct extraction and treatment system capital costs.
Project Management	8%	LS	$194,500	$15,600		8% of direct extraction and treatment system capital costs.
Permit Application	1	LS	$5,000	$5,000		Treated groundwater discharge permit application.
Construction Observation & Documentation	10%	LS	$194,500	$19,500		10% of direct extraction and treatment system capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$85,300	
Enhanced Phytoremediation						
Workplan/Regulatory Approval	5%	LS	$374,100	$18,700		5% of direct extraction and treatment system capital costs.
Design/Planning	10%	LS	$374,100	$37,400		10% of direct extraction and treatment system capital costs.
Project Management	8%	LS	$374,100	$29,900		8% of direct extraction and treatment system capital costs.
Permit Application	1	LS	$50,000	$50,000		Construction permitting/approval.
Construction Observation & Documentation	10%	LS	$374,100	$37,400		10% of direct extraction and treatment system capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$10,000	$15,000		
Subtotal					$189,400	
SUB-TOTAL					$1,175,040	
CONTINGENCY (20%)					$235,000	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$1,410,040	

Detailed Cost Estimate - Alternative F, Building I-1-23 VOC Source Area
Soil Excavation to 10 mg/kg, In-Situ Reductive Dechlorination, Phytoremediation Including Engineered Wetland, and ACLs

ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years of system operation.
Lactate Injection -chemical costs	3	EA	$5,000	$15,000		Materials only: based on 3 injection wells in US layer, ~36,000 gal /well/injection,
Initial injection labor	300	Hours	$75	$22,500		Assumes 3 site visits; 5 days/injection; 2 staff @ $75/hr
Monitoring Well Network Sampling labor & expenses	2	Events	$7,500	$15,000		Semiannual sampling of 15 monitoring wells and 3 surface water locations.
Analytical Testing (MW Network)	40	Sample	$250	$10,000		Assumes semiannual sampling of 15 monitoring wells and 3 surface water locations, and 2 QA/QC duplicate samples.
Phytoremediation Maintenance	3	Acre	$2,500	$7,500		
Administrative Costs	120	Hour	$100	$12,000		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS	-	$22,400		20% of O&M items
Subtotal					$134,400	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
Permit Renewal Application	0	Applic.	$5,000	$0		Assumes discharge permit renewal required every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for second 5 years of system operation.
Lactate Injection -chemical costs	0	EA	$4,500	$0		Injection assumed complete after 5 years.
Initial injection labor	0	Hours	$75	$0		Injection assumed complete after 5 years.
Monitoring Well Network Sampling labor & expenses	2	Events	$7,500	$15,000		Semiannual sampling of 15 monitoring wells and 3 surface water locations.
Analytical Testing (MW Network)	40	Sample	$250	$10,000		Assumes semiannual sampling of 15 monitoring wells and 3 surface water locations, and 2 QA/QC duplicate samples.
Phytoremediation Maintenance	3	Acre	$2,500	$7,500		
Administrative Costs	100	Hour	$100	$10,000		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS	-	$14,500		20% of O&M items
Subtotal					$87,000	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 11-30						Estimated annual operation, maintenance, and monitoring costs for years 11 to 30.
Lactate Injection -chemical costs	0	EA	$4,500	$0		Injection assumed complete after 5 years.
Initial injection labor	0	Hours	$75	$0		Injection assumed complete after 5 years.
Monitoring Well Network Sampling labor & expenses	1	Events	$7,500	$7,500		Annual sampling of 15 monitoring wells and 3 surface water locations.
Analytical Testing (MW Network)	20	Sample	$250	$5,000		Assumes annual sampling of 15 monitoring wells and 3 surface water locations, and 2 QA/QC duplicate samples.
Phytoremediation Maintenance	3	Acre	$2,500	$7,500		
Administrative Costs	80	Hour	$100	$8,000		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes initial semiannual reporting.
O&M Contingency	20%	LS	-	$8,600		20% of O&M items
Subtotal					$51,600	

Present Value Analysis
Alternative G - Building I-1-23 VOC Source Area
In-situ Electrical Resistive Heating (ERH) to 1 mg/kg and Phytoremediation

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$2,930,300	$0	$9,000	$2,939,300	1	$2,939,300	Construct system. No O&M costs in Year 0.
1	$0	$92,600	$0	$92,600	0.969	$89,700	Assumes system O&M and semi-annual GW monitoring.
2	$0	$44,700	$0	$44,700	0.940	$42,000	Assumes ERH system shut down and annual monitoring of GW and surface water.
3	$0	$44,700	$0	$44,700	0.911	$40,700	
4	$0	$44,700	$0	$44,700	0.881	$39,400	
5	$0	$44,700	$9,000	$53,700	0.855	$45,900	QAPP/FSP revision, and bid & contract lab assumed.
6	$0	$42,300	$0	$42,300	0.827	$35,000	
7	$0	$42,300	$0	$42,300	0.801	$33,900	
8	$0	$42,300	$0	$42,300	0.778	$32,900	
9	$0	$42,300	$0	$42,300	0.754	$31,900	
10	$0	$42,300	$9,000	$51,300	0.729	$37,400	QAPP/FSP revision, and bid & contract lab assumed.
11	$0	$42,300	$0	$42,300	0.707	$29,900	
12	$0	$42,300	$0	$42,300	0.686	$29,000	
13	$0	$42,300	$0	$42,300	0.664	$28,100	
14	$0	$42,300	$0	$42,300	0.643	$27,200	
15	$0	$42,300	$9,000	$51,300	0.624	$32,000	QAPP/FSP revision, and bid & contract lab assumed.
16	$0	$42,300	$0	$42,300	0.605	$25,600	
17	$0	$42,300	$0	$42,300	0.586	$24,800	
18	$0	$42,300	$0	$42,300	0.567	$24,000	
19	$0	$42,300	$0	$42,300	0.551	$23,300	
20	$0	$42,300	$9,000	$51,300	0.532	$27,300	QAPP/FSP revision, and bid & contract lab assumed.
21	$0	$42,300	$0	$42,300	0.515	$21,800	
22	$0	$42,300	$0	$42,300	0.501	$21,200	
23	$0	$42,300	$0	$42,300	0.485	$20,500	
24	$0	$42,300	$0	$42,300	0.470	$19,900	
25	$0	$42,300	$9,000	$51,300	0.454	$23,300	QAPP/FSP revision, and bid & contract lab assumed.
26	$0	$42,300	$0	$42,300	0.440	$18,600	
27	$0	$42,300	$0	$42,300	0.428	$18,100	
28	$0	$42,300	$0	$42,300	0.414	$17,500	
29	$0	$42,300	$0	$42,300	0.402	$17,000	
30	$0	$42,300	$9,000	$51,300	0.389	$19,943	QAPP/FSP revision, and bid & contract lab assumed.
TOTALS		**$1,328,900**	**$63,000**	**$4,322,200**		**$3,837,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative G - Building I-1-23 VOC Source Area
In-situ Electrical Resistive Heating (ERH) to 1 mg/kg and Phytoremediation

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/28/04

Description: Alternative G consists of target soil (volume with >1 mg/kg VOCs) treatment at I-1-23 by ERH with groundwater monitoring.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT CAPITAL COSTS						
Treatment of Source Area with ERH						Targeting volume of soil ≥ 1 mg/kg total VOCs.
Pilot Study	1	LS	$150,000	$150,000		Placeholder for ERH pilot study in source area.
Lab Testing/Modeling/Site Evaluation	1	LS	$12,000	$12,000		Site visit and detailed evaluation for equipment and system requirements.
Vendor Design Assistance	1	LS	$50,000	$50,000		Vendor input and assistance during system design and documentation.
Electrical Service Connection	1	LS	$25,000	$25,000		Assumes 807 kW electrical power requirement, 980 amps at 480V, 3-phase service.
Mobilization/Site Preparation	1	LS	$125,000	$125,000		Equipment mob and setup, site preparation, gravel surface, water hookup, and thermal surface liner.
Subsurface Installation	1	LS	$150,000	$150,000		Installation of ERH electrodes, vapor vents, and electrode irrigation systems.
Engineering Controls	1	LS	$25,000	$25,000		Placeholder cost for potential engineering controls that may be required.
Cuttings Disposal	1	LS	$10,000	$10,000		Placeholder cost for disposal of soil cuttings from drilling installations.
Utilities Protection	1	LS	$50,000	$50,000		Placeholder cost for potential engineering controls that may be required to protect area utilities.
ERH Equipment Construction and Setup	1	LS	$100,000	$100,000		Construction and connection of above-ground electrode and irrigation system components.
Soil Vapor Extraction (SVE) Construction and Setup	1	LS	$75,000	$75,000		Construction and connection of above-ground vapor collection and treatment system components.
Startup Operations	1	LS	$35,000	$35,000		System startup labor and associated costs.
ERH and SVE Operation	1	LS	$300,000	$300,000		Vendor labor and system operation/monitoring.
Electrical Use	1	LS	$175,000	$175,000		ERH electrical use estimate at $0.08/kWhr.
Carbon Use	1	LS	$20,000	$20,000		For SVE vapor treatment.
Condensate Handling/Disposal	1	LS	$20,000	$20,000		From SVE vapor.
Indoor Air Vapor Monitoring	1	LS	$0	$0		None assumed.
Quality Assurance Monitoring	1	LS	$50,000	$50,000		Independent third party QA monitoring during operation phase.
Additional Monitoring	1	LS	$75,000	$75,000		Placeholder for additional groundwater and vapor monitoring outside of the treatment zone.
Demobilization	1	LS	$50,000	$50,000		Removal of ERH equipment and area restoration.
Well Replacement	1	LS	$10,000	$10,000		Replacement of wells likely to be destroyed by ERH.
Confirmation Sampling	1	LS	$100,000	$100,000		Placeholder cost for final sampling program to assess VOC removal effectiveness and remaining concentrations.
Subtotal					$1,607,000	
Phytoremediation						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Cottonwood Trees; Procure and Install	0.5	Acre	$15,000	$7,600		Assumes a 100' x 220' area to be planted with cottonwoods. Approximately 440 trees.
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey.
Subtotal					$64,600	
Initiation of Groundwater Monitoring						
Monitoring Well Installation	200	VF	$77	$15,400		Assumes installation of 2 sets of two nested wells. Cost includes soil disposal and surveying.
Groundwater Sampling	2	Events	$5,000	$10,000		Labor and expenses for initial sampling of 4 new monitoring wells for VOCs.
Data Review	1	LS	$5,000	$5,000		
Project Management	1	LS	$5,000	$5,000		
Subtotal					$35,400	
INDIRECT CAPITAL COSTS						
ERH Operation						
Preliminary Design/Regulatory Approval	6%	LS	$1,707,000	$102,420		6% of direct ERH treatment system capital costs.
Final Design/Planning	6%	LS	$1,707,000	$102,420		6% of direct ERH treatment system capital costs.
Project Management	6%	LS	$1,707,000	$102,420		6% of direct ERH treatment system capital costs.
Bidding and Contracting	3%	LS	$1,707,000	$51,210		3% of direct ERH treatment system capital costs.
Guaranteed, Performance-Based Contract Premium	12%	LS	$1,707,000	$204,840		12% of direct ERH treatment system capital costs to account for performance based, guaranteed vendor contract.
Construction Observation & Documentation	8%	LS	$1,707,000	$136,560		8% of direct ERH treatment system capital costs.
Health and Safety Monitoring	1	LS	$10,000	$10,000		Health and Safety Plan preparation, field monitoring equipment, documentation.
Documentation Report	1	LS	$25,000	$25,000		
Subtotal					$734,870	
SUB-TOTAL					$2,441,870	
CONTINGENCY (20%)					$488,400	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$2,930,300	

Detailed Cost Estimate - Alternative G - Building I-1-23 VOC Source Area
In-situ Electrical Resistive Heating (ERH) to 1 mg/kg and Phytoremediation

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/28/04

Description: #REF!

	COST ESTIMATES					
ITEM OF WORK	**QUANTITY**	**UNIT**	**UNIT PRICE**	**COST**	**SUBTOTAL**	**COMMENTS**
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Year 1						Estimated annual monitoring costs for year 1 of system operation.
Site Visits	4	Visit	$2,450	$9,800		Assumes quarterly inspections. 3 hrs prep., 8 hrs on site, 13 hrs travel, 2 hrs report, $500 expenses.
Groundwater and Surface Water Sampling	2	Event	$5,700	$11,400		Assumes semiannual sampling of 6 MWs, 2 new bedrock wells, 1 surface water.
Analytical Testing (Water Samples)	22	Sample	$250	$5,500		Assumes semiannual analyses of 6 MWs, 2 new bedrock wells, 1 surface water + 2 QA/QC samples.
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS		$15,430		20% of O&M items
Subtotal					$92,600	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years.
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 2-75						Estimated annual monitoring costs for years 2-75.
Site Visits	1	Visit	$2,450	$2,450		Assumes quarterly inspections. 3 hrs prep., 8 hrs on site, 13 hrs travel, 2 hrs report, $500 expenses.
Groundwater and Surface Water Sampling	1	Event	$6,200	$6,200		Assumes annual sampling of 6 MWs, 2 bedrock wells, 1 surface water.
Analytical Testing (Water Samples)	11	Sample	$250	$2,750		Assumes annual analyses of 6 MWs, 2 bedrock wells, 1 surface water + 2 QA/QC samples.
Phytoremediation Maintenance	0.5	Acre	$2,500	$1,250		
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS		$7,450		20% of O&M items
Subtotal					$44,700	

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Buildings I-1-2/I-1-3

Crab Orchard National Wildlife Refuge
PCB Operable Unit - Sites 32/33
Area I-1-2/I-1-3 Cost Estimate Summary

Alternative	Description	Total Capital Cost ($)	Total Cost ($)	Total Present Value ($)
A	Limited Excavation (I-1-3 hotspot) and Multi-phase Extraction with Pneumatic Fracturing	1,935,000	3,763,600	3,257,000
B	Permeable Reactive Barrier	1,783,000	7,059,500	4,692,000
C	Alternate Concentration Limits	77,000	1,821,700	1,237,000
D	Soil Excavation to 10 mg/kg and Alternate Concentration Limits	902,000	2,647,430	2,062,000
E	Soil Excavation to 10 mg/kg, In-situ Reductive Dechlorination with Pneumatic Fracturing, and ACLs	1,753,000	3,613,600	3,084,000
F	In-situ Electrical Resistive Heating (ERH) in 10 mg/kg Source Area	3,030,000	4,414,600	3,930,000

Note:
Total present value is for a 30-year period with an annual discount rate of 3.2 percent.
Total cost is total realized dollars (sum of capital, operation, maintenance, and monitoring costs) over the common 30-year estimating period for all alternatives, not adjusted for inflation or discounting rates.

Present Value Analysis
Alternative A - Building I-1-2/I-1-3 VOC Source Area
Limited Excavation (I-1-3 hotspot) and Multi-phase Extraction with Pneumatic Fracturing

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$1,935,200	$0	$14,000	$1,949,200	1	$1,949,200	Construct system. No O&M costs in Year 0. Discharge permit acquisition.
1	$0	$276,300	$0	$276,300	0.969	$267,700	Assumes system O&M and semi-annual GW monitoring.
2	$0	$276,300	$0	$276,300	0.939	$259,400	
3	$0	$50,100	$0	$50,100	0.910	$45,600	Assumes MPE system shut down and annual monitoring for GW.
4	$0	$50,100	$0	$50,100	0.882	$44,200	
5	$0	$50,100	$9,000	$59,100	0.854	$50,500	QAPP/FSP revision, and bid & contract lab assumed.
6	$0	$42,300	$0	$42,300	0.827	$35,000	
7	$0	$42,300	$0	$42,300	0.801	$33,900	
8	$0	$42,300	$0	$42,300	0.778	$32,900	
9	$0	$42,300	$0	$42,300	0.754	$31,900	
10	$0	$42,300	$9,000	$51,300	0.729	$37,400	QAPP/FSP revision, and bid & contract lab assumed.
11	$0	$42,300	$0	$42,300	0.707	$29,900	
12	$0	$42,300	$0	$42,300	0.686	$29,000	
13	$0	$42,300	$0	$42,300	0.664	$28,100	
14	$0	$42,300	$0	$42,300	0.643	$27,200	
15	$0	$42,300	$9,000	$51,300	0.624	$32,000	QAPP/FSP revision, and bid & contract lab assumed.
16	$0	$42,300	$0	$42,300	0.605	$25,600	
17	$0	$42,300	$0	$42,300	0.586	$24,800	
18	$0	$42,300	$0	$42,300	0.567	$24,000	
19	$0	$42,300	$0	$42,300	0.551	$23,300	
20	$0	$42,300	$9,000	$51,300	0.532	$27,300	QAPP/FSP revision, and bid & contract lab assumed.
21	$0	$42,300	$0	$42,300	0.515	$21,800	
22	$0	$42,300	$0	$42,300	0.501	$21,200	
23	$0	$42,300	$0	$42,300	0.485	$20,500	
24	$0	$42,300	$0	$42,300	0.470	$19,900	
25	$0	$42,300	$9,000	$51,300	0.454	$23,300	QAPP/FSP revision, and bid & contract lab assumed.
26	$0	$42,300	$0	$42,300	0.440	$18,600	
27	$0	$42,300	$0	$42,300	0.428	$18,100	
28	$0	$42,300	$0	$42,300	0.414	$17,500	
29	$0	$42,300	$0	$42,300	0.402	$17,000	
30	$0	$42,300	$9,000	$51,300	0.389	$19,943	QAPP/FSP revision, and bid & contract lab assumed.
TOTALS		**$1,760,400**	**$68,000**	**$3,763,600**		**$3,257,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative A - Buildings I-1-2/I-1-3 VOC Source Area
Limited Excavation (I-1-3 hotspot) and Multi-phase Extraction with Pneumatic Fracturing

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-2/I-1-3 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: Alternative A consists of target soil (≥ 10 mg/kg VOC in soil ≤ 6 feet bgs), groundwater and soil treatment by multi-phase extraction enhanced via pneumatic fracturing for 2 years, then shut down.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT CAPITAL COSTS						
Multi-Phase Extraction System						
Pilot Study	1	LS	$50,000	$50,000		Assumed limited, pneumatic fracturing study.
Mobilization/Site Preparation	1	LS	$20,000	$20,000		Oversight and construction personnel and equipment.
Access Road to Treatment Building	1	LS	$10,000	$10,000		
Treatment Building	1	LS	$75,000	$75,000		
Electrical Power Installation	1	LS	$25,000	$25,000		
Mechanical Installation	1	LS	$50,000	$50,000		
Fracturing Borehole Installation	2,214	VF	$35	$77,490		Assumes 66 boreholes ranging in depth from 20 to 49 feet bgs.
Pneumatic Fracturing	312	Fracture	$500	$156,078		Fracturing zones in the 66 boreholes targeting various depths from 10 to 45 feet bgs.
Extraction Line Piping - 1-inch	613	LF	$5	$3,065		
Extraction Line Piping - 2-inch	990	LF	$8	$7,920		
Discharge Line Piping - 3-inch	800	LF	$10	$8,000		
Trenching	1,790	LF	$35	$62,650		Conveyance, discharge, and utility line trenching.
Soil Transport - Non-haz	450	Ton	$50	$22,500		Assumes 265 cy to be disposed at 1.7 t/cy; offsite, non-hazardous disposal.
Soil Transport - Haz	450	Ton	$70	$31,500		Assumes 265 cy to be disposed at 1.7 t/cy; offsite, hazardous disposal.
Soil Disposal - Non-haz	450	Ton	$70	$31,500		Assumes 265 cy to be disposed at 1.7 t/cy; offsite, non-hazardous disposal.
Soil Disposal - Haz	450	Ton	$130	$58,500		Assumes 265 cy to be disposed at 1.7 t/cy; offsite, hazardous disposal.
MPE Skid	3	Each	$30,000	$90,000		
Carbon Treatment System - Liquid Phase	1	LS	$18,500	$18,500		Assumes two 1,500 lb vessels and initial carbon supply (for up to 40 gpm flow).
Carbon Treatment System - Vapor Phase	1	LS	$11,000	$11,000		Assumes two 2,000 lb vessels and initial carbon supply (for estimated 800 cfm flow).
Well Installation - Materials and Labor	2,214	VF	$25	$55,350		Assumes 66 wells installed in the fractured boreholes.
Well Heads	66	Each	$500	$33,000		
Control Panel and PLC Programming	1	LS	$25,000	$25,000		Conventional PLC-based panel; no SCADA.
Holding Tank	1	Tank	$5,000	$5,000		
Outfall	1	LS	$5,000	$5,000		For up to 40 gpm flow.
Misc. Equipment	1	LS	$15,000	$15,000		From other project experience; possible additional piping, valving, transfer pumps, influent pretreatment, etc.
Bedrock Monitoring Well Installation	110	VF	$77	$8,470		Assumes installation of 2 bedrock wells. Cost includes soil disposal and survey.
Startup/ System Shakedown	200	Hours	$75	$15,000		
Subtotal					$970,523	
Soil Excavation; Offsite Disposal						Excavation of soil ≥ 10 mg/kg, ≤ 6 feet bgs
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment.
Clearing and Grubbing	0	Acre	$4,000	$0		
Soil Excavation	550	CY	$15	$8,250		Assumes 50% of hot spot soil haz, 50% non-haz.
Soil Transport - Non-haz	468	Ton	$50	$23,380		275 CY @ 1.7ton/CY
Soil Transport - Haz	468	Ton	$70	$32,730		275 CY @ 1.7ton/CY
Backfill & Site restoration	550	CY	$20	$11,000		
Soil Disposal - Non-haz	468	Ton	$70	$32,725		Assumes non-haz disposal, PCB conc. <50 ppm.
Soil Disposal - Haz	468	Ton	$130	$60,775		Assumes haz disposal, PCB conc. <50 ppm.
Monitoring Well Abandonment and Replacement	130	VF	$70	$9,100		Abandonment and replacement of 33MWC-24 and 33MWC-13
Demobilize	1	LS	$5,000	$5,000		
Level "C" contingency	10%	%	$192,960	$19,300		10% of contractor costs due to slower pace of work & PPE costs.
Subtotal					$212,260	
INDIRECT CAPITAL COSTS						
Multi-Phase Extraction System and Soil Excavation						
Preliminary Design/Regulatory Approval	5.5%	LS	$1,182,783	$65,053		5.5% of direct MPE treatment system capital costs.
Final Design/Planning	10%	LS	$1,182,783	$118,278		10% of direct MPE treatment system capital costs.
Project Management	5%	LS	$1,182,783	$59,139		5% of direct MPE treatment system capital costs.
Permit Application	1	LS	$5,000	$5,000		Treated groundwater and air discharge permit application.
Construction Observation & Documentation	15%	LS	$1,182,783	$177,417		15% of direct MPE treatment system capital costs.
Health and Safety Monitoring	1	LS	$5,000	$5,000		Health and Safety Plan preparation, field monitoring equipment, documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$429,888	
SUB-TOTAL					$1,612,671	
CONTINGENCY (20%)					$322,500	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$1,935,200	

Detailed Cost Estimate - Alternative A - Building I-1-2/I-1-3 VOC Source Area
Limited Excavation (I-1-3 hotspot) and Multi-phase Extraction with Pneumatic Fracturing

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-2/I-1-3 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: Alternative A consists of target soil (> 10 mg/kg VOC in soil < 6 feet bgs), groundwater and soil treatment by multi-phase extraction enhanced via pneumatic fracturing for 2 years, then shut down.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 1-2						Estimated annual operation, maintenance, and monitoring costs for years 1 & 2 of system operation.
Site Visits	12	Visit	$1,700	$20,400		Assumes monthly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Treatment System Performance Sampling	72	Sample	$100	$7,200		Assumes monthly sampling of treatment system vapor and fluid influent, mid-train, and effluent.
Analytical Testing (Performance Sampling)	72	Sample	$250	$18,000		Assumes monthly sampling of treatment system influent, mid-train, and effluent.
Treatment System Operation	12	Month	$3,650	$30,000		Includes 40 hr/mo labor, equipment.
Power Consumption	12	Month	$3,135	$37,624		Assumes 80 hp at 90% run-time @ 0.08/kWH.
Carbon Replacement - Liquid Phase	12	Month	$3,000	$36,000		Assuming 50 lb/day carbon usage at $2.00/lb carbon.
Carbon Replacement - Vapor Phase	12	Month	$1,200	$14,400		Assuming 20 lb/day carbon usage at $2.00/lb carbon.
Monitoring Well Network Sampling	2	Event	$5,700	$11,400		Assumes semiannual sampling of 6 MWs, 2 bedrock wells, 1 staff gage.
Analytical Testing (MW Network)	22	Sample	$250	$5,500		Assumes semiannual sampling of 6 MWs, 2 bedrock wells, 1 staff gage + 2 QA/QC samples.
Outfall Inspection/Clearing	1	Year	$500	$500		
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS	-	$46,045		20% of O&M items
Subtotal					$276,300	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 3-5						Estimated annual operation, maintenance, and monitoring costs for years 3-5.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Well Network Sampling	1	Event	$6,200	$6,200		Assumes annual sampling of 6 MWs, 2 bedrock wells, 1 staff gage.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 6 MWs, 2 bedrock wells, 1 staff gage + 2 QA/QC samples.
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$8,350		20% of O&M items
Subtotal					$50,100	
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 6-30						Estimated annual operation, maintenance, and monitoring costs for years 6-30.
Site Visits	1	Visit	$1,700	$1,700		Assumes annual inspection. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Well Network Sampling	1	Event	$6,200	$6,200		Assumes annual sampling of 6 MWs, 2 bedrock wells, 1 staff gage.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 6 MWs, 2 bedrock wells, 1 staff gage + 2 QA/QC samples.
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$7,050		20% of O&M items
Subtotal					$42,300	

Present Value Analysis
Alternative B - Buildings I-1-2/I-1-3 VOC Source Area
Permeable Reactive Barrier

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$1,783,000	$0	$9,000	$1,792,000	1	$1,792,000	PRB construction. No O&M in year 0.
1	$0	$116,300	$0	$116,300	0.969	$112,700	Assumes quarterly sampling of PRB wells and semiannual sampling of monitoring wells.
2	$0	$116,300	$0	$116,300	0.939	$109,200	
3	$0	$116,300	$0	$116,300	0.910	$105,800	
4	$0	$116,300	$0	$116,300	0.881	$102,500	
5	$0	$116,300	$9,000	$125,300	0.854	$107,000	Assumes monitoring reduced to semi-annual for PRB and GW monitoring well networks. QAPP/FSP revision, bid & contract lab assumed.
6	$0	$70,200	$0	$70,200	0.828	$58,100	
7	$0	$70,200	$0	$70,200	0.802	$56,300	
8	$0	$70,200	$0	$70,200	0.778	$54,600	
9	$0	$70,200	$0	$70,200	0.754	$52,900	
10	$0	$70,200	$9,000	$79,200	0.730	$57,800	Assumes monitoring reduced to annual for PRB and GW monitoring well networks. QAPP/FSP revision, bid & contract lab assumed.
11	$0	$49,900	$0	$49,900	0.707	$35,300	
12	$0	$49,900	$0	$49,900	0.685	$34,200	
13	$0	$49,900	$0	$49,900	0.663	$33,100	
14	$0	$49,900	$0	$49,900	0.643	$32,100	
15	$0	$49,900	$9,000	$58,900	0.623	$36,700	QAPP/FSP revision, bid & contract lab assumed.
16	$0	$49,900	$0	$49,900	0.603	$30,100	
17	$0	$49,900	$0	$49,900	0.585	$29,200	
18	$0	$49,900	$0	$49,900	0.567	$28,300	
19	$0	$49,900	$0	$49,900	0.549	$27,400	
20	$0	$49,900	$1,792,000	$1,841,900	0.533	$981,000	QAPP/FSP revision, bid & contract lab assumed.
21	$0	$49,900	$0	$49,900	0.517	$25,800	
22	$0	$49,900	$0	$49,900	0.501	$25,000	
23	$0	$49,900	$0	$49,900	0.485	$24,200	
24	$0	$49,900	$0	$49,900	0.469	$23,400	
25	$0	$49,900	$9,000	$58,900	0.455	$26,800	QAPP/FSP revision, bid & contract lab assumed.
26	$0	$49,900	$0	$49,900	0.441	$22,000	
27	$0	$49,900	$0	$49,900	0.427	$21,300	
28	$0	$49,900	$0	$49,900	0.415	$20,700	
29	$0	$49,900	$0	$49,900	0.401	$20,000	
30	$0	$49,900	$1,509,000	$1,558,900	0.389	$606,034	QAPP/FSP revision, bid & contract lab assumed; replace PRB @ $1.5 MM
TOTALS		**$1,930,500**	**$3,346,000**	**$7,059,500**		**$4,692,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative B - Building I-1-2/I-1-3 VOC Source Area
Permeable Reactive Barrier

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-2/I-1-3 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: Alternative B includes the installation of a permeable reactive barrier containing zero-valent iron. Assumes the saturated Upper Sand (approximately 7-foot thickness) will be treated by a 40-foot deep permeable reactive barrier.

ITEM OF WORK	COST ESTIMATES QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Permeable Reactive Barrier						
Mobilization	1	Estimate	$50,000	$50,000		Oversight personnel, contractor personnel, and equipment.
Utility Relocation	1	LS	$36,000	$36,000		For utilities in the area of PRB construction.
Trenching	26,000	SF	$20	$520,000		Assuming 650 ft long, 40 ft deep, 3 ft wide.
Soil Replacement	4,052	Ton	$10	$40,500		Assumes top 33 ft excavated soil can be replaced into the top of the trench.
Soil Transportation	859	Ton	$50	$42,972		Assumes bottom 7 ft excavated soil will require off-site, non-hazardous disposal; 1.7 t/cy.
Soil Disposal	859	Ton	$70	$60,161		Assumes bottom 7 ft excavated soil will require off-site, non-hazardous disposal; 1.7 t/cy.
Iron Material	512	Ton	$450	$230,300		Assumes bulk density of 0.08 tons/cubic foot, bottom 7' of trench filled with 1:1 iron/sand-mixture. Delivered.
Sand Material	375	Ton	$15	$5,630		Assumes 1:1ratio of iron:sand and bulk density of 0.055 tons/cubic foot for sand. Saturated US treated with iron/sand mix.
Monitoring Well Installation	550	VF	$70	$38,500		Assumes installation of 16 new wells; 14 around PRB and 2 bedrock wells. Cost includes soil disposal and survey.
Bedrock Monitoring Well Installation	110	VF	$77	$8,470		Assumes installation of 2 bedrock wells. Cost includes soil disposal and survey.
Subtotal					$1,032,500	
INDIRECT CAPITAL COSTS						
Permeable Reactive Barrier						
Bench-scale Testing	1	LS	$17,000	$17,000		Per vendor estimate.
Data Review	1	LS	$2,500	$2,500		
Preliminary Design/Regulatory Approval	5%	LS	$1,032,500	$51,625		5% of direct PRB capital cost.
Final Design/Planning	7%	LS	$1,032,500	$72,275		7% of direct PRB capital cost.
Project Management	6%	LS	$1,032,500	$61,950		6% of direct PRB capital cost.
Field Design/Implementation Assistance	1	LS	$7,500	$7,500		EnviroMetal.
Site License Fee for Use of Zero-Valent Iron PRB	15%	LS	$1,032,500	$154,875		15% of direct PRB capital costs to EnviroMetal.
Construction Observation & Documentation	8%	LS	$1,032,500	$82,600		8% of direct PRB capital cost.
Health and Safety Monitoring	1	LS	$3,000	$3,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$7,500	$7,500		
Subtotal					$453,325	
SUB-TOTAL					$1,485,825	
CONTINGENCY (20%)					$297,200	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$1,783,000	
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years.
Site Inspection	4	Visit	$1,700	$6,800		Assumes quarterly inspections for water level evaluation. 16 hours labor and $500 expenses.
PRB Monitoring Network Well Sampling	2	Event	$6,000	$12,000		Assumes 2 quarterly sampling events of 14 PRB wells (2 other events incl. w/SA GW monitoring- costs incl. below).
Analytical Testing (PRB Network)	32	Sample	$250	$8,000		Assumes 2 quarterly sampling events of 14 PRB wells with 2 QA/QC duplicate samples per quarter.
Monitoring Well Network Sampling	2	Event	$9,500	$19,000		Assumes semiannual sampling of 6 monitoring wells and 14 PRB wells.
Analytical Testing (MW Network)	46	Sample	$250	$11,500		Assumes semiannual sampling of 6 monitoring wells and 14 PRB wells with 3 QA/QC samples per event.
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semi-annual reporting.
O&M Contingency	20%	LS	-	$19,380		20% of O&M items.
Subtotal					$116,300	
PERIODIC COSTS *						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
REPLACEMENT OF PRB IN YEAR 20*						Cost for complete replacement of PRB in year 20.
Direct Capital Cost	1	LS	$1,032,500	$1,032,500		Assumes same cost as original construction.
Indirect Capital Cost	1	LS	$453,325	$453,325		Assumes same cost as original construction.
Contingency	20%	LS	$1,485,825	$297,165		20% of direct and indirect costs.
Subtotal					$1,783,000	
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for years 6-10.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 12 hours labor and $500 expenses.
PRB Monitoring Network Well Sampling	0	Event	$6,000	$0		Included with GW monitoring- costs incl. below.
Analytical Testing (PRB Network)	0	Sample	$250	$0		Included with GW monitoring- costs incl. below.
Monitoring Well Network Sampling	2	Event	$9,500	$19,000		Assumes semiannual sampling of 6 monitoring wells and 14 PRB wells.
Analytical Testing (MW Network)	46	Sample	$250	$11,500		Assumes semiannual sampling of 6 monitoring wells and 14 PRB wells with 3 QA/QC samples per event.
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$11,700		20% of O&M items.
Subtotal					$70,200	
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 11-30						Estimated annual operation, maintenance, and monitoring costs for years 11-30.
Site Visits	1	Visit	$1,700	$1,700		Assumes annual inspections. 12 hours labor and $500 expenses.
PRB Monitoring Network Well Sampling	0	Event	$6,000	$0		Included with GW monitoring- costs incl. below.
Analytical Testing (PRB Network)	0	Sample	$250	$0		Included with GW monitoring- costs incl. below.
Monitoring Well Network Sampling	1	Event	$9,500	$9,500		Assumes annual sampling of 6 monitoring wells and 14 PRB wells.
Analytical Testing (MW Network)	23	Sample	$250	$5,750		Assumes annual sampling of 6 monitoring wells and 14 PRB wells with 3 QA/QC samples per event.
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$8,310		20% of O&M items.
Subtotal					$49,900	

* Assumes PRB bed will require replacement in year 20.

Present Value Analysis
Alternative C - Buildings I-1-2/I-1-3 VOC Source Area
Alternate Concentration Limits

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$76,700	$0	$9,000	$85,700	1	$85,700	System installation
1	$0	$81,600	$0	$81,600	0.969	$79,100	Semiannual sampling
2	$0	$81,600	$0	$81,600	0.939	$76,600	
3	$0	$81,600	$0	$81,600	0.909	$74,200	
4	$0	$81,600	$0	$81,600	0.881	$71,900	
5	$0	$81,600	$9,000	$90,600	0.854	$77,400	QAPP/FSP revision, bid & contract lab assumed.
6	$0	$55,600	$0	$55,600	0.827	$46,000	Assumes annual monitoring.
7	$0	$55,600	$0	$55,600	0.802	$44,600	
8	$0	$55,600	$0	$55,600	0.777	$43,200	
9	$0	$55,600	$0	$55,600	0.754	$41,900	
10	$0	$55,600	$9,000	$64,600	0.729	$47,100	QAPP/FSP revision, bid & contract lab assumed.
11	$0	$49,800	$0	$49,800	0.707	$35,200	
12	$0	$49,800	$0	$49,800	0.685	$34,100	
13	$0	$49,800	$0	$49,800	0.665	$33,100	
14	$0	$49,800	$0	$49,800	0.643	$32,000	
15	$0	$49,800	$9,000	$58,800	0.624	$36,700	QAPP/FSP revision, bid & contract lab assumed.
16	$0	$49,800	$0	$49,800	0.604	$30,100	
17	$0	$49,800	$0	$49,800	0.586	$29,200	
18	$0	$49,800	$0	$49,800	0.566	$28,200	
19	$0	$49,800	$0	$49,800	0.550	$27,400	
20	$0	$49,800	$9,000	$58,800	0.532	$31,300	QAPP/FSP revision, bid & contract lab assumed.
21	$0	$49,800	$0	$49,800	0.516	$25,700	
22	$0	$49,800	$0	$49,800	0.500	$24,900	
23	$0	$49,800	$0	$49,800	0.484	$24,100	
24	$0	$49,800	$0	$49,800	0.470	$23,400	
25	$0	$49,800	$9,000	$58,800	0.456	$26,800	QAPP/FSP revision, bid & contract lab assumed.
26	$0	$49,800	$0	$49,800	0.442	$22,000	
27	$0	$49,800	$0	$49,800	0.428	$21,300	
28	$0	$49,800	$0	$49,800	0.414	$20,600	
29	$0	$49,800	$0	$49,800	0.402	$20,000	
30	$0	$49,800	$9,000	$58,800	0.389	$22,859	QAPP/FSP revision, bid & contract lab assumed.
TOTALS		**$1,682,000**	**$63,000**	**$1,821,700**		**$1,237,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative C - Building I-1-2/I-1-3 VOC Source Area
Alternate Concentration Limits

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-2/I-1-3 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: Alternative D includes the establishment of Alternate Concentration Limits (ACLs) for shallow groundwater quality.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT AND INDIRECT CAPITAL COSTS						
Establishment of ACLs						
Monitoring Well Installation	200	VF	$77	$15,400		Assumes installation of 2 sets of two nested wells. Cost includes soil disposal and survey.
Groundwater Sampling labor & expenses	2	Events	$5,000	$10,000		Sampling of 4 new monitoring wells for VOCs.
Bedrock Monitoring Well Installation	110	VF	$77	$8,470		Assumes installation of 2 bedrock wells. Cost includes soil disposal and survey.
Data Review	1	LS	$5,000	$5,000		
ACLs Development Submittal	1	LS	$20,000	$20,000		
Project Management	1	LS	$5,000	$5,000		
Subtotal					$63,900	
SUB-TOTAL					$63,900	
CONTINGENCY (20%)					$12,800	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$76,700	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years.
Site Visits	4	Visit	$1,700	$6,800		Assumes quarterly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	2	Events	$6,200	$12,400		Semiannual sampling of 8 monitoring points.
Analytical Testing	20	Sample	$250	$5,000		Assumes semiannual sampling of 5 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Administrative Costs	288	Hour	$100	$28,800		Assumes average labor rate and 24 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$13,600		20% of O&M items
Subtotal					$81,600	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for second 5 years.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	1	Event	$6,200	$6,200		Annual sampling of 8 monitoring points.
Analytical Testing	10	Sample	$250	$2,500		Assumes annual sampling of 5 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$9,260		20% of O&M items
Subtotal					$55,600	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 11-30						Estimated annual operation, maintenance, and monitoring costs for years 11-30.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	1	Event	$6,200	$6,200		Annual sampling of 8 monitoring points.
Analytical Testing	10	Sample	$250	$2,500		Assumes annual sampling of 5 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$8,300		20% of O&M items
Subtotal					$49,800	

Present Value Analysis
Alternative D - Buildings I-1-2/I-1-3 VOC Source Area
Soil Excavation to 10 mg/kg and Alternate Concentration Limits

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$902,430	$0	$9,000	$911,430	1	$911,430	System installation
1	$0	$81,600	$0	$81,600	0.969	$79,100	Semiannual sampling
2	$0	$81,600	$0	$81,600	0.939	$76,600	
3	$0	$81,600	$0	$81,600	0.909	$74,200	
4	$0	$81,600	$0	$81,600	0.881	$71,900	
5	$0	$81,600	$9,000	$90,600	0.854	$77,400	QAPP/FSP revision, bid & contract lab assumed.
6	$0	$55,600	$0	$55,600	0.827	$46,000	Assumes annual monitoring.
7	$0	$55,600	$0	$55,600	0.802	$44,600	
8	$0	$55,600	$0	$55,600	0.777	$43,200	
9	$0	$55,600	$0	$55,600	0.754	$41,900	
10	$0	$55,600	$9,000	$64,600	0.729	$47,100	QAPP/FSP revision, bid & contract lab assumed.
11	$0	$49,800	$0	$49,800	0.707	$35,200	
12	$0	$49,800	$0	$49,800	0.685	$34,100	
13	$0	$49,800	$0	$49,800	0.665	$33,100	
14	$0	$49,800	$0	$49,800	0.643	$32,000	
15	$0	$49,800	$9,000	$58,800	0.624	$36,700	QAPP/FSP revision, bid & contract lab assumed.
16	$0	$49,800	$0	$49,800	0.604	$30,100	
17	$0	$49,800	$0	$49,800	0.586	$29,200	
18	$0	$49,800	$0	$49,800	0.566	$28,200	
19	$0	$49,800	$0	$49,800	0.550	$27,400	
20	$0	$49,800	$9,000	$58,800	0.532	$31,300	QAPP/FSP revision, bid & contract lab assumed.
21	$0	$49,800	$0	$49,800	0.516	$25,700	
22	$0	$49,800	$0	$49,800	0.500	$24,900	
23	$0	$49,800	$0	$49,800	0.484	$24,100	
24	$0	$49,800	$0	$49,800	0.470	$23,400	
25	$0	$49,800	$9,000	$58,800	0.456	$26,800	QAPP/FSP revision, bid & contract lab assumed.
26	$0	$49,800	$0	$49,800	0.442	$22,000	
27	$0	$49,800	$0	$49,800	0.428	$21,300	
28	$0	$49,800	$0	$49,800	0.414	$20,600	
29	$0	$49,800	$0	$49,800	0.402	$20,000	
30	$0	$49,800	$9,000	$58,800	0.389	$22,859	QAPP/FSP revision, bid & contract lab assumed.
TOTALS		**$1,682,000**	**$63,000**	**$2,647,430**		**$2,062,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative D, Building I-1-2/I-1-3 VOC Source Area
Soil Excavation to 10 mg/kg and Alternate Concentration Limits

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-23 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: Alternative D consists of target soil (≥10 mg/kg VOC target in soil ≤12 feet deep) excavation, and the establishment of Alternate Concentration Limits (ACLs) for shallow groundwater quality, and institutional controls.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT CAPITAL COSTS						
Soil Excavation; Offsite Disposal						Excavation of soil ≥ 10 mg/kg, ≤ 12 feet bgs
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment.
Clearing and Grubbing	0	Acre	$4,000	$0		
Soil Excavation	2,720	CY	$15	$40,800		1,280 cy @ I-1-2 and 1,440 cy @ I-1-3.
Soil Transport - Non-haz	1,088	Ton	$50	$54,400		Transport R/T to Peoria, IL. (430 cy from I-1-2 and 850 cy from I-1-3 @ 1.7ton/CY). Assumes 50% non-haz.
Soil Transport - Haz	1,088	Ton	$70	$76,160		Transport R/T to Emelle, AL. (430 cy from I-1-2 and 850 cy from I-1-3 @ 1.7ton/CY). Assumes 50% haz.
Backfill & Site restoration	2,720	CY	$20	$54,400		Re-use 1,440 CY of uncontaminated soil, formerly above contaminated areas.
Soil Disposal - Non-haz	1,088	Ton	$70	$76,160		Assumes disposal at PDC #1, Peoria, IL. PCB conc. <50 ppm.
Soil Disposal - Haz	1,088	Ton	$130	$141,440		Assumes disposal at WM Emelle, Alabama; PCB conc. <50 ppm.
Monitoring Well Abandonment and Replacement	130	VF	$70	$9,100		Abandonment and replacement of 33MWC-24 and 33MWC-13
Bedrock Monitoring Well Installation	110	VF	$77	$8,470		Assumes installation of 2 bedrock wells. Cost includes soil disposal and survey.
Demobilize	1	LS	$5,000	$5,000		
Level "C" contingency	10%	%	$475,930	$47,600		10% of contractor costs due to slower pace of work & PPE costs.
Subtotal					$523,530	
Establishment of ACLs						
Monitoring Well Installation	200	VF	$77	$15,400		Assumes installation of 2 sets of two nested wells. Cost includes soil disposal and survey.
Groundwater Sampling labor & expenses	2	Events	$5,000	$10,000		Sampling of 4 new monitoring wells for VOCs.
Data Review	1	LS	$5,000	$5,000		
ACLs Development Submittal	1	LS	$20,000	$20,000		
Project Management	1	LS	$5,000	$5,000		
Subtotal					$55,400	
INDIRECT CAPITAL COSTS						
Soil Excavation at Building I-1-23; Offsite Disposal						
Preliminary Design/Regulatory Approval	8%	LS	$523,530	$41,900		8% of direct soil excavation capital costs.
Final Design/Planning	7%	LS	$523,530	$36,600		7% of direct soil excavation capital costs.
Project Management	8%	LS	$523,530	$41,900		8% of direct soil excavation capital costs.
Bidding & Contracting	5%	LS	$523,530	$26,200		5% of direct soil excavation capital costs.
Permitting	1	LS	$5,000	$5,000		Disposal facility profile.
Construction Observation & Documentation	10%	LS	$523,530	$52,400		10% of direct soil excavation capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$10,000	$10,000		
Subtotal					$173,100	
SUB-TOTAL					$752,030	
CONTINGENCY (20%)					$150,400	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$902,430	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years.
Site Visits	4	Visit	$1,700	$6,800		Assumes quarterly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	2	Events	$6,200	$12,400		Semiannual sampling of 8 monitoring points.
Analytical Testing	20	Sample	$250	$5,000		Assumes semiannual sampling of 5 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Administrative Costs	288	Hour	$100	$28,800		Assumes average labor rate and 24 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$13,600		20% of O&M items
Subtotal					$81,600	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for second 5 years.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	1	Event	$6,200	$6,200		Annual sampling of 8 monitoring points.
Analytical Testing	10	Sample	$250	$2,500		Assumes annual sampling of 5 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$9,260		20% of O&M items
Subtotal					$55,600	
ANNUAL OPERATION, MAINTENANCE & MONITORING COSTS - Years 11-30						Estimated annual operation, maintenance, and monitoring costs for years 11-30.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Network Sampling labor & expenses	1	Event	$6,200	$6,200		Annual sampling of 8 monitoring points.
Analytical Testing	10	Sample	$250	$2,500		Assumes annual sampling of 5 monitoring wells and 3 surface water locations with 2 QA/QC samples per event.
Administrative Costs	144	Hour	$100	$14,400		Assumes average labor rate and 12 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$8,300		20% of O&M items
Subtotal					$49,800	

Present Value Analysis
Alternative E - Building I-1-2/I-1-3 VOC Source Area
Soil Excavation to 10 mg/kg, In-situ Reductive Dechlorination with Pneumatic Fracturing, and ACLs

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$1,753,100	$0	$9,000	$1,762,100	1	$1,762,100	Construct system. No O&M costs in Year 0. Discharge permit acquisition.
1	$0	$148,000	$0	$148,000	0.969	$143,400	Assumes system O&M and semi-annual GW monitoring.
2	$0	$148,000	$0	$148,000	0.939	$139,000	
3	$0	$148,000	$0	$148,000	0.910	$134,700	Assumes MPE system shut down and annual monitoring for GW.
4	$0	$148,000	$0	$148,000	0.882	$130,500	
5	$0	$148,000	$9,000	$157,000	0.854	$134,100	QAPP/FSP revision, and bid & contract lab assumed.
6	$0	$42,300	$0	$42,300	0.827	$35,000	
7	$0	$42,300	$0	$42,300	0.801	$33,900	
8	$0	$42,300	$0	$42,300	0.778	$32,900	
9	$0	$42,300	$0	$42,300	0.754	$31,900	
10	$0	$42,300	$9,000	$51,300	0.729	$37,400	QAPP/FSP revision, and bid & contract lab assumed.
11	$0	$42,300	$0	$42,300	0.707	$29,900	
12	$0	$42,300	$0	$42,300	0.686	$29,000	
13	$0	$42,300	$0	$42,300	0.664	$28,100	
14	$0	$42,300	$0	$42,300	0.643	$27,200	
15	$0	$42,300	$9,000	$51,300	0.624	$32,000	QAPP/FSP revision, and bid & contract lab assumed.
16	$0	$42,300	$0	$42,300	0.605	$25,600	
17	$0	$42,300	$0	$42,300	0.586	$24,800	
18	$0	$42,300	$0	$42,300	0.567	$24,000	
19	$0	$42,300	$0	$42,300	0.551	$23,300	
20	$0	$42,300	$9,000	$51,300	0.532	$27,300	QAPP/FSP revision, and bid & contract lab assumed.
21	$0	$42,300	$0	$42,300	0.515	$21,800	
22	$0	$42,300	$0	$42,300	0.501	$21,200	
23	$0	$42,300	$0	$42,300	0.485	$20,500	
24	$0	$42,300	$0	$42,300	0.470	$19,900	
25	$0	$42,300	$9,000	$51,300	0.454	$23,300	QAPP/FSP revision, and bid & contract lab assumed.
26	$0	$42,300	$0	$42,300	0.440	$18,600	
27	$0	$42,300	$0	$42,300	0.428	$18,100	
28	$0	$42,300	$0	$42,300	0.414	$17,500	
29	$0	$42,300	$0	$42,300	0.402	$17,000	
30	$0	$42,300	$9,000	$51,300	0.389	$19,943	QAPP/FSP revision, and bid & contract lab assumed.
TOTALS		**$1,797,500**	**$63,000**	**$3,613,600**		**$3,084,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative E - Buildings I-1-2/I-1-3 VOC Source Area
Soil Excavation to 10 mg/kg, In-situ Reductive Dechlorination with Pneumatic Fracturing, and ACLs

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-2/I-1-3 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: Alternative E consists of target soil excavation at I-1-2 and I-1-3 to 10 mg/kg and groundwater and soil treatment by bioremediation enhanced via pneumatic fracturing and emulsified soybean oil injection.

ITEM OF WORK	COST ESTIMATES QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Soil Excavation; Offsite Disposal (Assumes 50 % non-hazardous disposal)						Excavation of soil ≥ 10 mg/kg, ≤ 12 feet bgs
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment.
Clearing and Grubbing	0	Acre	$4,000	$0		
Soil Excavation	2,720	CY	$15	$40,800		1,280 cy @ I-1-2 and 1,440 cy @ I-1-3.
Soil Transport - Non-haz	1,088	Ton	$50	$54,400		Transport R/T from CONWR to Peoria, IL. (430 cy from I-1-2 and 850 cy from I-1-3 @ 1.7ton/CY). Assumes 50% non-haz.
Soil Transport - Haz	1,088	Ton	$70	$76,160		Transport R/T from CONWR to Peoria, IL. (430 cy from I-1-2 and 850 cy from I-1-3 @ 1.7ton/CY). Assumes 50% haz.
Backfill & Site restoration	2,720	CY	$20	$54,400		Re-use 1,440 CY of uncontaminated soil, formerly above contaminated areas.
Soil Disposal - Non-haz	1,088	Ton	$70	$76,160		Assumes disposal at PDC #1, Peoria, IL. PCB conc. <50 ppm.
Soil Disposal - Haz	1,088	Ton	$130	$141,440		Assumes disposal at WM Emelle, Alabama; PCB conc. <50 ppm.
Monitoring Well Abandonment and Replacement	130	VF	$70	$9,100		Abandonment and replacement of 33MWC-24 and 33MWC-13
Bedrock Monitoring Well Installation	110	VF	$77	$8,470		Assumes installation of 2 bedrock wells. Cost includes soil disposal and survey.
Demobilize	1	LS	$5,000	$5,000		
Level "C" contingency	10%	%	$475,930	$47,600		10% of contractor costs due to slower pace of work & PPE costs.
Subtotal					$523,530	
Enhanced Bioremediation System						
Pilot Study	1	LS	$100,000	$100,000		Assumed limited, 6-month pilot study.
Mobilization/Site Preparation	1	LS	$20,000	$20,000		Oversight and construction personnel and equipment.
Access Road to Treatment Area	1	LS	$10,000	$10,000		
Fracturing Borehole Installation	738	VF	$35	$25,830		Assumes 22 boreholes ranging in depth from 16 to 45 feet bgs.
Soil Disposal	28	Drum	$100	$2,838		Assumes soil cuttings to be disposed offsite, non-hazardous disposal.
Pneumatic Fracturing	104	Fracture	$725	$75,348		Fracturing zones targeting from 10 to 45 feet bgs.
Injection Wells - Materials/Installation	613	VF	$25	$15,325		Assumes 22 wells installed in the fracture boreholes.
Well Heads	22	Each	$500	$11,000		
Misc. Equipment	1	LS	$10,000	$10,000		Potential required field equipment to implement technology.
Monitoring Well Installation	350	VF	$77	$26,950		Assumes installation of 2 bedrock and 8 unconsolidated deposit wells. Cost includes soil disposal and surveying.
Injection Effort	1	LS	$43,750	$43,750		Assumes 3 week effort, labor, expenses, and materials.
Injection Material	1	LS	$125,000	$125,000		Emulsified vegetable oil; cost for approx 20,000 lb substrate.
Substrate for Placement in Excavation Pits	1	EA	$10,000	$10,000		Materials only: based on soybean oil to be placed in excavation pits prior to backfilling
Subtotal					$476,041	
Establishment of ACLs						
Monitoring Well Installation	200	VF	$77	$15,400		Assumes installation of 2 sets of two nested wells. Cost includes soil disposal and survey.
Groundwater Sampling labor & expenses	2	Events	$5,000	$10,000		Sampling of 4 new monitoring wells for VOCs.
Data Review	1	LS	$5,000	$5,000		
ACLs Development Submittal	1	LS	$20,000	$20,000		
Project Management	1	LS	$5,000	$5,000		
Subtotal					$55,400	
INDIRECT CAPITAL COSTS						
Enhanced Bioremediation System & Excavation						
Process Development/Testing	5%	LS	$1,054,971	$52,749		5% of direct EBR treatment system capital costs.
Preliminary Design/Regulatory Approval	8%	LS	$1,054,971	$84,398		8% of direct EBR treatment system capital costs.
Final Design/Planning	7%	LS	$1,054,971	$73,848		7% of direct EBR treatment system capital costs.
Project Management	8%	LS	$1,054,971	$84,398		8% of direct EBR treatment system capital costs.
Bidding and Contracting	5%	LS	$1,054,971	$52,749		5% of direct EBR treatment system capital costs.
Construction Observation & Documentation	10%	LS	$1,054,971	$105,497		10% of direct EBR treatment system capital costs.
Health and Safety Monitoring	1	LS	$5,000	$5,000		Health and Safety Plan preparation, field monitoring equipment, documentation.
Documentation Report	1	LS	$15,000	$15,000		
Subtotal					$405,889	
SUB-TOTAL					$1,460,860	
CONTINGENCY (20%)					$292,200	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$1,753,100	

Detailed Cost Estimate - Alternative E - Building I-1-2/I-1-3 VOC Source Area
Soil Excavation to 10 mg/kg, In-situ Reductive Dechlorination with Pneumatic Fracturing, and ACLs

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-2/I-1-3 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: Alternative E consists of target soil excavation at I-1-2 and I-1-3 to 10 mg/kg and groundwater and soil treatment by bioremediation enhanced via pneumatic fracturing and emulsified soybean oil injection.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 1-5						Estimated annual monitoring costs for years 1 through 5 of system operation.
Site Visits	4	Visit	$1,700	$6,800		Assumes quarterly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Well Network Sampling	2	Event	$5,700	$11,400		Assumes semiannual sampling of 6 MWs, 2 bedrock wells, 1 staff gage.
Analytical Testing (MW Network)	22	Sample	$250	$5,500		Assumes semiannual sampling of 6 MWs, 2 bedrock wells, 1 staff gage + 2 QA/QC samples.
Substrate Addition	1	LS	$60,000	$60,000		Assumes two additional injection efforts needed over the five-year period.
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS	-	$24,660		20% of O&M items
Subtotal					$148,000	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 6-75						Estimated annual monitoring costs for years 6-75.
Site Visits	1	Visit	$1,700	$1,700		Assumes annual inspection. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
Monitoring Well Network Sampling	1	Event	$6,200	$6,200		Assumes annual sampling of 6 MWs, 2 bedrock wells, 1 staff gage.
Analytical Testing (MW Network)	11	Sample	$250	$2,750		Assumes annual sampling of 6 MWs, 2 bedrock wells, 1 staff gage + 2 QA/QC samples.
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$7,050		20% of O&M items
Subtotal					$42,300	

Present Value Analysis
Alternative F - Building I-1-2/I-1-3 VOC Source Area
In-situ Electrical Resistive Heating (ERH) in 10 mg/kg Source Area

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$3,030,200	$0	$9,000	$3,039,200	1	$3,039,200	Construct system. No O&M costs in Year 0.
1	$0	$91,100	$0	$91,100	0.969	$88,300	Assumes system O&M and semi-annual GW monitoring.
2	$0	$43,200	$0	$43,200	0.940	$40,600	Assumes ERH system shut down and annual monitoring of GW and surface water.
3	$0	$43,200	$0	$43,200	0.910	$39,300	
4	$0	$43,200	$0	$43,200	0.882	$38,100	
5	$0	$43,200	$9,000	$52,200	0.854	$44,600	QAPP/FSP revision, and bid & contract lab assumed.
6	$0	$42,300	$0	$42,300	0.827	$35,000	
7	$0	$42,300	$0	$42,300	0.801	$33,900	
8	$0	$42,300	$0	$42,300	0.778	$32,900	
9	$0	$42,300	$0	$42,300	0.754	$31,900	
10	$0	$42,300	$9,000	$51,300	0.729	$37,400	QAPP/FSP revision, and bid & contract lab assumed.
11	$0	$42,300	$0	$42,300	0.707	$29,900	
12	$0	$42,300	$0	$42,300	0.686	$29,000	
13	$0	$42,300	$0	$42,300	0.664	$28,100	
14	$0	$42,300	$0	$42,300	0.643	$27,200	
15	$0	$42,300	$9,000	$51,300	0.624	$32,000	QAPP/FSP revision, and bid & contract lab assumed.
16	$0	$42,300	$0	$42,300	0.605	$25,600	
17	$0	$42,300	$0	$42,300	0.586	$24,800	
18	$0	$42,300	$0	$42,300	0.567	$24,000	
19	$0	$42,300	$0	$42,300	0.551	$23,300	
20	$0	$42,300	$9,000	$51,300	0.532	$27,300	QAPP/FSP revision, and bid & contract lab assumed.
21	$0	$42,300	$0	$42,300	0.515	$21,800	
22	$0	$42,300	$0	$42,300	0.501	$21,200	
23	$0	$42,300	$0	$42,300	0.485	$20,500	
24	$0	$42,300	$0	$42,300	0.470	$19,900	
25	$0	$42,300	$9,000	$51,300	0.454	$23,300	QAPP/FSP revision, and bid & contract lab assumed.
26	$0	$42,300	$0	$42,300	0.440	$18,600	
27	$0	$42,300	$0	$42,300	0.428	$18,100	
28	$0	$42,300	$0	$42,300	0.414	$17,500	
29	$0	$42,300	$0	$42,300	0.402	$17,000	
30	$0	$42,300	$9,000	$51,300	0.389	$19,943	QAPP/FSP revision, and bid & contract lab assumed.
TOTALS		**$1,321,400**	**$63,000**	**$4,414,600**		**$3,930,000**	30 year total (linked to Summary sheet)

Detailed Cost Estimate - Alternative F - Buildings I-1-2/I-1-3 VOC Source Area
In-situ Electrical Resistive Heating (ERH) in 10 mg/kg Source Area

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-2/I-1-3 Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: Alternative F consists of target soil (volume with >10 mg/kg VOCs) treatment at I-1-2 and I-1-3 by ERH with groundwater monitoring.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT CAPITAL COSTS						
Treatment of Source Area with ERH						Targeting volume of soil ≥ 10 mg/kg total VOCs.
Pilot Study	1	LS	$150,000	$150,000		Assumed limited area pilot study.
Lab Testing/Modeling/Site Evaluation	1	LS	$15,000	$15,000		Site visit and detailed evaluation for equipment and system requirements.
Vendor Design Assistance	1	LS	$125,000	$125,000		Vendor input and assistance during system design and documentation.
Electrical Service Connection	1	LS	$50,000	$50,000		Assumes 4,774 kW electrical power requirement, 5,750 amps at 480V, 3-phase service.
Mobilization/Site Preparation	1	LS	$250,000	$250,000		Equipment mob and setup, site preparation, gravel surface, water hookup, and thermal surface liner.
Subsurface Installation	1	LS	$225,000	$225,000		Installation of ERH electrodes, vapor vents, and electrode irrigation systems.
Engineering Controls	1	LS	$25,000	$25,000		Placeholder cost for potential engineering controls required for protection of stored ordnance in the adjacent bldgs.
Cuttings Disposal	1	LS	$7,500	$7,500		Placeholder cost for disposal of soil cuttings from drilling installations.
Utilities Protection	1	LS	$50,000	$50,000		Placeholder cost for potential engineering controls that may be required to protect area utilities.
ERH Equipment Construction and Setup	1	LS	$75,000	$75,000		Construction and connection of above-ground electrode and irrigation system components.
Soil Vapor Extraction (SVE) Construction and Setup	1	LS	$60,000	$60,000		Construction and connection of above-ground vapor collection and treatment system components.
Startup Operations	1	LS	$33,750	$33,750		System startup labor and associated costs.
ERH and SVE Operation	1	LS	$150,000	$150,000		Vendor labor and system operation/monitoring.
Electrical Use	1	LS	$225,000	$225,000		ERH electrical use estimate at $0.08/kWhr.
Carbon Use	1	LS	$9,000	$9,000		For SVE vapor treatment.
Condensate Handling/Disposal	1	LS	$45,000	$45,000		From SVE vapor.
Indoor Air Vapor Monitoring	1	LS	$50,000	$50,000		Placeholder for conducting real-time vapor monitoring/sampling within the adjacent buildings.
Quality Assurance Monitoring	1	LS	$25,000	$25,000		Independent third party QA monitoring during operation phase.
Additional Monitoring	1	LS	$50,000	$50,000		Placeholder for additional groundwater and vapor monitoring outside of the treatment zone.
Demobilization	1	LS	$45,000	$45,000		Removal of ERH equipment and area restoration.
Well Replacement	1	LS	$10,000	$10,000		Replacement of wells likely to be destroyed by ERH.
Bedrock Monitoring Well Installation	110	VF	$77	$8,470		Assumes installation of 2 bedrock wells. Cost includes soil disposal and survey.
Confirmation Sampling	1	LS	$50,000	$50,000		Placeholder cost for final sampling program to assess VOC removal effectiveness and remaining concentrations.
Subtotal					$1,733,720	
Initiation of Groundwater Monitoring						
Monitoring Well Installation	200	VF	$77	$15,400		Assumes installation of 2 sets of two nested wells. Cost includes soil disposal and surveying.
Groundwater Sampling	2	Events	$5,000	$10,000		Labor and expenses for initial sampling of 4 new monitoring wells for VOCs.
Data Review	1	LS	$5,000	$5,000		
Project Management	1	LS	$5,000	$5,000		
Subtotal					$35,400	
INDIRECT CAPITAL COSTS						
Preliminary Design/Regulatory Approval	6%	LS	$1,769,120	$106,147		6% of direct ERH treatment system capital costs.
Final Design/Planning	6%	LS	$1,769,120	$106,147		6% of direct ERH treatment system capital costs.
Project Management	6%	LS	$1,769,120	$106,147		6% of direct ERH treatment system capital costs.
Bidding and Contracting	3%	LS	$1,769,120	$53,074		3% of direct ERH treatment system capital costs.
Guaranteed, Performance-Based Contract Premium	12%	LS	$1,733,720	$208,046		12% of direct ERH treatment system capital costs to account for performance based, guaranteed vendor contract.
Construction Observation & Documentation	8%	LS	$1,769,120	$141,530		8% of direct ERH treatment system capital costs.
Health and Safety Monitoring	1	LS	$10,000	$10,000		Health and Safety Plan preparation, field monitoring equipment, documentation.
Documentation Report	1	LS	$25,000	$25,000		
Subtotal					$756,091	
SUB-TOTAL					$2,525,211	
CONTINGENCY (20%)					$505,000	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$3,030,200	

Detailed Cost Estimate - Alternative F - Building I-1-2/I-1-3 VOC Source Area
In-situ Electrical Resistive Heating (ERH) in 10 mg/kg Source Area

Site: Crab Orchard National Wildlife Refuge
Location: Building I-1-2/I-1-3 Area
Base Year: 2003
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: Alternative F consists of target soil (volume with >10 mg/kg VOCs) treatment at I-1-2 and I-1-3 by ERH with groundwater monitoring.

	COST ESTIMATES					
ITEM OF WORK	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Year 1						Estimated annual monitoring costs for year 1 of system operation.
Site Visits	4	Visit	$2,450	$9,800		Assumes quarterly inspections. 3 hrs prep., 8 hrs on site, 13 hrs travel, 2 hrs report, $500 expenses.
Groundwater and Surface Water Sampling	2	Event	$5,700	$11,400		Assumes semiannual sampling of 6 MWs, 2 new bedrock wells, 1 surface water.
Analytical Testing (Water Samples)	22	Sample	$250	$5,500		Assumes semiannual analyses of 6 MWs, 2 new bedrock wells, 1 surface water + 2 QA/QC samples.
Administrative Costs	192	Hour	$100	$19,200		Assumes average labor rate and 16 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semiannual reporting.
O&M Contingency	20%	LS		$15,180		20% of O&M items
Subtotal					$91,100	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years.
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 2-30						Estimated annual monitoring costs for years 2-30.
Site Visits	1	Visit	$2,450	$2,450		Assumes quarterly inspections. 3 hrs prep., 8 hrs on site, 13 hrs travel, 2 hrs report, $500 expenses.
Groundwater and Surface Water Sampling	1	Event	$6,200	$6,200		Assumes annual sampling of 6 MWs, 2 bedrock wells, 1 surface water.
Analytical Testing (Water Samples)	11	Sample	$250	$2,750		Assumes annual analyses of 6 MWs, 2 bedrock wells, 1 surface water + 2 QA/QC samples.
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS		$7,200		20% of O&M items
Subtotal					$43,200	

Repository

Crab Orchard National Wildlife Refuge
PCB Operable Unit - Sites 32/33
Repository Cost Estimate Summary

Alternative	Description	Total Capital Cost ($)	Total Cost ($)	Total Present Value ($)
A	Phytoremediation and Monitored Natural Attenuation	199,400	1,854,800	1,322,400
B	Phytoremediation and Alternate Concentration Limits	174,800	1,708,300	1,210,300

Note:
Total present value is for a 30-year period with an annual discount rate of 3.2 percent.
Total cost is total realized dollars (sum of capital, operation, maintenance, and monitoring costs) over the common 30-year estimating period for all alternatives, not adjusted for inflation or discounting rates.

Present Value Analysis
Alternative A - Repository VOC Source Area
Phytoremediation and Monitored Natural Attenuation

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$199,400	$16,400	$0	$215,800	1.000	$215,800	Assumes monitoring semiannually for MNA.
1	$0	$87,700	$0	$87,700	0.969	$85,000	
2	$0	$87,700	$0	$87,700	0.939	$82,400	
3	$0	$87,700	$0	$87,700	0.910	$79,800	
4	$0	$87,700	$0	$87,700	0.882	$77,300	
5	$0	$87,700	$9,000	$96,700	0.854	$82,600	Assumes QAPP/FSP revision, bid & contract lab.
6	$0	$52,100	$0	$52,100	0.828	$43,100	Assumes monitoring reduced to annually for MNA, semi-annual site visit.
7	$0	$52,100	$0	$52,100	0.802	$41,800	
8	$0	$52,100	$0	$52,100	0.777	$40,500	
9	$0	$52,100	$0	$52,100	0.753	$39,200	
10	$0	$52,100	$9,000	$61,100	0.730	$44,600	Assumes QAPP/FSP revision, bid & contract lab.
11	$0	$44,300	$0	$44,300	0.707	$31,300	Assumes monitoring annually for MNA and annual site visit.
12	$0	$44,300	$0	$44,300	0.685	$30,400	
13	$0	$44,300	$0	$44,300	0.664	$29,400	
14	$0	$44,300	$0	$44,300	0.644	$28,500	
15	$0	$44,300	$9,000	$53,300	0.624	$33,200	Assumes QAPP/FSP revision, bid & contract lab.
16	$0	$44,300	$0	$44,300	0.604	$26,800	
17	$0	$44,300	$0	$44,300	0.585	$25,900	
18	$0	$44,300	$0	$44,300	0.567	$25,100	
19	$0	$44,300	$0	$44,300	0.550	$24,400	
20	$0	$44,300	$9,000	$53,300	0.533	$28,400	Assumes QAPP/FSP revision, bid & contract lab.
21	$0	$44,300	$0	$44,300	0.516	$22,900	
22	$0	$44,300	$0	$44,300	0.500	$22,200	
23	$0	$44,300	$0	$44,300	0.485	$21,500	
24	$0	$44,300	$0	$44,300	0.470	$20,800	
25	$0	$44,300	$9,000	$53,300	0.455	$24,300	Assumes QAPP/FSP revision, bid & contract lab.
26	$0	$44,300	$0	$44,300	0.441	$19,500	
27	$0	$44,300	$0	$44,300	0.427	$18,900	
28	$0	$44,300	$0	$44,300	0.414	$18,300	
29	$0	$44,300	$0	$44,300	0.401	$17,800	
30	$0	$44,300	$9,000	$53,300	0.389	$20,700	Assumes QAPP/FSP revision, bid & contract lab.
TOTALS		**$1,601,400**	**$54,000**	**$1,854,800**		**$1,322,400**	30 years

Detailed Cost Estimate - Alternative A - Repository VOC Source Area
Phytoremediation and Monitored Natural Attenuation

Site: Crab Orchard National Wildlife Refuge
Location: Repository Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: This alternative consists of phytoremediation using cultivated cottonwood trees and constructed prairie located in the areas near and between the Center Swale and teh East Swale. Monitored natural attenuation would also be used to evaluate groundwater quality improvement over time.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT CAPITAL COSTS						
Establishment of MNA Program						
Data Review	1	LS	$5,000	$5,000		
Preliminary Development/Regulatory Approval	1	LS	$15,000	$15,000		
Final Development/Plans	1	LS	$10,000	$10,000		
Project Management	1	LS	$10,000	$10,000		
Monitoring Well Installation	150	VF	$70	$10,500		Assumes installation of 5 new wells, assumed average depth of 30 feet. Cost includes soil disposal and survey.
Subtotal					$50,500	
Phytoremediation						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Cottonwood Trees; Procure and Install	1	Acre	$15,000	$12,000		Assumes two 30' x 570' areas to be planted with cottonwoods. Approximately 1,000 trees.
Constructed Prairie Area Installation	4	Acre	$5,000	$20,000		Up to Level 3 prairie constructed (3 to 4 grasses assumed).
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey.
Subtotal					$69,000	
INDIRECT CAPITAL COSTS						
Phytoremediation						
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Project Management	10%	LS	$69,000	$6,900		10% of direct capital costs.
Bidding & Contracting	5%	LS	$69,000	$3,450		5% of direct capital costs.
Construction Observation & Documentation	15%	LS	$69,000	$10,350		15% of direct capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$5,000	$5,000		
Subtotal					$46,700	
SUB-TOTAL					$166,200	
CONTINGENCY (20%)					$33,200	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$199,400	

ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years.
Site Visits	4	Visit	$1,700	$6,800		Assumes quarterly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
MNA Monitoring Network Well Sampling	2	Event	$7,500	$15,000		Assumes semiannual sampling of 10 monitoring wells and 3 surface water locations.
Analytical Testing (MNA Network)	30	Sample	$250	$7,500		Assumes semiannual sampling of 10 monitoring wells, 3 surface water locations, and 2 QA/QC samples.
Phytoremediation Maintenance	4.2	Acre	$1,000	$4,200		Tree and prairie areas.
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semi-annual reporting.
O&M Contingency	20%	LS	-	$14,620		20% of O&M items.
Subtotal					$87,700	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for second 5 years.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
MNA Monitoring Network Well Sampling	1	Event	$7,500	$7,500		Assumes annual sampling of 10 monitoring wells and 3 surface water locations.
Analytical Testing (MNA Network)	15	Sample	$250	$3,750		Assumes annual sampling of 10 monitoring wells, 3 surface water locations, and 2 QA/QC samples.
Phytoremediation Maintenance	4.2	Acre	$1,000	$4,200		
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$8,690		20% of O&M items.
Subtotal					$52,100	
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 11-30						Estimated annual operation, maintenance, and monitoring costs for years 11-30.
Site Visits	1	Visit	$1,700	$1,700		Assumes annual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
MNA Monitoring Network Well Sampling	1	Event	$7,500	$7,500		Assumes annual sampling of 10 monitoring wells and 3 surface water locations.
Analytical Testing (MNA Network)	15	Sample	$250	$3,750		Assumes annual sampling of 10 monitoring wells, 3 surface water locations, and 2 QA/QC samples.
Phytoremediation Maintenance	4.2	Acre	$1,000	$4,200		
Administrative Costs	48	Hour	$100	$4,800		Assumes average labor rate and 4 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$7,390		20% of O&M items.
Subtotal					$44,300	

Present Value Analysis
Alternative B - Repository VOC Source Area
Phytoremediation and Alternate Concentration Limits

Year	Capital Costs	Annual OM&M Costs	Periodic Costs	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%	Comments
0	$174,800	$0	$0	$174,800	1.000	$174,800	Assumes semiannual monitoring.
1	$0	$81,600	$0	$81,600	0.969	$79,100	
2	$0	$81,600	$0	$81,600	0.939	$76,600	
3	$0	$81,600	$0	$81,600	0.910	$74,300	
4	$0	$81,600	$0	$81,600	0.882	$72,000	
5	$0	$81,600	$9,000	$90,600	0.854	$77,400	Assumes QAPP/FSP revision, bid & contract lab.
6	$0	$49,100	$0	$49,100	0.828	$40,700	Assumes monitoring reduced to annual, semi-annual site visit.
7	$0	$49,100	$0	$49,100	0.802	$39,400	
8	$0	$49,100	$0	$49,100	0.777	$38,200	
9	$0	$49,100	$0	$49,100	0.753	$37,000	
10	$0	$49,100	$9,000	$58,100	0.730	$42,400	Assumes QAPP/FSP revision, bid & contract lab.
11	$0	$41,300	$0	$41,300	0.707	$29,200	Assumes monitoring and site visits conducted annually.
12	$0	$41,300	$0	$41,300	0.685	$28,300	
13	$0	$41,300	$0	$41,300	0.664	$27,400	
14	$0	$41,300	$0	$41,300	0.644	$26,600	
15	$0	$41,300	$9,000	$50,300	0.624	$31,400	Assumes QAPP/FSP revision, bid & contract lab.
16	$0	$41,300	$0	$41,300	0.604	$25,000	
17	$0	$41,300	$0	$41,300	0.585	$24,200	
18	$0	$41,300	$0	$41,300	0.567	$23,400	
19	$0	$41,300	$0	$41,300	0.550	$22,700	
20	$0	$41,300	$9,000	$50,300	0.533	$26,800	Assumes QAPP/FSP revision, bid & contract lab.
21	$0	$41,300	$0	$41,300	0.516	$21,300	
22	$0	$41,300	$0	$41,300	0.500	$20,700	
23	$0	$41,300	$0	$41,300	0.485	$20,000	
24	$0	$41,300	$0	$41,300	0.470	$19,400	
25	$0	$41,300	$9,000	$50,300	0.455	$22,900	Assumes QAPP/FSP revision, bid & contract lab.
26	$0	$41,300	$0	$41,300	0.441	$18,200	
27	$0	$41,300	$0	$41,300	0.427	$17,600	
28	$0	$41,300	$0	$41,300	0.414	$17,100	
29	$0	$41,300	$0	$41,300	0.401	$16,600	
30	$0	$41,300	$9,000	$50,300	0.389	$19,600	Assumes QAPP/FSP revision, bid & contract lab.
TOTALS		**$1,479,500**	**$54,000**	**$1,708,300**		**$1,210,300**	30 years

Detailed Cost Estimate - Alternative B - Repository VOC Source Area
Phytoremediation and Alternate Concentration Limits

Site: Crab Orchard National Wildlife Refuge
Location: Repository Area
Base Year: 2004
Phase: Feasibility Study Cost Estimate (-30% to +50%)
Date: 6/30/04

Description: This alternative consists of phytoremediation using cultivated cottonwood trees and a constructed prairie located in the areas near and between the Center Swale and the East Swale. Alternate Concentration Limits would also be developed for shallow groundwater quality evaluation.

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT CAPITAL COSTS						
Establishment of ACLs						
Data Review	1	LS	$5,000	$5,000		
ACL Development Submittal	1	LS	$20,000	$20,000		
Project Management	1	LS	$5,000	$5,000		
Subtotal					$30,000	
Phytoremediation						
Vendor Design Fees	1	LS	$25,000	$25,000		Based on vendor quotes.
Site Prep	1	LS	$5,000	$5,000		Based on vendor quotes.
Cottonwood Trees; Procure and Install	1	Acre	$15,000	$12,000		Assumes two 30' x 570' areas to be planted with cottonwoods. Approximately 1,000 trees.
Constructed Prairie Area Installation	4	Acre	$5,000	$20,000		Up to Level 3 prairie constructed (3 to 4 grasses assumed).
Monitoring Well Installation	100	VF	$70	$7,000		Assumes installation of 5 new wells, assumed average depth of 20 feet. Cost includes soil disposal and survey.
Subtotal					$69,000	
INDIRECT CAPITAL COSTS						
Phytoremediation						
Preliminary Design/Regulatory Approval	1	LS	$10,000	$10,000		Developing prelim design and working with agency for approval.
Final Design/Plans	1	LS	$10,000	$10,000		Incorporating agency comments and finalizing design and site plans.
Project Management	10%	LS	$69,000	$6,900		10% of direct capital costs.
Bidding & Contracting	5%	LS	$69,000	$3,450		5% of direct capital costs.
Construction Observation & Documentation	15%	LS	$69,000	$10,350		15% of direct capital costs.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Documentation Report	1	LS	$5,000	$5,000		
Subtotal					$46,700	
SUB-TOTAL					$145,700	
CONTINGENCY (20%)					$29,100	
TOTAL DIRECT AND INDIRECT COST WITH CONTINGENCY					$174,800	
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 1-5						Estimated annual operation, maintenance, and monitoring costs for initial 5 years.
Site Visits	4	Visit	$1,700	$6,800		Assumes quarterly inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
ACL Sampling	2	Event	$6,200	$12,400		Assumes semiannual sampling of 8 monitoring locations.
Analytical Testing	20	Sample	$250	$5,000		Assumes semiannual sampling of 5 monitoring wells and 3 surface water locations and 2 QA/QC samples
Phytoremediation Maintenance	4.2	Acre	$1,000	$4,200		Tree and prairie areas.
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	2	Report	$15,000	$30,000		Assumes semi-annual reporting.
O&M Contingency	20%	LS	-	$13,600		20% of O&M items.
Subtotal					$81,600	
PERIODIC COSTS						
Revise QAPP/FSP and bid/contract new laboratory	1	Each	$9,000	$9,000		Assumes QAPP/FSP revision and bid out & contract lab every 5 years starting in year 5.
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 6-10						Estimated annual operation, maintenance, and monitoring costs for second 5 years.
Site Visits	2	Visit	$1,700	$3,400		Assumes semiannual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
ACL Sampling	1	Event	$6,200	$6,200		Assumes semiannual sampling of 8 monitoring locations.
Analytical Testing	10	Sample	$250	$2,500		Assumes annual sampling of 5 monitoring wells and 3 surface water locations and 2 QA/QC samples
Phytoremediation Maintenance	4.2	Acre	$1,000	$4,200		
Administrative Costs	96	Hour	$100	$9,600		Assumes average labor rate and 8 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$8,180		20% of O&M items.
Subtotal					$49,100	
ANNUAL OPERATION, MAINTENANCE, & MONITORING COSTS - Years 11-30						Estimated annual operation, maintenance, and monitoring costs for years 11-30.
Site Visits	1	Visit	$1,700	$1,700		Assumes annual inspections. 2 hrs prep., 8 hrs on site, 4 hrs travel, 2 hrs report, $500 expenses.
ACL Sampling	1	Event	$6,200	$6,200		Assumes semiannual sampling of 8 monitoring locations.
Analytical Testing	10	Sample	$250	$2,500		Assumes annual sampling of 5 monitoring wells and 3 surface water locations and 2 QA/QC samples
Phytoremediation Maintenance	4.2	Acre	$1,000	$4,200		
Administrative Costs	48	Hour	$100	$4,800		Assumes average labor rate and 4 hours/month effort.
Reporting Costs	1	Report	$15,000	$15,000		Assumes annual reporting.
O&M Contingency	20%	LS	-	$6,880		20% of O&M items.
Subtotal					$41,300	

Appendix B
Documentation for Groundwater Flow and Contaminant Transport Models

Groundwater Flow and Transport Model Calibration Documentation

B.1 Conceptual Model of Groundwater Flow

The groundwater flow system has been described in detail in the Groundwater Investigation Report and Focused Feasibility Study – Revision 1, Section 4 (RMT, January 2000), and updated with additional investigation data in the Preliminary Design Report (RMT, May, 2001). The description of the groundwater flow system, summarized briefly here, is taken largely from Appendix K of the Groundwater Investigation Report and Focused Feasibility Study – Revision 1 (RMT, January 2000), hereafter referred to as the Groundwater Investigation Report. As shown on Figure B-1 (Cross Sections A and B), the uppermost geologic stratum is a silty clay layer that ranges in thickness from approximately 15 to 30 feet. Discontinuous lenses of sand were encountered occasionally when drilling through the Upper Clay unit. This Upper Clay unit is underlain by a permeable Upper Sand unit in most but not all areas of the site, that ranges in thickness from less than 1 foot to over 15 feet. The Upper Sand unit is not present beneath the Buildings I-1-2/I-1-3 source areas. Where present, the Upper Sand layer is underlain by a Lower Clay unit that is typically 15 to 20 feet thick, and a discontinuous Lower Sand unit that ranges in thickness from less than 1 foot to 15 feet or more. Sandstone bedrock lies beneath the Lower Sand unit, at depths ranging from approximately 30 to 80 feet below ground surface.

Tables B-1 and B-2 (previously Tables 4-4 and 4-5 from the Groundwater Investigation Report) present the range of values measured for hydraulic conductivity for the geologic strata at the site. The hydraulic conductivity values calculated from the pumping tests are more reliable, because the low permeability values from the slug test results are likely affected by coating of the sidewalls of the borehole with clay from the underlying strata. The pumping test results are in relatively close agreement; hydraulic conductivity estimates for the Upper Sand unit commonly are near 7×10^{-3} cm/s in the vicinity of Buildings I-1-23 and I-1-2.

The hydraulic conductivities of the Lower Clay and the Lower Sand units have been estimated using slug test results. On the basis of the substantial difference in hydraulic head between the Upper Sand and the Lower Sand units in many areas, it is clear that the Lower Clay unit acts as a confining unit. Based on slug test results, the geometric mean of hydraulic conductivity values for the Lower Clay unit is 2×10^{-6} cm/s. The geometric mean of the hydraulic conductivity values for the Lower Sand unit is 1.9×10^{-3} cm/s, based on slug test results. Given that some degree of borehole smearing is likely, and on the basis of the soil boring descriptions, the hydraulic conductivity of the Lower Sand is likely similar to that of the Upper Sand, i.e., approximately 7×10^{-3} cm/s.

The fact that hydraulic heads from the Upper Sand to the Lower Sand units typically differ by two to three feet (Table 4-6 Remedial Investigation and Focused Feasibility Study, Revision 1, RMT, 2000) demonstrates the effectiveness of the Lower Clay as a confining unit. With calculated hydraulic conductivities that average 2 x 10^{-6} cm/s, the hydraulic conductivity of the Lower Clay is more than 1,000 times lower than that of the Upper Sand unit. Soil analyses that were conducted on samples form borings collected from the I-1-2/I-1-3 source areas showed that high levels of VOCs reached the Lower Clay unit in several locations; however, concentrations near the base of the Lower Clay were typically far lower than those near the top of the unit, showing a marked attenuation within the confining unit. For example, a sample from boring SB-126 produced total VOC concentration of 150 mg/kg within the Lower Clay approximately 10 feet above the base, whereas a sample from the same boring near the base of the Lower Clay produced a VOC concentration of only 1.1 mg/kg. Further evidence of the effectiveness of the Lower Clay as a confining unit is seen in the I-1-23 area, where there is a general absence of TCE in the Lower Sand unit (which lies beneath the Lower Clay) despite concentrations of over 1,000 µg/L in the overlying Upper Sand unit over a wide area.

Hydraulic head distributions illustrated on Figures B-2 and B-3 show that shallow groundwater flow is generally toward Crab Orchard Lake and the swales and surface water discharge zones that occur over the site. The head distribution in the shallow groundwater is a muted image of the surface topography to a large degree, which is typical in near-surface, low permeability strata similar to the Upper Clay unit. Horizontal hydraulic gradients in the Upper Sand are commonly 0.003 to 0.006 ft/ft. Groundwater flow is primarily downward from the Upper Clay to the Upper Sand layer over much of the area, based on the measured heads in these units. However, groundwater gradients vary from upward to downward over the site, with downward gradients characterizing the upland areas (most of the site), and upward gradients typically occurring near the lake and surface water discharge zones (the swales and marsh areas). Vertical gradients vary widely, ranging up to 0.3 ft/ft.

Contaminant concentrations in the groundwater are shown on Figure B-4. The contaminants in the groundwater are dominated by chlorinated solvents, especially TCE, DCE, and PCE. Of these contaminants, TCE is present at the highest concentrations over most of the site. Contaminants occur mainly within the Upper Clay and the Upper Sand units; monitoring wells within the underlying Lower Clay and Lower Sand units generally show non-detectable concentrations.

The conceptual model for transport of contaminants at the site, presented in Section 8 of the Groundwater Investigation Report (RMT, 2000), is that dissolved contaminants migrate vertically downward from the source areas, through the Upper Clay into the Upper Sand unit. The high permeability of the Upper Sand unit relative to the Lower Clay unit results in flow that is primarily horizontal. Although there is a significant downward gradient from the Upper

Sand to the Lower Sand over much of the site, the low permeability of the Lower Clay confining unit restricts the downward flow of groundwater to the Lower Sand unit.

It appears that the permeable Upper Sand unit is the primary pathway for lateral contaminant migration in groundwater at the site. TCE and related compounds occur in groundwater plumes that extend up to 1,000 feet or more in the Upper Sand unit. The general absence of contaminants in the Lower Sand unit indicates that, despite the existence of relatively strong downward gradients over portions of the site, contaminants have not reached the Lower Sand. Although the process responsible for this attenuation has not been investigated in detail, the presence of daughter products of biodegradation of the chlorinated solvents within the upper strata indicates that biodegradation is likely occurring at the site, and is limiting the migration of contaminants into the Lower Clay and the Lower Sand units. Additional evidence of this biodegradation is presented in the following section on calibration of the contaminant transport model.

B.2 Model Setup

The model domain is illustrated on Figure B-5. The domain of the model includes all of the site and an additional area extending approximately 6,000 feet east, 4,000 feet west, 2,400 feet north, and 7,000 feet south of the site. The total model domain measures 15,000 feet (north-south) by 13,000 feet (east-west). The model domain was selected to extend away from the site so that model boundaries could be set at existing groundwater divides. The groundwater divides were assumed to be at roughly the same location as surface water divides; given the relatively thin, near-surface layers of geologic strata that are simulated, this assumption is justified. U.S. Geological Survey 7.5-minute topographic maps (Crab Orchard Lake and Marion Illinois quadrangles) were used to identify surface water divides.

The three-dimensional finite difference numerical groundwater flow model Modflow (McDonald and Harbaugh, 1988) was used to simulate the groundwater flow system. MT3D (Zheng, 1990) was used to simulate contaminant transport. Visual Modflow ver. 3.1.0.85 (Guigier and Franz, 2003) incorporated the latest versions of Modflow and MT3D along with a graphical user interface to integrate the flow and transport models. A grid of 127 x 113 x 6 with variable grid spacing ranging from 6 ft to 300 ft was constructed using a topographic map overlay of the site, to simulate the hydraulic conditions at the site (Figure B-6). For simulations of the PRB, the number of columns was increased and grid spacing was as small as 2 ft in the vicinity of the PRB. The five layers of the model represent the following hydrogeologic strata:

- Layer 1: Upper Portion of Upper Clay
- Layer 2: Lower Portion of Upper Clay
- Layer 3: Upper Sand
- Layer 4: Upper Portion of Lower Clay

- Layer 5: Lower Portion of Lower Clay
- Layer 6: Lower Sand

The Upper Clay unit was divided into two layers to more accurately simulate remedial alternatives in the relatively thick uppermost unit, where much of the remedial action may occur. The Lower Clay unit was divided into two layers to more accurately simulate contaminant transport in this unit because of the high concentration gradient between the Upper Sand and the Lower Clay units. Because of the general absence of contaminants in the Lower Sand unit, there was no need to extend the model deeper, and the base of the model was set at the base of the Lower Sand.

B.3 Boundary Conditions

The boundary conditions of the flow model were set to represent actual hydraulic boundaries at the site, based on available site data. Boundary conditions for the model are shown on Figure B-5. As shown on Cross Section A on Figure B-1, the Upper Sand unit thins and pinches out to the south and under Buildings I-1-2 and I-1-3; conversely, it thickens in the topographically low areas such as the swales (see Cross Sections A, B, C, and D on Figures B-1 and B-7). Based on these observations, it was estimated that the Upper Sand unit does not exist in the topographic high areas above an elevation of 430 feet. This assumption appears reasonable if the Upper Sand unit represents an outwash deposit from glacial meltwater, which would tend to be focused in the topographically low areas. No-flow boundaries were set at approximately the 430-foot contour to represent the limits of the Upper Sand.

No-flow boundaries were set in the Lower Sand to coincide with those in the Upper Sand; there are few data on the extent of the Lower Sand, but this assumption is reasonable given the likely similar glacial outwash origin of the Lower Sand. Because groundwater flow in low permeability clays tends to be largely vertical, the Upper and Lower Clay units were assigned no-flow boundaries at the same locations as those of the Upper Sand.

Constant-head nodes of 605 feet were assigned to the northern boundary of the model where Crab Orchard Lake exists (see Figure B-5).

Modflow RIVER nodes were assigned to two surface water bodies: Wolf Creek and an unnamed creek, both located west of the site (see Figure B-5). DRAIN nodes were assigned to more ephemeral surface water drainageways, such as the West Swale, the Center Swale, the East Swale, and to the Heron Flats area to the west of Highway 148. Because these surface water features generally represent discharge zones for groundwater, they are appropriate to simulate as drains in Modflow. Surface water elevations for the RIVER and DRAIN nodes were estimated from topographic map elevations. Conductance terms were adjusted during calibration to obtain an appropriate degree of influence of the swales and creeks on the groundwater heads.

Constant-concentration nodes were set in the transport model to represent the source areas (see Figures B-8 and B-9). The source areas around Buildings I-1-23 and I-1-2, and the Repository, have yielded groundwater samples with concentrations well over 10,000 µg/L of TCE. TCE at a concentration of 67,000 µg/L has been observed in groundwater at the site, and it is possible that higher concentrations would be revealed if densely spaced (although impractical) monitoring well networks were installed at the source areas. The persistence of VOC concentrations at this level measured at these locations, years after the release of contaminants ceased at the sites, indicates that residual TCE likely exists at these locations, dispersed as small ganglia and blebs within the aquifer sediments, representing a continuing source of contaminants to the groundwater. Initial attempts to calibrate the transport model without the presence of constant-concentration nodes (representing the source areas) failed to reproduce the persistent plumes of the lengths that have been observed at the site. For these reasons, constant-concentration nodes were set in the source areas at the upgradient end of the major groundwater contaminant plumes. Based on the iterative process of calibration of the model to measured concentrations in the plume, constant-concentration nodes were set at 20,000 µg/L TCE for the Upper Clay and Upper Sand units at the Building I-1-23 area and the Repository. For the Buildings I-1-2/I-1-3 source areas, constant-concentration nodes were set at 100,000 µg/L TCE in the Upper Clay, and 30,000 µg/L TCE in the upper portion of the Lower Clay. The Upper Sand unit is not present in the source areas at Buildings I-1-2/I-1-3.

These constant-concentration values were chosen based on adjustments made during calibration to reproduce the observed concentrations in the aquifer, and do not take into account removal of source materials during the PCB remedial action in 1996. It is possible that current plume concentrations at specific locations have decreased from higher values that might have been present prior to the PCB-impacted soil removal action. However, groundwater concentrations observed from the groundwater monitoring events since 1996 do not show a definitive decreasing trend. Therefore, the calibration of the transport model to measured values that exist in the aquifer is considered appropriate and representative of a system that is in quasi-equilibrium with the remaining source area TCE residuals. During predictive modeling and sensitivity testing, the effect of additional soil excavation to remove TCE source mass on source area concentrations is considered for a number of remedial alternatives. These changes in source area constant-concentration values are discussed in Section 7 of this report for the various remedial alternatives.

The length of time for the estimated mass of NAPL residuals to persist in the source zones was estimated for each of the remedial alternatives, and is presented in Tables B-4 and B-5. These estimated times were used to define the length of time that the constant-concentration nodes in the source zones were operative, during model simulations.

B.4 Model Parameters

Model parameter values were based on measured values from the site where available, or were estimated based on typical values reported in the literature for similar sites. Parameter values were adjusted during calibration to achieve the best match to measured head values. Some additional adjustment of the flow parameters was made during calibration of the transport model, to achieve a reasonable match to observed contaminant distributions as well. Table B-3 presents the model parameter values used for the five model layers in the calibrated model.

B.4.1 Hydraulic Conductivity

The hydraulic conductivity values of model layers 1 and 2 (the Upper Clay) were uniformly set at 2×10^{-4} cm/s over the model. The hydraulic conductivity of model layer 3 (the Upper Sand) for most of the model domain was initially set at the geometric mean of the measured values, 7×10^{-3} cm/s; however, it was adjusted upward to 1.4×10^{-2} cm/s during calibration of the flow and transport model, to more accurately reproduce the hydraulic head distribution, and the transport rate and size of the contaminant plume in the Upper Sand. This adjustment in hydraulic conductivity values for the Upper Sand is justified because hydraulic conductivity estimates from pumping test results are commonly only accurate to within a factor of two (+100 percent, -50 percent); further uncertainties arise from extrapolating estimates from a limited area to a broad area covered by the model. The assignment of a higher value of hydraulic conductivity resulted in a much better match of both hydraulic heads and contaminant plume concentrations. Hydraulic conductivity values for model layer 3 (equivalent to the Upper Sand over most of the model) were adjusted downward to 2×10^{-3} cm/s in the Buildings I-1-2/I-1-3 source areas, and 1×10^{-3} and 4×10^{-3} cm/s in the areas east and north of the Repository, where field measurements indicate that zones of lower hydraulic conductivity occur (see Figure B-10). For simplicity, the Upper Sand unit was simulated with two zones of hydraulic conductivity, although it is recognized that there is likely more heterogeneity (e.g., with sand lenses) than is simulated.

The horizontal hydraulic conductivity of the Lower Clay unit (model layers 4 and 5) was adjusted downward to 1×10^{-6} cm/s based on slug test results, boring logs descriptions, and on model calibration trials. The vertical hydraulic conductivities of model layers 4 and 5 were adjusted downward to 5×10^{-8} cm/s to create a strong vertical gradient in the model to match observed gradients, and to retard the movement of contaminants into the Lower Sand unit in the model.

B.4.2 Recharge

Groundwater recharge was set at 6 inches/year over the model domain, to create a representative head distribution. The value of 6 inches/year falls well within the range of values reported for sites with similar soil types and climate in the midwestern U.S.

(Walton, 1970), and is a common value for areas with sediments of moderate permeability.

B.4.3 Dispersion

A horizontal dispersivity value of 50 feet was used in most of the model, based on the scale of the model domain. A value of 10 ft was used for the Lower Clay unit (model layers 4 and 5) based on calibration to measured concentration values. The vertical dispersivity was assigned a value of 1 percent of the longitudinal dispersivity, or 0.5 feet, in all units except the Lower Clay, which was assigned a value of 0.1 ft. Dispersivity values were adjusted downward during sensitivity testing of the model, as discussed in Subsection B.6, which resulted in a poorer match to observed concentrations.

B.4.4 Sorption

Linear isotherm sorption is assumed in the transport model. The sorption of TCE and related compounds to aquifer solids is simulated by MT3D using a distribution coefficient (K_d) value, that is a product of the organic carbon distribution coefficient (K_{oc}) for TCE times the fraction of particulate organic carbon (f_{oc}) in the aquifer. A K_{oc} (organic carbon partitioning coefficient) value of 126 mL/g for TCE was based on literature values reported in Mabey (1982). A f_{oc} (fraction of organic carbon in soil) value of 0.003 was used, based on reported values for the site (IT Corp., 1995b). The resulting K_d (site-specific partitioning coefficient) value for TCE of 0.062 mL/g was assumed to be uniform for all five model layers, although the existing f_{oc} data are primarily from the Upper Clay and Upper Sand units.

B.4.5 Biodegradation

Biodegradation half-life constants were estimated based on reported values in the literature, and were adjusted during calibration of the transport portion of the model to best represent measured contaminant concentration values. Literature values for biodegradation half-lives for TCE generally range from approximately 0.3 to 3 years; however, some sites report very long half-life values over 10 years, and there are likely many sites that have not reported long half-life values, where biodegradation is so slow that it is difficult to quantify (Wiedemeier et al., 1998).

The biodegradation half-life values used for TCE in the calibrated transport model are 24 years for model layers 1 and 2, 2.4 years for model layer 3, and 1.5 years for model layers 4 and 5. Initial attempts at calibrating the model to uniform half-life values ranging from 2 years to 12 years showed that the contaminant plume would be attenuated far too quickly in the Upper Sand unit, such that it was impossible to reproduce a plume that resembled the observed plume. Conversely, the observed absence of contaminants in the Lower Sand unit required that the half-life values for the Lower Clay and the Lower Sand units must be sufficiently short (e.g., 1.5 years) to attenuate the plume before measurable levels of contaminants could build up in the lower geologic strata. If no dispersion occurred in the aquifer, the calculation of vertical groundwater velocities would indicate that the contaminants might not have had time to arrive at the Lower Clay and Lower Sand units; however, when dispersion is taken into account, the transport model indicates that relatively high concentrations would migrate into the deeper geologic strata at the site (which is not consistent with monitoring well results) unless biodegradation is occurring. The half-life value of 1.5 years for the Lower Clay and Lower Sand unit resulted in the best match of predicted concentrations to observed concentrations. Measured values of geochemical indicator species support the concept that conditions for biodegradation are more favorable for biodegradation in the Lower Clay and Lower Sand units than in the shallow groundwater. Dissolved oxygen, redox potential, and other geochemical indicator species indicate that mildly reducing to mildly oxidizing conditions occur in the shallow groundwater, with dissolved oxygen concentrations ranging generally between 0 and 1 mg/L in the plume. Under these conditions, and with limited organic carbon, conditions in the Upper Clay and Upper Sand units would likely be less than favorable for reductive dechlorination of TCE and daughter products. Sulfate concentrations above 100 mg/L in the shallow groundwater can also cause competitive exclusion of dechlorination through sulfate reduction reactions (Wiedemeier et al., 1998). Deeper groundwater tends to be depleted in dissolved oxygen and chemically reduced, creating more favorable conditions for reductive dechlorination. Further discussion of the biodegradation half-life values is presented in Subsection B.6.

B.5 Calibration

The flow model was calibrated to August 1998 groundwater elevations. This data set was chosen because it represented the most complete set of groundwater elevations (along with the December 1998 data) at the time of the initial model development, and because this period was judged to be more representative of typical hydraulic conditions than the December 1998 period. Figures B-2 and B-3 show the measured hydraulic head values for the water table (generally within the Upper Clay unit) and the Lower Sand unit. Comparison of equivalent hydraulic head maps for August and December 1998 indicates that, although the hydraulic heads change significantly from season to season, the magnitude and direction of the hydraulic gradients are similar.

Figures B-11 and B-12 show the calibrated model head distribution for the water table and the Lower Sand unit. A comparison of the model-derived head values to those measured during August 1998 shows a reasonably good fit of the model to the observed heads. Most of the model-generated contours agree with the measured points to within 1 foot, especially in the

Upper Clay and Upper Sand units (model layers 1, 2, and 3). The model-derived heads in the Lower Sand unit are generally within one to two feet of the measured values. Figure B-13 shows a graph of simulated hydraulic heads versus observed heads from on-site monitoring wells, from the August 1998 data set. As shown on the figure, the residual mean is 0.30 feet, with an absolute residual mean of 1.23 feet. The standard error of the estimate is 0.27 feet, the root-mean-squared is 1.48 feet, and the range is about 15 feet. The mass balance summary for groundwater flow is presented in Table B-3 and on Figure B-14. The inflow to the model is essentially entirely from recharge. Outflow is distributed among flow to the drains (swales and wetlands), river nodes (Wolf Creek), and flow to constant head nodes at Crab Orchard Lake. The mass balance between inflow and outflow to the model domain is good, with 0.0 percent discrepancy.

Using reasonable values of hydraulic parameters, the model has produced a hydraulic head distribution that is a reasonable match to measured hydraulic head values, and to the direction and magnitude of the hydraulic gradient, especially in the upper geologic strata where the contaminant migration occurs. For this reason, the flow model is considered to be calibrated sufficiently to test the remedial alternatives that are being considered.

The transport portion of the model was also calibrated to the existing contaminant plume concentrations. TCE was chosen as the representative contaminant for model calibration because TCE concentrations are generally the highest relative to existing drinking water standards, and because the distribution of the TCE plume is generally coincident with, and more extensive than, other contaminant distributions in the groundwater.

The TCE plume generated by the model for the Upper Sand unit is shown on Figures B-15 and B-16. A comparison of Figure B-15 to Figure B-4 shows that the extent and concentrations of the model-generated map are similar to those observed at the site, based on the data that are available, especially for the Building I-1-23 plume. The model also successfully simulates the absence of TCE in the Lower Sand unit. A mass balance summary, shown in Table B-3, shows that the constant concentration nodes in the source zone contribute essentially all of the contaminant mass to the model. The outflux of mass is distributed among biodegradation, constant concentration nodes, drains, mass storage, and constant head nodes. The mass balance between influx and outflux sources is good, with a discrepancy of 0.01 percent. Although the observed plume has some measured concentrations that are higher or lower than the model-predicted values, the extent, shape, and concentrations provide a reasonable approximation of the observed plume that is useful for the purpose of comparing the effectiveness of remedial alternatives. The results of these predictive simulations are presented in Section 7 of this report.

The calibrated model can be a useful tool for comparison, because it quantitatively estimates the extent of contaminants in the groundwater over time for each of the remedial alternatives.

However, because of the substantial uncertainties inherent in modeling remedial alternatives that have not been field-tested at the site, and the additional uncertainties regarding the quantity and distribution of VOC source material present in the identified source areas, caution should be exercised in using the model results. The results should be considered as a "semiquantitative" evaluation, and predicted concentrations should be considered more in a relative, rather than an absolute, sense.

B.6 Sensitivity Tests

Sensitivity testing was conducted to evaluate the sensitivity of the model results to variations in the value of key flow or transport parameters. The preliminary stages of sensitivity testing actually begin during the calibration process, when various parameters are varied within reasonable limits, to arrive at a model that closely matches observed conditions of hydraulic head and contaminant concentration. Formal sensitivity testing occurs after the model has been calibrated, where key parameters identified during the calibration process are varied, to test the effect of the change on the model results.

Table B-6 summarizes the results of the sensitivity testing. The results of the calibration run (Crab 629) are compared with those of six other simulations. In Crab 647, the rate of biodegradation was increased substantially in the Upper Clay and the Upper Sand units, by reducing the half-life of TCE from 24 years to 1.5 years. The resulting predicted TCE concentration in the Upper Sand unit at the Northern Access Road decreases from 3,522 µg/L in the calibration run to 875 µg/L in Crab 647. These results indicate that, since measured concentrations downgradient of the Northern Access Road range from approximately 1,000 to over 3,000 µg/L, the rate of biodegradation in the Upper Sand unit must be very low, similar to that of the calibration run (i.e., with a half-life of 24 years).

The opposite scenario, a decreased biodegradation rate, was tested in calibration run Crab 650. Here, the effect of decreasing the rate of biodegradation in the lower layers of the model (the Lower Clay and the Lower Sand units), from a half-life of 1.5 years to a half-life of 24 years, was simulated. With this slow rate of biodegradation in the lower geologic units, the maximum TCE concentration in the Upper Sand at the Northern Access Road increases to over 4,400 µg/L, which is higher than observed. More importantly, under this scenario, the concentration in the Lower Clay also increased to as high as several thousand µg/L, which far exceeds measured concentrations by orders of magnitude. These results indicate that very slow rates of biodegradation in the Lower Clay and Lower Sand result in unreasonably high predicted concentrations at depth.

The effect of removing constant-concentration source nodes from the model was simulated in calibration run Crab 651. Without a continuing source of mass into the aquifer, this simulation required initial conditions to be different from other sensitivity tests, that started with zero concentrations in the aquifer. In this simulation, the starting concentration was set equal to the calibrated model concentration. The model results indicate that, if there are no constant-concentration source nodes in the model, the plume concentrations would be far lower than those observed currently in the aquifer, with concentrations of less than 10 μg/L near the Northern Access Road instead of several thousand μg/L. These results illustrate that continuing sources of TCE are required in the model at the origins of the major plumes on-site, to reproduce the existing pattern of contaminants. As discussed earlier, it is likely that dispersed blebs and ganglia of TCE residuals are present in the subsurface, and represent a continuing source of TCE to the aquifer under current conditions.

The effect of decreasing the hydraulic conductivity of the Upper Sand was tested in calibration run Crab 648. The hydraulic conductivity value of the Upper Sand was decreased to half the value used in the calibrated model, to 7×10^{-2} cm/s. The results showed that the predicted maximum concentration of TCE would decrease somewhat, from over 3,500 to about 2,500 μg/L, at the Northern Access Road. The change in hydraulic conductivity directly affected head values in the Upper Sand unit, raising heads substantially (approximately 2 feet higher than in the calibrated model), and resulting in a worse match to measured heads.

The effect of a change in dispersivity values was tested in calibration runs Crab 649 and Crab 652. The horizontal and vertical dispersivity values (both longitudinal and transverse) were first decreased by a factor of 2.5. The resulting mass transport results indicate that the maximum concentration at the Northern Access Road would remain essentially unchanged if the dispersivity decreased; this is expected because, in the simulation of current conditions, the concentration in the core of the plume has reached essentially a steady-state condition, given a constant-concentration source. Similarly, at the fringe of the plume both laterally and vertically, predicted concentrations showed little sensitivity to dispersivity changes. An increase in dispersivity values, tested in run Crab 652, resulted in only a small change in concentrations in the plume, indicating that the model is relatively insensitive to the value of dispersivity.

B.7 Simulation of Building I-1-23 Remedial Alternatives

B.7.1 Alternative A1 – Excavation to 10 mg/kg VOC Contour, Long-Term or Short-Term Groundwater Extraction, and Phytoremediation

Alternative A1 involves excavation of source mass in the Upper Clay, groundwater extraction (short-term or long-term), and phytoremediation at the plume discharge zone near Crab Orchard Lake. The groundwater extraction component has three options: first, with a long-term duration of over 300 years (until the NAPL source is removed from all geologic units); second, with a pumping duration of 40 years; and third, with a pumping duration of 11 years (one year after NAPL is expected to be removed from the Upper Sand). The strategy and approach for estimating the length of time for NAPL source mass to persist in each source area is presented in Subsection 7.2 of this report.

The effect of excavation on source mass was incorporated by adjusting the length of time that the NAPL was estimated to persist in the various source areas, and in the different geologic units (layers) of the model. Table B-4 presents a summary of the mass of NAPL estimated to exist in the Building I-1-23 source area, and the estimated NAPL source mass removal for each remedial alternative.

As with all simulations, the presence of NAPL in the source zones was simulated with constant concentration nodes. As discussed in Subsection 7.2, concentrations are conservatively assumed to remain constant in a geologic unit in the source areas for as long as a portion of the NAPL source mass is present in that unit. In the simulation, the constant concentration nodes deliver mass to the through-flowing groundwater at a rate necessary to maintain a constant concentration in the groundwater in the source zone. Table B-7 presents setup parameters, including the length of time constant concentration nodes are held active in each geologic unit, for simulation of this alternative.

As with other simulations discussed below, the uptake of groundwater by the phytoremediation component of this remedial alternative was simulated with regularly-spaced extraction wells over the affected area. The extraction rate of each "well" is adjusted so that the combined rate is equal to typical rates of water and VOC uptake by plants from sites that have utilized this approach (estimated to be 15 inches per year for this site). The alternate concentration limits (ACL) component of this alternative would have no effect on the contaminant plume, and is not considered in the simulation.

The results of the simulation of the three variations of this alternative are presented and discussed in Subsection 7.3.1. Figures 7-2 and 7-3 show concentrations in the aquifer (Upper Sand unit) after 15 and 40 years of pumping, respectively. Figure 7-4 shows a plot of projected concentrations over time at a well located at the center of the plume near Crab Orchard Lake. Results for the simulation of 40 years of pumping and 30 years of rebound are presented on Figures 7-5 and 7-6. Results for the simulation of Alternative A-1 with pumping for 11 years are presented on Figures 7-7, 7-8, 7-9, and 7-10. The steady-state capture zone of the groundwater extraction well, pumping at a continuous rate of 10 gallons per minute, is shown on Figure B-17.

B.7.2 Alternative A2 – Excavation to 1 mg/kg VOC Contour, Short-Term Groundwater Extraction, and Phytoremediation

This simulation differs from Alternative A1 in that the excavation would be deeper (to near the base of the Upper Clay, if possible) and would extend out to the 1 mg/kg VOC contour. Pumping would continue for one year after the NAPL is expected to be removed from the Lower Sand unit, estimated to be a total of 11 years. As shown in Table B-4, an estimated 97% of NAPL mass would be removed from the Upper Clay by excavation. Based on current dissolved mass flux rates from the source area, it is estimated that NAPL residuals would be removed from the Lower Sand in approximately 10 years, and from the Upper Clay (after excavation) in approximately 14 years.

Phytoremediation at the West Swale is simulated with this alternative exactly as it was in Alternative A-1. ACLs do not affect the simulation of contaminant transport, and this component of the alternative was not simulated.

Table B-8 presents the setup parameters for this simulation. The results of this simulation are presented on Figures 7-11, 7-12, 7-13, and 7-14. The capture zone associated with this alternative is the same as with Alternative A-1, and is illustrated on Figure B-17.

B.7.3 Alternative B – Excavation to 10 mg/kg VOC Contour, Permeable Reactive Barrier, and Phytoremediation

This alternative involves soil excavation and phytoremediation similar to Alternative A-1, but with a permeable reactive barrier (PRB), and no groundwater extraction. The simulation setup is described in Table B-9, and the estimated time to remove residual NAPL following soil excavation is presented in Table B-4.

The PRB was simulated to be 700 feet long and 2 feet wide, and extending through the Upper Sand unit. The PRB was simulated with an enhanced rate of degradation for TCE, with a half life of 0.3 days. With the local groundwater velocity, this equates to a residence time of approximately 3 days for the plume within the PRB. Figure B-18 shows the location of the PRB at the Building I-1-23 area. The setup parameters for this simulation are shown in Table B-10.

Figures 7-15, 7-16, and 7-17 show the plume extent at 5, 15, and 50 years after this alternative was operational. Figure 7-18 indicates how the maximum concentration in groundwater at a point just south of Crab Orchard Lake is estimated to change over time in response to this remedial alternative.

B.7.4 Alternative C – Multi-phase Extraction with Pneumatic Fracturing, MPE/SVE in Upper Sand, Groundwater Extraction, and Phytoremediation

This alternative incorporates multi-phase extraction (MPE) of the Upper Clay and combined MPE and soil vapor extraction (SVE) in the Upper Sand unit after dewatering. The effects of MPE and SVE, with or without pneumatic fracturing, are incorporated in part by estimating the resulting effect on the NAPL source mass removal, and the effect on groundwater concentrations in the source area. These estimates are conducted external to the model, and serve as model inputs. The hydraulic effects of MPE are simulated directly with the model, using the DRAIN package of Modflow to simulate flow to the horizontal wells that would be part of this alternative. The DRAIN nodes (shown on Figure B-19) were activated for two years to draw the water levels into the Upper Sand unit. Figure B-20 shows the substantial depression of the water table in the vicinity of the horizontal wells at Building I-1-23. A comparison to the calibrated heads shown on Figure B-11 shows that the water table would be depressed by approximately 29 feet in the vicinity of the horizontal wells.

After two years of simulation, the horizontal wells were inactivated, and a vertical well, pumping at a 10 gpm rate, was activated. For the short-term pumping scenario, the vertical well was simulated for a period of three years after the horizontal wells were inactivated. This time was chosen to extend the pumping period for one year after the NAPL residuals were calculated to be removed from the Upper Sand. The simulation of the long-term pumping scenario extended the period of pumping to the entire length of the simulation, 50 years. The steady-state capture zone of the extraction well, operating at 10 gpm, is shown on Figure B-17. Phytoremediation is simulated as for the previous alternatives, with "wells" simulating the uptake of groundwater at low rates.

The setups for these two simulations are presented in Tables B-9 and B-10. Estimates of NAPL mass remaining and the time to remove the residual mass are presented in Table B-4, for both the long-term and short-term pumping scenarios.

Results from the simulation of this alternative are shown on Figures 7-19, 7-20, 7-21, and 7-22 for the long-term pumping scenario. This alternative with a short-term pumping scenario is presented on Figures 7-23 through 7-26.

B.7.5 Alternative D – Excavation to 10 mg/kg VOC Contour, Phytoremediation Including Engineered Wetland, and ACLs

This alternative was not simulated, as discussed in Subsection 7.3.5.

B.7.6 Alternative E – Phytoremediation Including Engineered Wetland and ACLs

This alternative was not simulated, as discussed in Subsection 7.3.6.

B.7.7 Alternative F – Excavation to 10 mg/kg VOC Contour, *In Situ* Reductive Dechlorination, Phytoremediation Including Engineered Wetland, and ACLs

This alternative is described in detail in Subsection 6.2.8. Subsection 7.3.7 presents the general approach and results of the simulation of this alternative. The amount of source mass removal by excavation in the Upper Clay is the same as with Alternative A1.

Additional source mass, especially in the Upper Sand, would be removed via reductive dechlorination, as presented in Table B-4. It is conservatively estimated that the effect of reductive dechlorination in the source area would be a 50% decrease in the source mass that remains after excavation, in both the Upper Clay and the Upper Sand units.

It was assumed that, following the injection of a substrate to enhance reductive dechlorination, the subsequent removal of source mass occurred instantaneously, although actual time for this process may be several months to a year or more. The injection of substrate into the zone of saturation would be accomplished through a number of injection points at such a low rate for a limited time that it would be insignificant hydrologically, and it is not simulated directly. As with other alternatives, the rate of removal of NAPL source mass was assumed to occur solely via the process of dissolution, and to occur at the current rate. Based on this rate and the estimated source mass remaining after treatment, a time of 12 years was estimated for the source mass to be removed from the Upper Sand, and over 300 years to be fully removed from the Upper Clay (see Table B-4).

As discussed in Subsection 7.3.7, it was assumed that there would be a 90% reduction in concentrations of TCE in the source area groundwater, and this is simulated with constant concentration nodes. Based on several literature studies of the effectiveness of *in situ* reductive dechlorination, a 90% reduction at the source is a reasonable estimate for the magnitude of the reduction in source zone VOC concentrations. Conservatively, it was assumed that only 50% of the NAPL mass would be removed by reductive dechlorination; the actual effectiveness of mass removal may be higher with this alternative. Because reductive dechlorination is a surface phenomenon, it tends to preferentially remove smaller dispersed blebs and ganglia of NAPL, which have a large surface area/mass ratio, versus the larger mass in larger blebs, ganglia, and pools that have a lower surface area/mass ratio. Smaller dispersed masses of NAPL in small blebs and ganglia experience a higher rate of dissolution, and thus contribute a disproportionately large amount to the dissolved plume. By preferentially removing the dispersed small blebs and ganglia, reductive dechlorination apparently has a large effect on source dissolved concentrations; this explains why source concentrations decrease substantially following initiation of enhanced reductive dechlorination treatment. Hence the assumption of a 90% decrease in the groundwater source concentration is justified, despite the relatively smaller (50%) estimated decrease in source mass, because it is the smaller dispersed masses of NAPL that contribute most to dissolved concentrations, that are preferentially removed (Pankow and Cherry, 1996).

As with other simulations discussed above, the uptake of groundwater by the phytoremediation component of this remedial alternative was simulated with regularly-spaced "extraction wells" over the affected area. The ACL component of this alternative would have no effect on the contaminant plume, and does not require simulation.

The results of the simulation of this alternative are discussed in Subsection 7.3.7, and are presented on Figures 7-27 through 7-30. As shown on Figure 7-30, if a smaller decrease in the concentrations than the estimated effectiveness results from the treatment, there could potentially be significantly higher concentrations in the downgradient plume than the simulated concentrations.

B.7.8 Alternative G – Electrical Resistive Heating (ERH) and Phytoremediation

This alternative is described in detail in Section 6, and involves removal of VOCs from the soil by heating and volatilization. The effect of ERH on NAPL residual mass in the source zone at Building I-1-23 was simulated by estimating, external to the model, the percentage of source mass that would be removed in the treatment zone, and then calculating how much time it would take to remove the remaining fraction from the soil. Based on reported experience at other sites and literature values, it was estimated that approximately 97% of the residual NAPL would be removed by ERH. Consistent with the approach used with the MPE and reductive dechlorination alternatives, it was assumed that the remaining fraction of NAPL source material would be dissolved from the Building I-1-23 source area at the same rate as it is currently, based on known concentrations and groundwater flowrates. It is estimated that, following ERH treatment, the remaining NAPL residuals would be removed from the Upper Sand after approximately 2.5 years, and from the Upper Clay unit after approximately 65 years (see Table B-4).

The model setup for this alternative is shown in Table B-12. Results of this simulation are shown on Figures 7-32, 7-33, 7-34, and 7-35. Figure 7-35 shows a sharp decrease in downgradient concentrations following treatment with ERH, based on the assumed substantial removal of source mass. A discussion of the modeling results is presented in Subsection 7.3.8.

B.8 Simulation of Buildings I-1-2/I-1-3 Remedial Alternatives

B.8.1 Alternative A – Limited Excavation and Multi-phase Extraction with Pneumatic Fracturing

This alternative involves limited excavation of a "hot spot" of source area soil combined with pneumatic fracturing in the Upper and Lower Clay units, and MPE in both the Upper Clay and the Lower Clay units. This alternative is described in detail in Subsection 6.3.2.

As discussed in Subsection 7.4.1, the model does not simulate the MPE wells directly, but rather takes account of the effect on the NAPL residual mass left after treatment with MPE, as well as the effect of excavation. As shown in Table B-5, it was estimated that the NAPL mass remaining in the source zones after treatment at Buildings I-1-2 and I-1-3 would be slightly less than one-half of the current mass. Based on current rates of dissolution of the residuals from the source zones, it was estimated that it would take approximately 49 years to remove these residuals from the Lower Clay unit at Building I-1-2, and 57 years to remove the NAPLs from the Upper Clay unit at Building I-1-3. Complete removal of NAPL residuals from the Upper Clay at Building I-1-2 and from the Lower Clay at Building I-1-3 is estimated to require up to 250 years.

The setup for simulation of this alternative is shown in Table B-13. Constant concentration nodes in the source area of Buildings I-1-2 and I-1-3 are used to simulate the NAPL residuals over the time periods as shown in the table. To account for the effect of MPE on concentration values in the source zones, an estimated reduction of 70% of the source zone concentrations was assumed, compared to constant concentration values that were used for the source zones in the model calibrated to current conditions. These constant concentration values are shown in Table B-13 for the Upper and Lower Clay units.

Results of the simulation of this alternative are discussed in Subsection 7.4.1, and are shown on Figures 7-36 to 7-40.

B.8.2 Alternative B – Permeable Reactive Barrier

The approach to simulating the PRB that comprises Alternative B for the source zones at Buildings I-1-2 and I-1-3 is similar to that discussed above for Building I-1-23 (Alternative B). The PRB would be installed into the more sandy portion of the clay unit, at a depth equivalent to the Upper Sand unit at Building I-1-23. This unit is simulated by Layer 3 in the model. The PRB would extend across width of the plume at points downgradient of, but near, the sources at Buildings I-1-2/I-1-3. The location of the PRB is shown on Figure 6-9. The degradation of TCE that would occur in the PRB is simulated with a reaction rate half-life of 0.3 days, the same as with the PRB at Building I-1-23. An increase in the hydraulic conductivity at the PRB is also simulated, reflecting the higher hydraulic conductivity of the sandy PRB material compared to that of the sandy clay.

Source area concentrations, represented by constant concentration nodes at the sources, would be unaffected by the presence of the PRB at a considerable distance from the source areas, due to location constraints. Consistent with the approach taken with other alternatives, the time to remove the existing NAPL residuals at Buildings I-1-2/I-1-3 is calculated based on the existing rate of dissolution and mass flux from the source areas. Table B-5 shows the calculated time to remove the NAPL residuals from the Upper and Lower Clay units. In the model, constant concentration nodes that are used to simulate the presence of NAPL residuals remain active for the duration of the time indicated in Table B-5. Concentrations at the source zones are assumed to remain at current levels until the NAPL residuals are completely removed; therefore, the values assigned to the constant TCE concentration nodes remain at 100,000 μg/L in the Upper Clay, and 30,000 μg/L in the Lower Clay, for the time that the NAPL residuals are calculated to exist at each location. This is a conservative assumption, but one that is consistent with the approach taken with other alternatives that do not treat the sources directly.

The results of the simulation of the PRB in Alternative B are shown on Figures 7-41 through 7-44. The results show a sharp attenuation of the plume as groundwater flows through the PRB, with concentrations approaching a steady-state condition downgradient after approximately 30 years. This simulation assumes that the PRB would be replaced or maintained as necessary if the performance begins to deteriorate. As shown on Figure 7-44, the concentrations downgradient could be higher if the PRB performance decreases over time, or lower than simulated if the source concentrations actually decrease over time as the NAPL residuals are removed.

B.8.3 Alternative C – Alternate Concentration Limits

This alternative, described in Subsection 6.3.4, does not involve any "active" measures that would change the condition of the plume or source areas. Therefore, this alternative was not simulated.

B.8.4 Alternative D – Excavation to 10 mg/kg VOC Contour and ACLs

This alternative, described in Subsection 6.3.5, involves partial source remediation through soil excavation to an estimated depth of 10 feet. However, residuals in the Lower Clay, and any residuals in the Upper Clay outside the limits of excavation, would remain and continue to contribute to the contaminant plume.

This alternative was not simulated because it is assumed (conservatively) that there would be no significant decrease in groundwater concentrations in the plume until essentially all of the NAPL residuals were removed from the source areas. This assumption is consistent with the approach taken with other alternatives with respect to the source areas.

B.8.5 Alternative E – Excavation to 10 mg/kg VOC Contour, *In Situ* Reductive Dechlorination, and Alternate Concentration Limits

The approach taken with this alternative is similar to that taken with Alternative E for the Building I-1-23 area. The effectiveness of removal of NAPL residuals in the source zones through excavation and enhanced reductive dechlorination has been estimated, and is shown in Table B-5. The time to remove the remaining NAPL residuals after excavation and treatment has been calculated and is also shown in Table B-5. Additional details on the time to remove NAPL residuals at Buildings I-1-2/I-1-3 are presented in the model setup shown in Table B-15.

A 90% reduction in TCE concentrations in the groundwater at the source zones is expected following treatment, based on case histories at other sites. The values of the constant concentration nodes were adjusted to reflect this 90% reduction in source concentrations, compared to current conditions.

Results from this simulation are presented on Figures 7-45 through 7-48. As shown on Figure 7-48, the simulated concentrations approach a substantially lower steady-state value within approximately 30 years. These concentrations would be expected to continue for decades until the NAPL residuals were fully removed from the source areas. As shown on Figure 7-48, there is a possibility that concentrations could be significantly higher if the treatment to enhance reductive dechlorination resulted in a smaller decrease in concentrations than expected. The possibility that the effectiveness of the treatment in reducing concentrations at the source would be greater than expected is also shown on Figure 7-48.

B.8.6 Alternative F – Electrical Resistive Heating

This alternative is described in detail in Section 6. As discussed above with Alternative G for Building I-1-23, the effect of ERH on NAPL residual mass in the source zone was simulated by estimating, external to the model, the percentage of source mass that would be removed in the treatment zone, and then calculating how much time it would take to remove the remaining fraction from the soil. It was estimated that approximately 97% of the residual NAPL in the source zones of Buildings I-1-2/I-1-3 would be removed by ERH. It was assumed that the remaining fraction of NAPL source material would be dissolved from the source areas at the current rate, based on known concentrations and groundwater flowrates. As shown in Table B-5, it is estimated that, following ERH treatment, the remaining NAPL residuals would be removed from the Upper Clay at Building I-1-3 after approximately 42 years, and from the Upper Clay at Building I-1-2 after approximately 82 years. The NAPL residuals were calculated to be removed from the Lower Clay after approximately 20 years and 48 years, respectively, at Buildings I-1-2 and I-1-3.

Constant concentration nodes were designated in the Upper Clay and Lower clay units to simulate the NAPL residuals over these time periods. It was estimated that the source zone TCE concentrations in groundwater would be reduced by 90% following ERH treatment, based on case studies at other sites. Accordingly, the constant TCE concentration nodes at the source areas were reduced in value by 90% compared to values calibrated to current conditions, to 10,000 µg/L in the Upper Clay, and to 3,000 µg/L in the Lower Clay unit.

The model setup for this alternative is shown in Table B-16. Initially, constant concentration nodes were designated for both the Upper Clay and Lower Clay. However, the initial results showed that the Lower Clay constant concentration nodes were acting as "sinks" rather than "sources," lowering the values in the groundwater to fit the assigned value. Therefore, the constant concentration nodes were removed from the final simulation, to more accurately simulate the migration of high concentrations from the shallow groundwater to the Lower Clay.

Results of this simulation are shown on Figures 7-49 through 7-54. A discussion of the modeling results for this alternative is presented in Subsection 7.4.6.

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Tables

Table B-1
Summary of Slug Test Results
Crab Orchard National Wildlife Refuge, PCBOU Sites 32/33
Marion, Illinois

WELL I.D.	GEOLOGIC UNIT	K (cm/s)(1)
32-63(2)	Upper clay	7.2 x 10^{-5}
32-109(2)	Upper clay	1.2 x 10^{-4}
33-341(2)	Upper clay	2.9 x 10^{-5}
33-342(2)	Upper clay	7.7 x 10^{-4}
33MWC-02(3)	Upper clay	3.9 X 10^{-5}
32-61(2)	Upper clay??	1.9 x 10^{-4}
32-62(2)	Upper clay??	1.6 x 10^{-5}
	GEOMETRIC MEAN =	8.1 x 10^{-5}
33MWC-21(4)	Upper sand	2.9 x 10^{-4}
33MWC-24(4)	Upper sand	7.1 x 10^{-4}
33MWC-27(4)	Upper sand	1.3 x 10^{-5}
33MWC-30(4)	Upper sand	4.4 x 10^{-3}
33MWC-33(4)	Upper sand	9.6 x 10^{-5}
33MWC-36(4)	Upper sand	4.5 x 10^{-5}
33MWC-39(4)	Upper sand	1.5 x 10^{-4}
	GEOMETRIC MEAN =	1.9 x 10^{-4}
33MWC-22(4)	Lower clay	1.1 x 10^{-6}
33MWC-28(4)	Lower clay	1.5 x 10^{-6}
33MWC-31(4)	Lower clay	5.0 x 10^{-6}
	GEOMETRIC MEAN =	2.0 x 10^{-6}
33MWC-23(4)	Lower sand	1.5 x 10^{-3}
33MWC-29(4)	Lower sand	9.4 x 10^{-4}
33MWC-32(4)	Lower sand	4.1 x 10^{-3}
33MWC-35(4)	Lower sand	6.3 x 10^{-6}
33MWC-41(4)	Lower sand	2.1 x 10^{-3}
	GEOMETRIC MEAN =	1.9 x 10^{-3}(5)

Notes:

(1) Reported hydraulic conductivity is geometric mean of available results.

(2) Hydraulic conductivity data taken from O'Brien and Gere RI report, July 1988.

(3) Hydraulic conductivity data taken from IT Corp. Final Supplemental Investigation Report, September 1995.

(4) Hydraulic conductivity data collected by FDGTI, summer 1998, analyzed by RMT, Inc.

(5) The geometric mean for the lower sand does not include data from 33MWC-35, as this well may be influenced by cement grout.

Table B-2
Summary of Aquifer Pumping Test Results
Crab Orchard National Wildlife Refuge, PCBOU Sites 32/33
Marion, Illinois

	TRANSMISSIVITY (ft^2/min)		STORATIVITY		K (cm/s)	
	THEIS	COOPER-JACOB	THEIS	COOPER-JACOB	THEIS	COOPER-JACOB
Building I-1-2						
EXT. WELL	2.0E-02	2.0E-02	NA	NA	7.8E-03	7.8E-03
MP-1	1.8E-02	2.3E-02	1.1E-03	8.7E-04	7.0E-03	9.0E-03
MP-2	2.0E-02	2.0E-02	1.0E-03	8.7E-04	7.7E-03	7.8E-03
MP-3	1.8E-02	1.8E-02	5.9E-04	5.9E-04	7.0E-03	7.0E-03
MP-4	1.6E-02	1.8E-02	5.0E-04	3.8E-04	6.4E-03	7.2E-03
				GEOM. MEAN	7.1E-03	7.7E-03
				VARIANCE	3.6E-07	6.3E-07
*Building I-1-23**						
MP-1	8.3E-02	1.0E-01	1.2E-02	8.6E-03	3.3E-03	4.0E-03
MP-2	1.9E-01	1.9E-01	5.7E-03	5.7E-03	7.5E-03	7.5E-03
MP-3	1.3E-01	8.9E-02	1.5E-02	1.5E-02	5.0E-03	3.6E-03
MP-4	1.8E-01	1.5E-01	4.6E-03	4.5E-03	7.4E-03	6.2E-03
				GEOM. MEAN	5.5E-03	5.1E-03
				VARIANCE	4.0E-06	3.5E-06
Area 9 Repository						
EXT. WELL	4.1E-04	4.2E-04	NA	NA	2.7E-05	2.8E-05
MP-1	9.7E-03	1.7E-02	6.8E-03	4.8E-03	6.5E-04	1.1E-03
MP-2	2.8E-03	3.7E-03	9.9E-03	6.0E-03	1.9E-04	2.5E-04
MP-3	1.5E-03	1.8E-03	8.4E-03	5.9E-03	9.7E-05	1.2E-04
MP-4	2.1E-03	2.6E-03	9.3E-03	6.3E-03	1.4E-04	1.7E-04
				GEOM. MEAN	1.4E-04	1.7E-04
				VARIANCE	6.1E-08	2.0E-07

Notes:

Data collected by FDGTI and analyzed by RMT.

NA = Not Applicable

* No available data for extraction well in Building I-1-23 area.

Table B-3
Model Parameters – Calibrated Model

	UPPER CLAY	UPPER SAND	LOWER CLAY	LOWER SAND
Model layer	1 &2	3	4 & 5	6
Hydraulic conductivity (horizontal) (cm/s)	2×10^{-4}	1.4×10^{-2}*	1×10^{-6}	7×10^{-3}
Hydraulic conductivity (vertical) (cm/s)	2×10^{-5}	7×10^{-4}	5×10^{-8}	7×10^{-4}
Recharge (in/yr)	6	--	--	--
Dispersivity – longitudinal horizontal (ft)	50	50	10	50
Dispersivity – transverse horizontal (ft)	5	5	1	5
Dispersivity – vertical (ft)	0.5	0.5	0.1	0.5
Distribution coefficient (mL/g)	0.062	0.062	0.062	0.062
Biodegradation half-life (years)	24	24	2.4 (layer 4) 1.5 (layer 5)	1.5

Note:

* Horizontal hydraulic conductivity values in two zones within the Upper Sand unit located beneath the Area 9 Repository are 1×10^{-3} cm/s and 4×10^{-3} cm/s, respectively. At the Buildings I-1-2/I-1-3 source areas, horizontal hydraulic conductivity values were adjusted downward in model Layer 3, to 2×10^{-3} cm/s, based on boring logs.

Mass Balance Summary - Flow Model Calibration Run

INFLOW (ft^3/d)		OUTFLOW (ft^3/d)	
Recharge	128,002	Drains	58,758
River leakage	96	River leakage	42,134
		Constant head	27,205
Total Inflow	**128,098**	**Total Outflow**	**128,098**
Percent Discrepancy	**0.0**		

Cumulative Mass Balance Summary - Transport Model Calibration Run

	INFLUX (Kg)	OUTFLUX (Kg)
Constant concentration	9,923	2,183
Constant head	0	606
Drains	0	1,333
Biodegradation	0	4,785
Mass storage (solute)	1.6	1,015
Mass storage (sorbed)	0	0.4
Total	**9,925**	**9,924**
Percent Discrepancy	**0.01**	

Table B-4
Estimate of TCE Mass Remaining/Time to Remove NAPL
Building I-1-23
Crab Orchard National Wildlife Refuge - PCBOU

Alternative	Unit	Estimated Total Mass at Source Area (lb)	Estimated Mass Within Excavation/ Treatment Area (lb)	Estimated Mass Removal Efficiency	Mass Removed By Remediation* (lb)	Percent of Mass in Unit Removed By Remediation (%)	Mass Remaining in Unit After Remediation* (lb)	NAPL Mass Remaining (lb)(1)	Percent of Mass Remaining in Unit* (%)	Percent of Total Mass in Source Area Remaining* (%)	Duration of Initial Short-term Action (yr)	Groundwater Source Mass Removal Rate (lb/day) (under pumping or non-pumping conditions)(2)(3)	Time to Remove NAPL Mass in Source (days)	Time to Remove NAPL Mass in Source (yrs)
A1 - **Excavate UC to 10 mg/kg Contour to 12 ft bgs** - Groundwater extraction in US - **long-term**	UC	3,278	772	100%	772	24%	2,506	2,401	76%	88%	0.1	0.0175	137,227	376
- Phytoremediation at West Swale	US	3,421	3,421	0%	0	0%	3,421	3,334	100%			0.921	3,620	10
A1 - **Excavate UC to 10 mg/kg Contour to 12 ft bgs** - Groundwater extraction in US - **short-term (11 yrs or less)**	UC	3,278	772	100%	772	24%	2,506	2,401	76%	88%	0.1	0.0133	180,526	494
- Phytoremediation at West Swale	US	3,421	3,421	0%	0	0%	3,421	3,334	100%			0.921	3,620	10
A2 - **Excavate UC to 1 mg/kg Contour to Top of US (if possible)** - Groundwater extraction in US - **short term (11 yrs or less)**	UC	3,278	3,180	100%	3,180	97%	98	87	3%	53%	0.2	0.0175	4,971	14
- Phytoremediation at West Swale	US	3,421	3,421	0%	0	0%	3,421	3,334	100%			0.921	3,620	10
B - **Excavate UC to 10 mg/kg Contour to 12 ft bgs** - Permeable Reactive Barrier across US	UC	3,278	772	100%	772	24%	2,506	2,401	76%	88%	0.1	0.0133	180,562	494
- Phytoremediation at West Swale	US	3,421	3,421	0%	0	0%	3,421	3,334	100%			0.363	9,186	25
C - **MPE w/ Pneumatic Fracturing in UC** - **MPE/SVE w/ dewatering in US**	UC	3,278	3,278	55%	1,803	55%	1,475	1,370	45%	45%	2	0.0175	78,304	214
- Groundwater extraction in US after MPE - **long-term** - Phytoremediation at West Swale	US	3,421	3,421	55%	1,882	55%	1,540	1,453	45%		2	0.921	1,577	4
C - **MPE w/ Pneumatic Fracturing in UC** - **MPE/SVE w/ dewatering in US**	UC	3,278	3,278	55%	1,803	55%	1,475	1,370	45%	45%	2	0.0133	103,008	282
- Groundwater extraction in US after MPE - **short-term (11 yrs or less)** - Phytoremediation at West Swale	US	3,421	3,421	55%	1,882	55%	1,539	1,452	45%		2	0.363	4,001	11
D - **Excavate UC to 10 mg/kg Contour to 12 ft bgs** - Phytoremediation at West Swale and bay of lake	UC	3,278	772	100%	772	24%	2,506	2,401	76%	88%	0.1	0.0133	180,562	494
	US	3,421	3,421	0%	0	0%	3,421	3,334	100%			0.363	9,186	25
E - **Phytoremediation at West Swale and bay of lake**	UC	3,278	3,278	0%	0	0%	3,278	3,173	100%	100%	0	0.0133	238,608	653
	US	3,421	3,421	0%	0	0%	3,421	3,334	100%		0	0.363	9,186	25
F **-Reductive Dechlorination** -Excavate UC to 10 mg/kg contour to 12 ft bgs	UC	3,278	3,278	50%(4)	2,025	62%(4)	1,253	1,213	38%	44%	5	0.0133	91,203	250
- Phytoremediation at West Swale and bay of lake	US	3,421	3,421	50%	1,710	50%	1,710	1,623	50%		5	0.363	4,563	12
G **-Electrical Resistive Heating (to 1 mg/kg contour)** -Phytoremediation at West Swale	UC	3,278	3,278	90%	2,950	90%	328	317	10%	10%	1	0.0133	23,835	65
	US	3,241	3,241	90%	3,079	90%	342	333	10%		1	0.363	917	2.5

Notes:

UC = Upper Clay unit.

US = Upper Sand unit.

* During initial short-term action at source area only. Does not include mass removal during long-term component of remedial action (groundwater extraction and treatment, PRB, phytoremediation, etc.).

Components of remedial alternatives in **bold type** are those to which the mass removal/remaining estimates apply for input to the groundwater model. Mass removal for components of remedial alternatives shown in non-bold type are calculated within the groundwater model.

1. Assumes total sorbed and dissolved mass in source area is 105 lb in the Upper Clay, and 87 lb in the Upper Sand unit.
2. NAPL mass removal rate is assumed to be constant over time, and equal to current conditions for non-continuous pumping scenarios.
3. NAPL mass removal rate is assumed to increase proportionately with groundwater flowrate as pumping occurs, based on estimates of residence time in the source area.
4. After removal of mass by excavation, a 50% removal effectiveness is estimated for reductive dechlorination.

Table B-5
Estimate of TCE Mass Remaining/Time to Remove NAPL
Buildings I-1-2/ I-1-3
Crab Orchard National Wildlife Refuge - PCBOU

Alternative	Unit	Estimated Total Mass at Source Area (lb)		TCE NAPL Mass Removed by Remediation*(1) (lb)		TCE Total Mass Remaining in Unit After Remediation* (lb)		TCE NAPL Mass Remaining (lb)		Groundwater Source Mass Removal Rate (lb/day) (under non-pumping conditions)(1)		Time to Remove TCE NAPL Mass in Source (days)		Time to Remove TCE NAPL Mass in Source (yrs)	
		I-1-2	I-1-3	I-1-2	I-1-3	I-1-2	I-1-3	I-1-2	I-1-3	I-1-2	I-1-3	I-1-2	I-1-3	I-1-2	I-1-3
A **- Limited Excavation and Multiphase Extraction, with Pneumatic Fracturing in Upper and Lower Clay**	Upper Clay	4,141	2,196	2,278	1,208	1,863	988	1,700	827	0.0186	0.0396	91,398	20,884	250	57
	Lower Clay	2,302	8,241	1,266	4,532	1,036	3,709	876	3,607	0.0492	0.072	17,805	50,097	49	137
B **- Permeable Reactive Barrier**	Upper Clay	4,141	2,196	0	0	4,141	2,196	3,979	2,035	0.0186	0.0396	213,925	51,389	586	141
	Lower Clay	2,302	8,241	0	0	2,302	8,241	2,142	8,139	0.0492	0.072	43,537	113,042	119	309
C **- Alternate Concentration Limits only (no active remediation component)**	Upper Clay	4,141	2,196	0	0	4,141	2,196	3,979	2,035	0.0186	0.0396	213,925	51,389	586	141
	Lower Clay	2,302	8,241	0	0	2,302	8,241	2,142	8,139	0.0492	0.072	43,537	113,041	119	309
D **- Excavate Upper Clay to 10 mg/kg Contour and Alternate Concentration Limits**	Upper Clay	4,141	2,196	1,592	1,526	2,549	670	2,387	509	0.0186	0.0396	128,333	12,853	351	35
	Lower Clay	2,302	8,241	0	0	2,302	8,241	2,142	8,139	0.0492	0.072	43,537	113,041	119	309
E **- Excavate Upper Clay to 10 mg/kg Contour and Reductive Dechlorination with Pneumatic Fracturing(2)**	Upper Clay	4,141	2,196	2,867	1,861	1,274	331	1,194	254	0.0186	0.0396	64,167	6,414	176	18
	Lower Clay	2,302	8,241	1,151	4,121	1,151	4,121	1,070	4,069	0.0492	0.072	21,768	56,514	60	155
F **- Electrical Resistive Heating (to 10 mg/kg contour)**	Upper Clay	4,141	2,196	3,585	1,908	556	288	398	204	0.0186	0.0396	21,398	5,151	59	14
	Lower Clay	2,302	8,241	1,932	7,374	370	867	214	814	0.0492	0.072	4,350	11,305	12	31

Note:

* During initial short-term action at source area only. Does not include mass removal during long-term component of remedial action (groundwater extraction and treatment, PRB, phytoremediation, etc.).

Components of remedial alternatives in **bold type** are those to which the mass removal/remaining estimates apply for input to the groundwater model. Mass removal for components of remedial alternatives shown in non-bold type are calculated within the groundwater model.

1. NAPL mass removal rate by solution into groundwater is assumed to be constant over time, and equal to current conditions.
2. After removal of mass by excavation, a 50% removal effectiveness is estimated for reductive dechlorination.

Table B-6
Sensitivity Analysis

RUN #			RESULTS
CURRENT CONDITIONS SIMULATIONS	PARAMETER/ BOUNDARY CONDITION	CHANGE	MAX. TCE CONC. AT NORTHERN ACCESS ROAD, IN UPPER SAND (µg/L)
Crab 629 (calibration)	--	--	3,522
Crab 647	Biodegradation half-life	Reduce from 24 yr. to 1.5 yr. in Upper Clay and Upper Sand	875
Crab 651	Constant-concentration source nodes	Remove	6
Crab 648	Hydraulic conductivity of Upper Sand unit	Decrease, from 1.4×10^{-2} to 7×10^{-3} cm/s	2,561
Crab 649	Dispersivity	α_{L}, from 50′ to 20′ α_{TH} from 5′ to 2′ α_{TV} from 0.5′ to 0.2′	3,585
Crab 652	Dispersivity	α_{L}, from 50′ to 125′ α_{TH} from 5′ to 12.5′ α_{TV} from 0.5′ to 1.25′	3,559
Crab 650	Biodegradation half-life	Increase from 1.5 yr. to 24 yr. in Lower Clay and Lower Sand	4,423

Notes:

α_{L} = longitudinal dispersivity.

α_{TH} = transverse, horizontal dispersivity.

α_{TV} = transverse, vertical dispersivity.

For Crab 651 (constant concentration nodes removed), the initial concentration was set to the value of current conditions in the calibrated model, and the simulation was run to project conditions after a period of 30 years.

Table B-6a
Model Run Summary - Alternative A1 at Building I-1-23 - Excavation, Long-Term Groundwater Extraction, Phytoremediation
Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Pumping Rate @ RW-1 (gpm)	Description	Constant Conc. Values in Upper Clay (ug/L)	Constant Conc. Values in Upper Sand (ug/L)	Phyto. Simulated with Wells
643	0	3,620	3,620	9.9	10	Constant concentrations in upper sand and lower portion of Upper Clay	20,000	20,000	Yes
643B	3,620	14,600	10,980	40.0	10	Constant concentrations in lower portion of Upper Clay only	20,000	None	Yes
	14,600	137,227	122,627	376.0	10	Constant concentrations in lower portion of Upper Clay only, with pumping for 40 years. Not simulated - source concentrations are at steady-state after 40 years, and continue until source mass is removed in Upper Clay (376 yrs.)	20,000	None	Yes

Table B-6b

Model Run Summary - Alternative A1 at Building I-1-23 - Excavation, Short-Term (11 Years) Groundwater Extraction, Phytoremediation

Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Pumping Rate @ RW-1 (gpm)	Description	Constant Conc. Values in Upper Clay (ug/L)	Constant Conc. Values in Upper Sand (ug/L)	Phyto. Simulated with Wells
633	0	3,620	3,620	9.9	10	Constant concentrations in Upper Sand and lower portion of Upper Clay	20,000	20,000	Yes
633B	3,620	3,985	10,980	10.9	10	Constant concentrations in lower portion of Upper Clay only	20,000	None	Yes
633C	3,985	17,805	13,820	48.8	0	Constant concentrations in lower portion of Upper Clay only, with no pumping.	20,000	None	Yes

Table B-7
Model Run Summary - Alternative A1 at Building I-1-23 - Excavation, 40 years for Groundwater Extraction
Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Pumping Rate @ RW-1 (gpm)	Description	Constant Conc. Values in Upper Clay (ug/L)	Constant Conc. Values in Upper Sand (ug/L)	Phyto. Simulated with Wells
643	0	3,620	3,620	9.9	10	Constant concentrations in Upper Sand and lower portion of Upper Clay	20,000	20,000	Yes
643B	3,620	14,600	10,980	40.0	10	Constant concentrations in lower portion of Upper Clay only	20,000	None	Yes
643C	14,600	25,550	10,950	70.0	0	Constant concentrations in lower portion of Upper Clay only, with no pumping	20,000	None	Yes

Table B-8
Model Run Summary - Alternative A2 at Building I-1-23 - Excavation, Short-Term Groundwater Extraction, Phytoremediation
Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Pumping Rate @ RW-1 (gpm)	Description	Constant Conc. Values in Upper Clay (ug/L)	Constant Conc. Values in Upper Sand (ug/L)	Phyto. Simulated with Wells
643A2	0	3,620	3,620	9.9	10	Constant concentrations in Upper Sand and lower portion of Upper Clay	20,000	20,000	Yes
643A2-B	3,620	3,985	365	10.9	10	Constant concentrations in lower portion of Upper Clay only	20,000	None	Yes
643A2-C	3,985	4,971	986	13.6	0	Constant concentrations in lower portion of Upper Clay only, with no pumping	20,000	None	Yes
643A2-D	4,971	18,250	13,279	50	0	No constant concentrations	None	None	Yes

Table B-9

Model Run Summary - Alternative B at Building I-1-23 - Excavation, PRB, Phytoremediation

Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Pumping Rate @ RW-1 (gpm)	Description	Constant Conc. Values in Upper Clay (ug/L)	Constant Conc. Values in Upper Sand (ug/L)	Phyto. Simulated with Wells
642	0	9,125	9,125	25.0	0	Constant concentrations in Upper Sand and lower portion of Upper Clay	20,000	20,000	Yes
642B	9,125	30,615	21,490	83.9	0	Constant concentrations in lower portion of Upper Clay only	20,000	None	Yes

Table B-10a

Model Run Summary - Alternative C at Building I-1-23 - Multiphase Extraction Followed by Long-Term Groundwater Extraction, and Phytoremediation

Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Pumping at horizontal wells?	Pumping Rate @ RW-1 (gpm)	Description	Constant Conc. Values in Upper Clay (ug/L)	Constant Conc. Values in Upper Sand (ug/L)	Phyto. Simulated with Wells
646	0	730	730	2.0	Yes (80 gpm)	0	Constant concentrations in Upper Sand and Upper Clay	6,000	6,000	Yes
646B	730	1,577	847	4.3	No	10	Constant concentrations in Upper Clay	6,000	6,000	Yes
646C	1,577	1,942	365	5.3	No	10	Constant concentrations in Upper Clay	6,000	None	Yes
644D	1,942	17,805	15,863	48.8	No	10	Constant concentrations in Upper Clay	6,000	None	Yes

Table B-10b

Model Run Summary - Alternative C at Building I-1-23 - Multiphase Extraction Followed by Short-Term Groundwater Extraction, and Phytoremediation

Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Pumping at horizontal wells?	Pumping Rate @ RW-1 (gpm)	Description	Constant Conc. Values in Upper Clay (ug/L)	Constant Conc. Values in Upper Sand (ug/L)	Phyto. Simulated with Wells
646	0	730	730	2.0	Yes (80 gpm)	0	Constant concentrations in Upper Sand and Upper Clay	6,000	6,000	Yes
646B	730	1,577	847	4.3	No	10	Constant concentrations in Upper Clay	6,000	6,000	Yes
646C	1,577	1,942	365	5.3	No	10	Constant concentrations in Upper Clay	6,000	None	Yes
646D	1,942	17,805	15,863	48.8	No	0	Constant concentrations in Upper Clay	6,000	None	Yes

Table B-11

Model Run Summary - Alternative F at Building I-1-23 - Excavation, Reductive Dechlorination, Phytoremediation

Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Description	Constant Conc. Values in Upper Clay (ug/L)	Constant Conc. Values in Upper Sand (ug/L)	Phyto. Simulated with Wells
645	0	4,563	4,563	12.5	Constant concentrations in Upper Sand and Upper Clay	2,000	2,000	Yes
645B, 645C	4,563	21,768	17,205	59.6	Constant concentrations in Upper Clay	2,000	None	Yes
645D-645F	21,768	91,203	69,435	249.9	Constant concentrations in Upper Clay	2,000	None	Yes
645G	91,203	102,153	10,950	279.9	No constant concentration nodes	None	None	Yes

Table B-12
Model Run Summary - Alternative G at Building I-1-23 - ERH and Phytoremediation
Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Description	Constant Conc. Values in Upper Clay (ug/L)	Constant Conc. Values in Upper Sand (ug/L)	Phytoremediation Simulated With Wells
648A	0	917	917	2.5	Constant concentrations in Upper Clay and Upper Sand	2,000	2,000	Yes
648B	917	23,835	22,918	65.3	Turn off constant concentrations in Upper Sand	2,000	None	Yes
648C	23,835	54,750	30,915	150.0	Turn off constant concentrations in Upper Clay	None	None	Yes

Table B-13

Model Run Summary - Alternative A at Buildings I-1-2/I-1-3 - Limited Excavation and MPE

Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Description	Constant Conc. Values at I-1-2 in Upper Clay (ug/L)	Constant Conc. Values at I-1-3 in Upper Clay (ug/L)	Constant Conc. Values at I-1-2 in Lower Clay (ug/L)	Constant Conc. Values at I-1-3 in Lower Clay (ug/L)
646A-D	0	17,805	17,805	48.8	Constant concentrations in Upper and Lower Clay	30,000	30,000	9,000	9,000
646E	17,805	20,884	3,079	57.2	Remove constant concentrations in Lower Clay at I-1-2	30,000	30,000	None	9,000
646F	20,884	50,097	29,213	137.3	Remove constant concentrations in Upper Clay at I-1-3	30,000	None	None	9,000

Table B-14
Model Run Summary - Alternative B at Buildings I-1-2/I-1-3 - Permeable Reactive Barrier
Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Description	Constant Conc. Values at I-1-2 in Upper Clay (ug/L)	Constant Conc. Values at I-1-3 in Upper Clay (ug/L)	Constant Conc. Values at I-1-2 in Lower Clay (ug/L)	Constant Conc. Values at I-1-3 in Lower Clay (ug/L)
635A-B	0	43,537	43,537	119.3	Constant concentrations in Upper and Lower Clay at I-1-2 and I-1-3	100,000	100,000	30,000	30,000
635C	43,537	51,389	7,852	140.8	Remove constant concentrations in Lower Clay at I-1-2	100,000	100,000	None	30,000
635D	51,389	113,042	61,653	309.7	Remove constant concentrations in Upper Clay at I-1-3	100,000	None	None	30,000
635E	113,042	149,579	36,537	409.8	Remove constant concentrations in Lower Clay at I-1-3	100,000	None	None	None
635F	149,579	213,924	64,345	586.1	Remove constant concentrations in Upper Clay at I-1-2	None	None	None	None

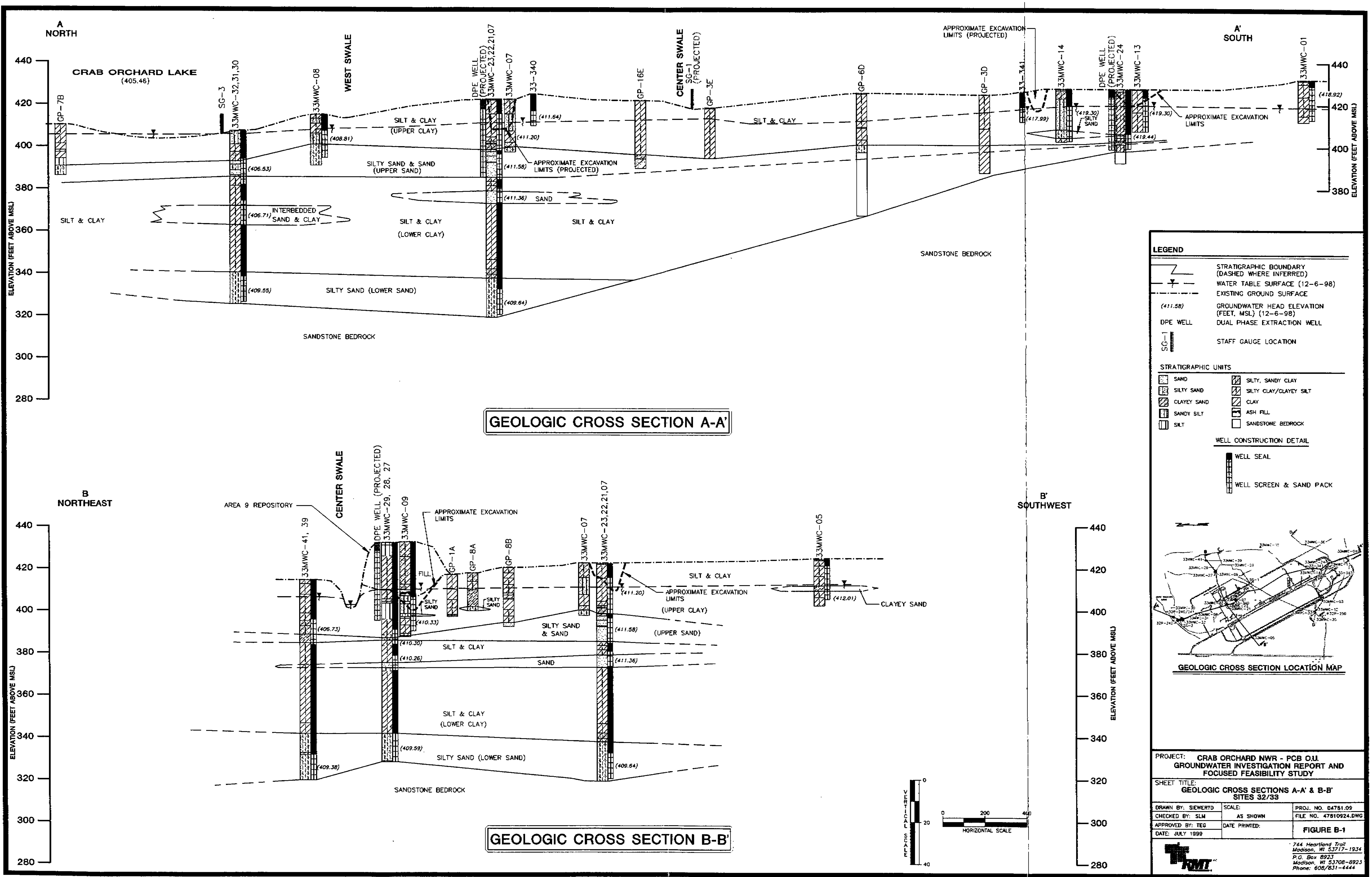
Table B-15
Model Run Summary - Alternative E at Buildings I-1-2/I-1-3 - Excavation and Reductive Dechlorination
Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Description	Constant Conc. Values at I-1-2 in Upper Clay (ug/L)	Constant Conc. Values at I-1-3 in Upper Clay (ug/L)	Constant Conc. Values at I-1-2 in Lower Clay (ug/L)	Constant Conc. Values at I-1-3 in Lower Clay (ug/L)
645A,645B	0	6,426	6,426	17.6	Constant concentrations in Upper and Lower Clay at I-1-2 and I-1-3	10,000	10,000	3,000	3,000
645C	6,426	21,768	15,342	59.6	Remove constant concentrations in Upper Clay at I-1-3	10,000	None	3,000	3,000
645D	21,768	56,520	34,752	154.8	Remove constant concentrations in Lower Clay at I-1-2	10,000	None	None	3,000
645E	56,520	64,167	7,647	175.8	Remove constant concentrations in Lower Clay at I-1-3	10,000	None	None	None
645F	64,167	91,203	27,036	249.9	Remove constant concentrations in Upper Clay at I-1-2	None	None	None	None

Table B-16
Model Run Summary - Alternative F at Buildings I-1-2/I-1-3 - ERH
Crab Orchard National Wildlife Refuge

Model Run	Start Time (days)	Stop Time (days)	Stress Period time (days)	Elapsed Time (years)	Description	Constant Conc. Values at I-1-2 in Upper Clay (ug/L)	Constant Conc. Values at I-1-3 in Upper Clay (ug/L)	Constant Conc. Values at I-1-2 in Lower Clay (ug/L)	Constant Conc. Values at I-1-3 in Lower Clay (ug/L)
649A	0	4,350	4,350	12	Constant concentrations in Upper Clay only	10,000	10,000	None	None
649B	4,350	21,398	17,048	59	Turn off constant concentrations in Upper Clay @ I-1-3	10,000	None	None	None
649C	17,048	47,963	30,915	131	Turn off constant concentrations in Upper Clay @ I-1-2	None	None	None	None

Figures



GEOLOGIC CROSS SECTION A-A'

GEOLOGIC CROSS SECTION B-B'

LEGEND

STRATIGRAPHIC BOUNDARY (DASHED WHERE INFERRED)
WATER TABLE SURFACE (12-6-98)
EXISTING GROUND SURFACE
(411.58) GROUNDWATER HEAD ELEVATION (FEET, MSL) (12-6-98)
DPE WELL DUAL PHASE EXTRACTION WELL
SG-1 STAFF GAUGE LOCATION

STRATIGRAPHIC UNITS

▨	SAND	▨	SILTY, SANDY CLAY
▨	SILTY SAND	▨	SILTY CLAY/CLAYEY SILT
▨	CLAYEY SAND	▨	CLAY
▨	SANDY SILT	▨	ASH FILL
▨	SILT	☐	SANDSTONE BEDROCK

WELL CONSTRUCTION DETAIL

■ WELL SEAL
▨ WELL SCREEN & SAND PACK

PROJECT: **CRAB ORCHARD NWR - PCB O.U. GROUNDWATER INVESTIGATION REPORT AND FOCUSED FEASIBILITY STUDY**

SHEET TITLE: **GEOLOGIC CROSS SECTIONS A-A' & B-B' SITES 32/33**

DRAWN BY: SIEWERTD	SCALE: AS SHOWN	PROJ. NO. 04781.09
CHECKED BY: SLM		FILE NO. 47810924.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE B-1
DATE: JULY 1999		

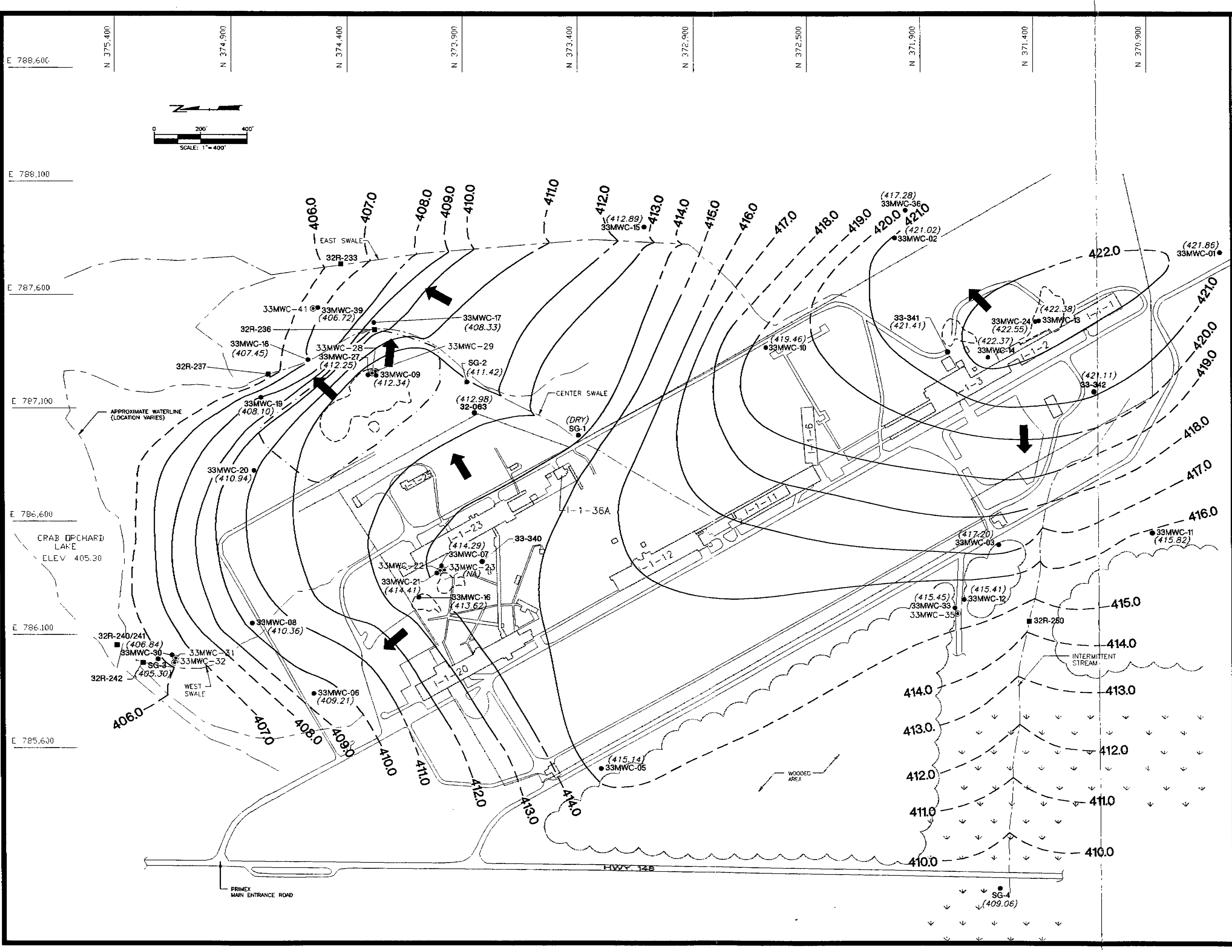
RMT

744 Heartland Trail
Madison, WI 53717-1934
P.O. Box 8923
Madison, WI 53708-8923
Phone: 608/831-4444

RMT COMPUTER AIDED DESIGN & DRAFTING

Operator Name: siewertd
Scale: 1"=200'
Dwg Size: 2179947 Bytes
Plot Date: Monday, August
Plot Time: 1:05:35 PM
Attached Xref's: No xref's attached.

RMT COMPUTER AIDED DESIGN & DRAFTING



LEGEND

● 33MWC-30	SHALLOW MONITORING WELL
◉ 33MWC-22	PIEZOMETER
● SG-4	STAFF GAUGE
■ 32R-242	SURFACE WATER SAMPLING LOCATION
— - —	APPROXIMATE CENTERLINE OF SURFACE DRAINAGE CHANNEL/SWALE
——	FENCE
- - - -	APPROXIMATE LIMITS OF SOIL EXCAVATION
— · —	APPROXIMATE FOOTPRINT OF AREA 9 REPOSITORY
(421.86)	WATER ELEVATION (FT. AMSL)
421.0 ——	GROUNDWATER ELEVATION CONTOUR (1.0 FT. INCREMENT) (DASHED WHERE INFERRED)
➡	DIRECTION OF GROUNDWATER FLOW
▨	MARSH/WETLAND
⌒⌒	APPROXIMATE LOCATION OF WOODED AREAS WEST OF SITE 32/33

NOTES

1. SOURCE: BASE MAP FROM "1998 TCE INVESTIGATION, WORKPLAN AND PILOT STUDY FOR THE PCB OPERABLE UNIT AT THE CRAB ORCHARD NATIONAL WILDLIFE REFUGE SUPERFUND SITE, MARION, ILLINOIS" REV. 1, MAY 1998, PREPARED BY FLUOR DANIEL GTI.
2. APPROXIMATE EXTENT OF MARSH/WETLANDS ESTIMATED FROM SITE TOPOGRAPHIC MAP.

PROJECT: CRAB ORCHARD NWR - PCB O.U.
GROUNDWATER INVESTIGATION REPORT AND
FOCUSED FEASIBILITY STUDY

SHEET TITLE:
WATER TABLE MAP - AUGUST 1998
SITES 32/33

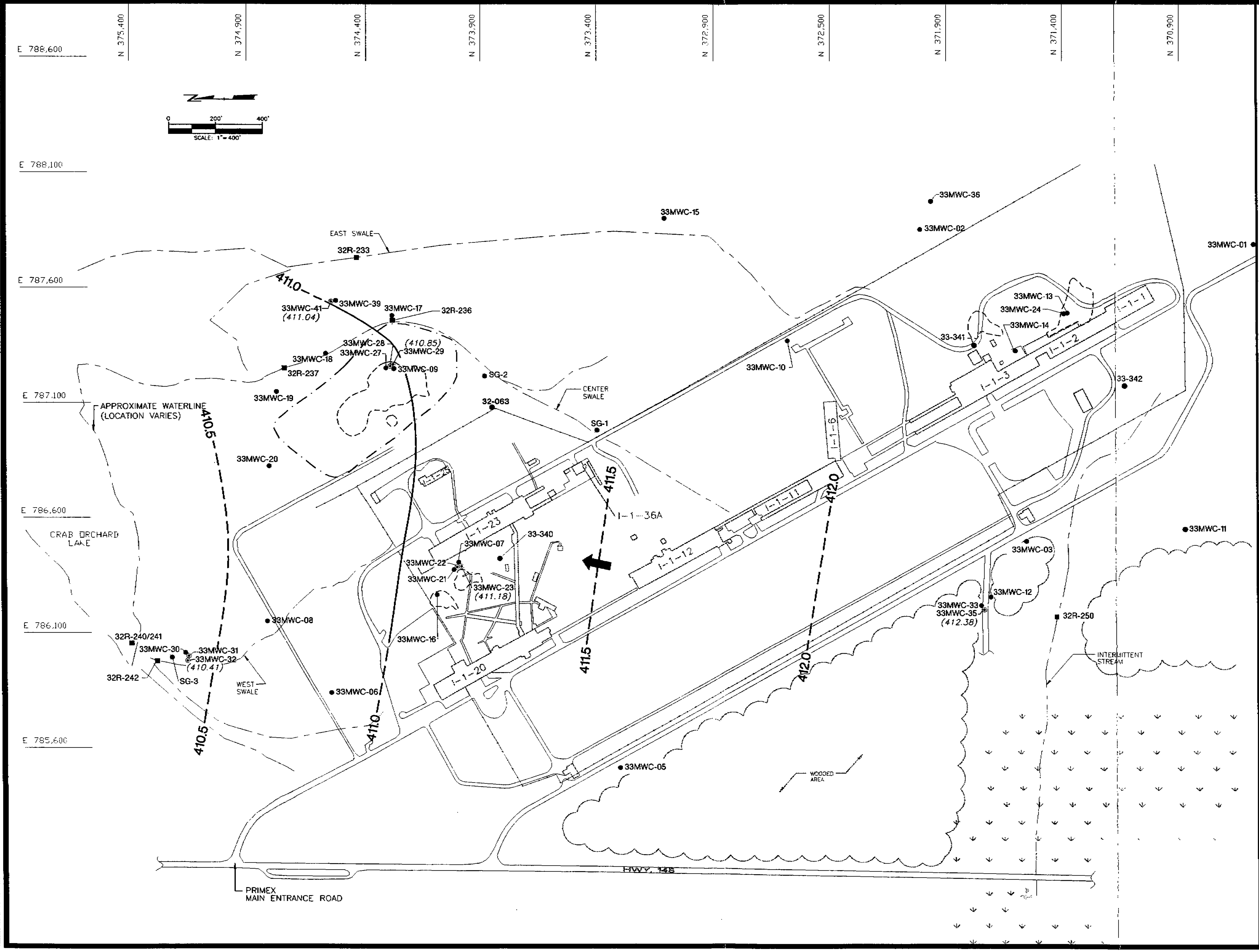
DRAWN BY: SIEWERTD	SCALE: 1"=400'	PROJ. NO. 04781.09
CHECKED BY: SLM		FILE NO. 47810922.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE B-2
DATE: JULY 1999		

RMT

744 Heartland Trail
Madison, WI 53717-1934

P.O. Box 8923
Madison, WI 53708-8923
Phone: 608/831-4444

Operator Name: siewertd
Scale: 1"=200'
Dwg Size: 633668 Bytes
Plot Date: Monday, August 4,
Plot Time: 12:57:32 PM
Attached Xref's: No xref's attached.



LEGEND

● 33MWC-30	SHALLOW MONITORING WELL
◉ 33MWC-22	PIEZOMETER
● SG-4	STAFF GAUGE
■ 32R-242	SURFACE WATER SAMPLING LOCATION
— - —	APPROXIMATE CENTERLINE OF SURFACE DRAINAGE CHANNEL/SWALE
———	FENCE
- - - - - -	APPROXIMATE LIMITS OF SOIL EXCAVATION
— · — · —	APPROXIMATE FOOTPRINT OF AREA 9 REPOSITORY
(412.38)	WATER LEVEL ELEVATION (FT. AMSL)
412.0 ———	POTENTIOMETRIC SURFACE CONTOUR (0.5 FT. INTERVAL) (DASHED WHERE INFERRED)
➡	DIRECTION OF GROUNDWATER FLOW
⩛	MARSH/WETLAND
⌒⌒⌒	APPROXIMATE LOCATION OF WOODED AREAS WEST OF SITE 32/33

NOTES

1. SOURCE: BASE MAP FROM "1998 TCE INVESTIGATION, WORKPLAN AND PILOT STUDY FOR THE PCB OPERABLE UNIT AT THE CRAB ORCHARD NATIONAL WILDLIFE REFUGE SUPERFUND SITE, MARION, ILLINOIS" REV. 1, MAY 1998, PREPARED BY FLUOR DANIEL GTI.
2. APPROXIMATE EXTENT OF MARSH/WETLANDS ESTIMATED FROM SITE TOPOGRAPHIC MAP.

PROJECT: **CRAB ORCHARD NWR - PCB O.U.**
GROUNDWATER INVESTIGATION REPORT AND
FOCUSED FEASIBILITY STUDY

SHEET TITLE:
POTENTIOMETRIC SURFACE MAP LOWER SAND UNIT
SITES 32/33 - AUGUST 1998

DRAWN BY: SIEWERTD	SCALE: 1"=400'	PROJ. NO. 04781.09
CHECKED BY: SLM		FILE NO. 47810921.DWG
APPROVED BY: TEG	DATE PRINTED:	**FIGURE B-3**
DATE: JULY 1999		

RMT

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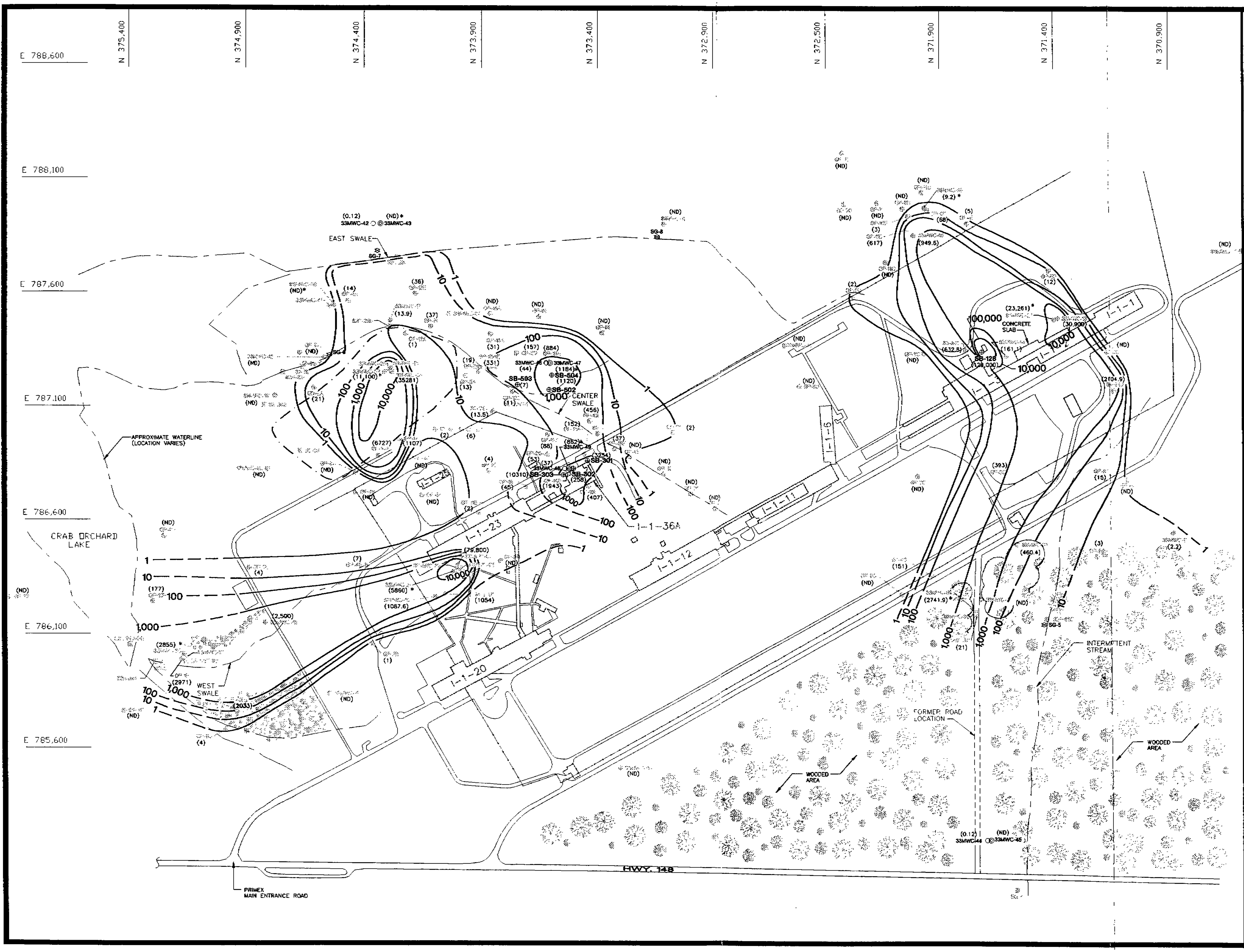
Phone: 608/831-4444



LEGEND

SG-5	LOCATION OF SURFACE WATER STAFF GAUGE – INSTALLED FALL 2000
○ 33MWC-42	SHALLOW MONITORING WELL (UPPER CLAY) – INSTALLED FALL 2000
◎ 33MWC-43	SHALLOW MONITORING WELL (UPPER SAND) – INSTALLED FALL 2000
	SHALLOW MONITORING WELL
	PIEZOMETER
	EXISTING STAFF GAUGE REPLACED DURING PRE–DESIGN INVESTIGATION
	SURFACE WATER SAMPLING LOCATION
	GEOPROBE SAMPLE LOCATION
	MONITORING WELL, ABANDONED (APPROXIMATE LOCATION)
—— – ——	APPROXIMATE CENTERLINE OF SURFACE DRAINAGE CHANNEL/SWALE
————	FENCE
— — —	APPROXIMATE LIMITS OF SOIL EXCAVATION
— · —	APPROXIMATE FOOTPRINT OF AREA 9 REPOSITORY
—10—	TOTAL CVOC ISOCONCENTRATION CONTOUR, LOGARITHMIC CONTOUR INTERVAL (ug/L) (DASHED WHERE INFERRED)
(393)	TOTAL CONCENTRATION OF CHLORINATED VOLATILE ORGANIC COMPOUNDS (CVOCs) DETECTED IN GROUNDWATER (ug/L).
ND	NOT DETECTED
▨	WOODED AREA
⊕ SB-128	GEOPROBE BORING LOCATION (INSTALLED BY RMT IN 2000)

NOTES

1. SOURCE: BASE MAP FROM "1998 TCE INVESTIGATION, WORKPLAN AND PILOT STUDY FOR THE PCB OPERABLE UNIT AT THE CRAB ORCHARD NATIONAL WILDLIFE REFUGE SUPERFUND SITE, MARION, ILLINOIS" REV. 1, MAY 1998, PREPARED BY FLUOR DANIEL GTI.
2. * INDICATES WELL IS SCREENED ACROSS THE UPPER SAND UNIT. OTHER BORINGS AND MONITORING WELLS ARE COMPLETED IN THE UPPER CLAY AND/OR THE UPPERMOST PORTION OF THE UPPER SAND UNIT.
3. CVOC DATA FOR MONITORING WELLS 33MWC–07, 33MWC–08, 33MWC–09, 33MWC–13, 33MWC–21, 33MWC–24, 33MWC–27, 33MWC–30, AND 33MWC–42 THROUGH 33MWC–49, AND FROM ALL "SB–" DESIGNATED BORINGS ARE FROM THE FALL 2000 INVESTIGATION. CVOC DATA FOR THE REMAINING WELLS ARE FROM THE DECEMBER 1998 SAMPLING EVENT. CVOC DATA FROM THE "GP–" DESIGNATED GEOPROBE LOCATIONS ARE FROM MAY THROUGH JULY 1998.
4. TOTAL CVOC VALUE REPORTED AT 33MWC–24 INCLUDES 22,000 ug/L OF TENTATIVELY IDENTIFIED COMPOUND, 1,1,2–TRICHLORO–1,2,2–ETHANE.
5. LOCATION OF ALL WOODED AREAS NOT SHOWN.

0 200' 400'

SCALE: 1"=200'

NO.	BY	DATE	REVISION	APP'D.
2.				
1.				
0.				

PROJECT: **CRAB ORCHARD NWR - PCB O.U.**
MARION, ILLINOIS
PRELIMINARY DESIGN REPORT

SHEET TITLE: **TOTAL CVOC ISOPLETH MAP**
UPPER CLAY & UPPER SAND UNITS-SITES 32/33

DRAWN BY: SIEWERTD	SCALE: 1"=200'	PROJ. NO. 4781.09
CHECKED BY: SLM		FILE NO. 47810920.DWG
APPROVED BY: TEG	DATE PRINTED:	**FIGURE B-4**
DATE: MAY 2001		

RMT

744 Heartland Trail
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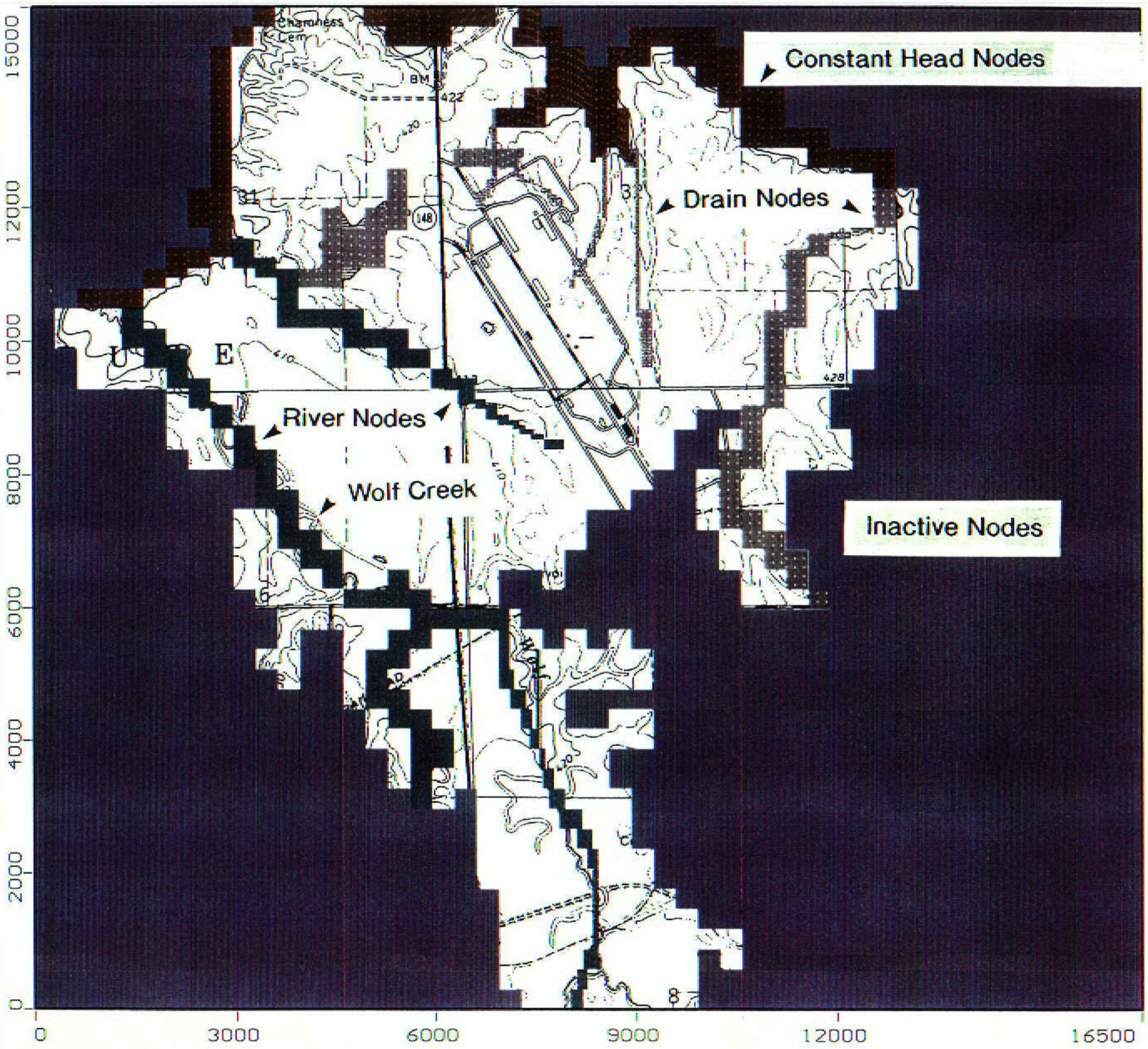
Phone: 608/831–4444

Revision Level

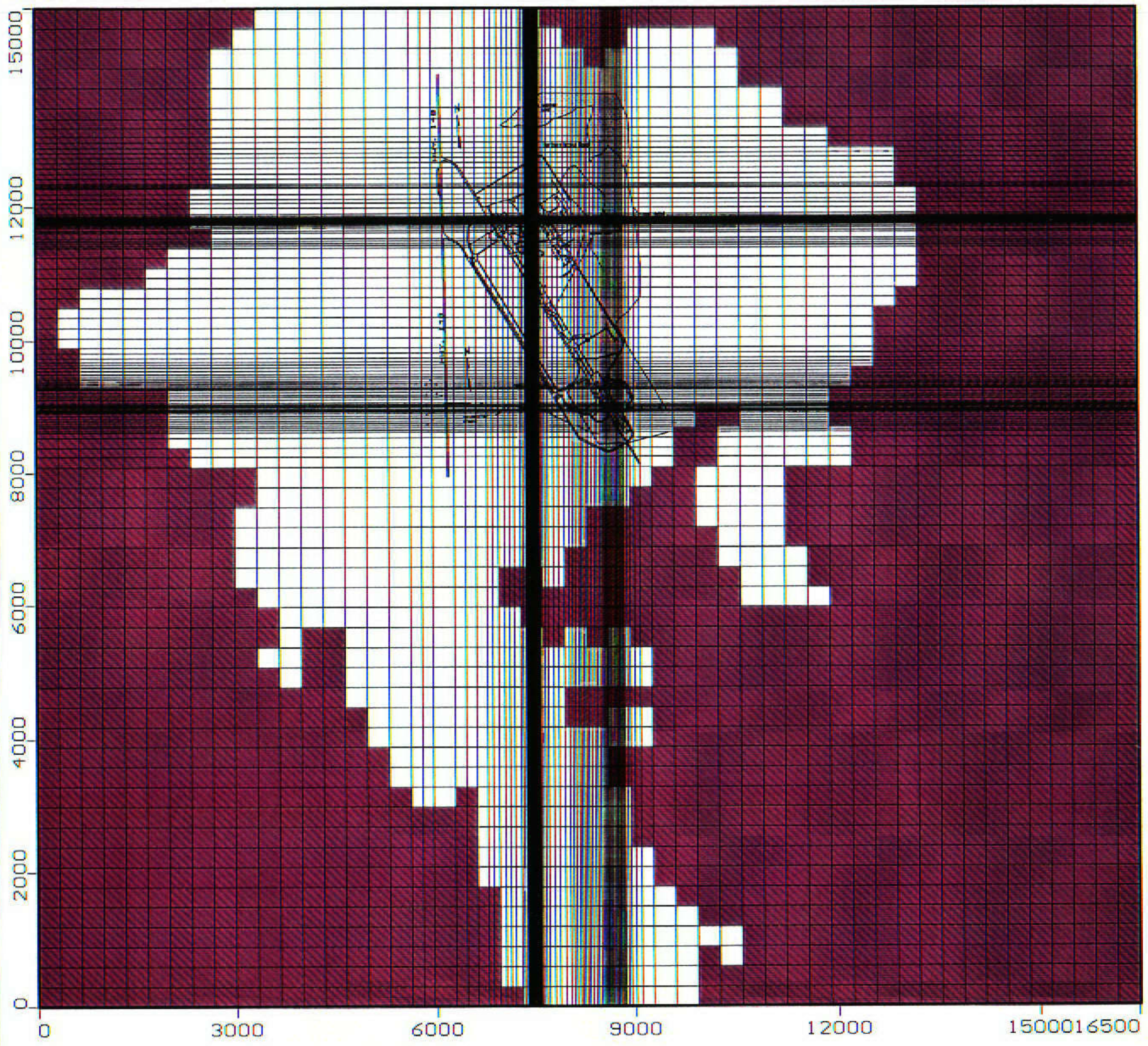


rmt
Project: CRAB ORCHARD
Description: Crab200b 20 yrs MT3D
Modeller: SSPapa. 96 version
23 Apr 99

Visual MODFLOW v.2.7.2, (C) 1995–1997
Waterloo Hydrogeologic, Inc.
NC: 90 NR: 104 NL: 5
Current Layer: 1

FIGURE B - 5

Model Domain and Boundary Conditions
Model Layer 1 (Upper Clay)

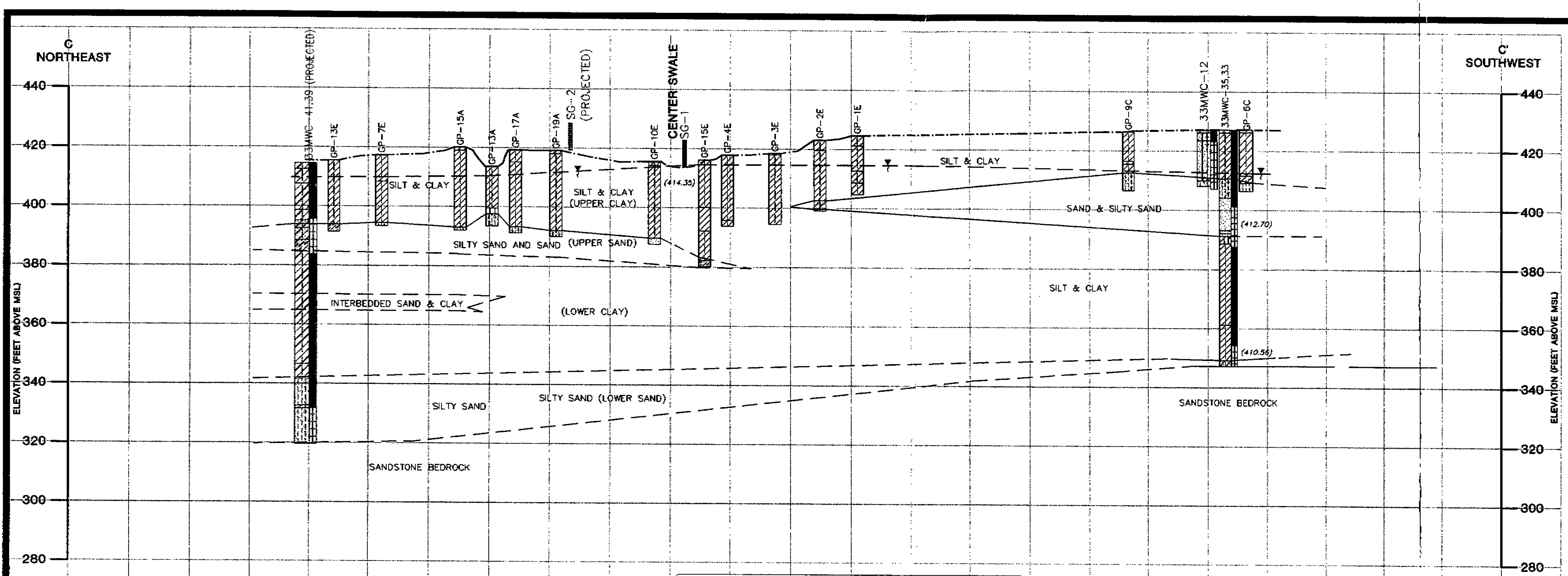


RMT, Inc.
Project: Crab Orchard
Description: Model Grid
Modeller: GK
28 Jul 03

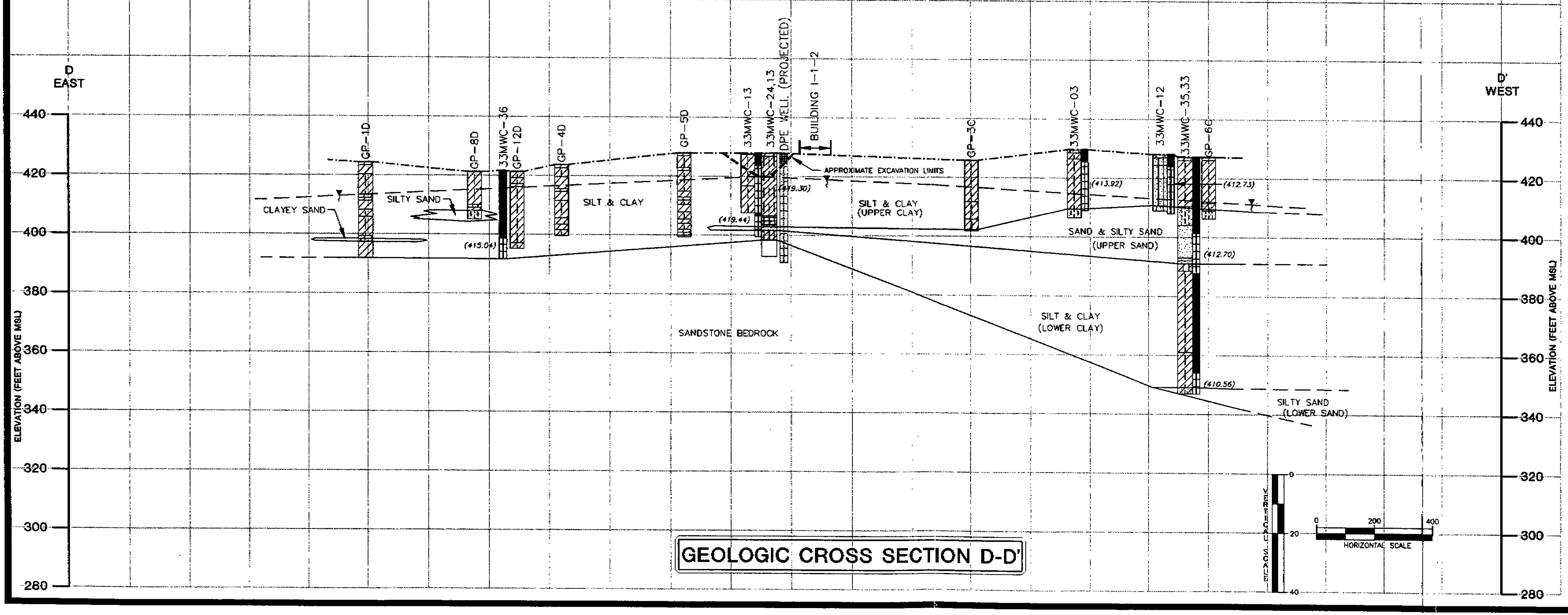
Visual MODFLOW v.3.1.0, (C) 1995–2002
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 6
Current Layer: 1

FIGURE B - 6

Model Grid



GEOLOGIC CROSS SECTION C-C'



GEOLOGIC CROSS SECTION D-D'

LEGEND

—Z—	STRATIGRAPHIC BOUNDARY (DASHED WHERE INFERRED)
— ▼ —	WATER TABLE SURFACE (12-6-98)
—·—·—	EXISTING GROUND SURFACE
(412.70)	GROUNDWATER HEAD ELEVATION (FEET, MSL) (12-6-98)
DPE	DUAL PHASE EXTRACTION WELL
SG-1	STAFF GAUGE LOCATION

STRATIGRAPHIC UNITS

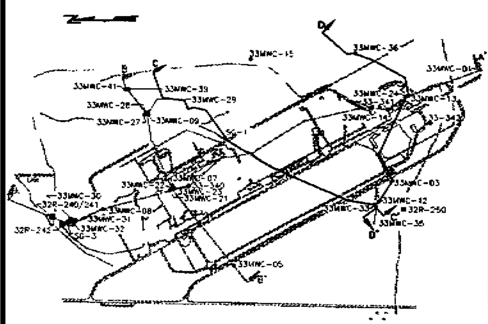
▨	SAND	▨	SILTY, SANDY CLAY
▨	SILTY SAND	▨	SILTY CLAY/CLAYEY SILT
▨	CLAYEY SAND	▨	CLAY
▨	SANDY SILT	▨	ASH FILL
▨	SILT	☐	SANDSTONE BEDROCK

WELL CONSTRUCTION DETAIL

- ■ WELL SEAL
- ▦ WELL SCREEN & SAND PACK

NOTES

1. WELL 33MWC-36 WAS BLIND-DRILLED AND INSTALLED AT BEDROCK SURFACE. ADJACENT BORING GP-12D ENCOUNTERED BEDROCK APPROXIMATELY 3 FEET HIGHER THAN 33MWC-36.



GEOLOGIC CROSS SECTION LOCATION MAP

PROJECT: CRAB ORCHARD NWR - PCB O.U.
GROUNDWATER INVESTIGATION REPORT AND
FOCUSED FEASIBILITY STUDY

SHEET TITLE:
GEOLOGIC CROSS SECTIONS C-C' & D-D'
SITES 32/33

DRAWN BY: SIEWERTO	SCALE: AS SHOWN	PROJ. NO. 04781.09
CHECKED BY: SLM		FILE NO. 47810923.DWG
APPROVED BY: TEG	DATE PRINTED:	FIGURE B-7
DATE: JULY 1999		

RMT

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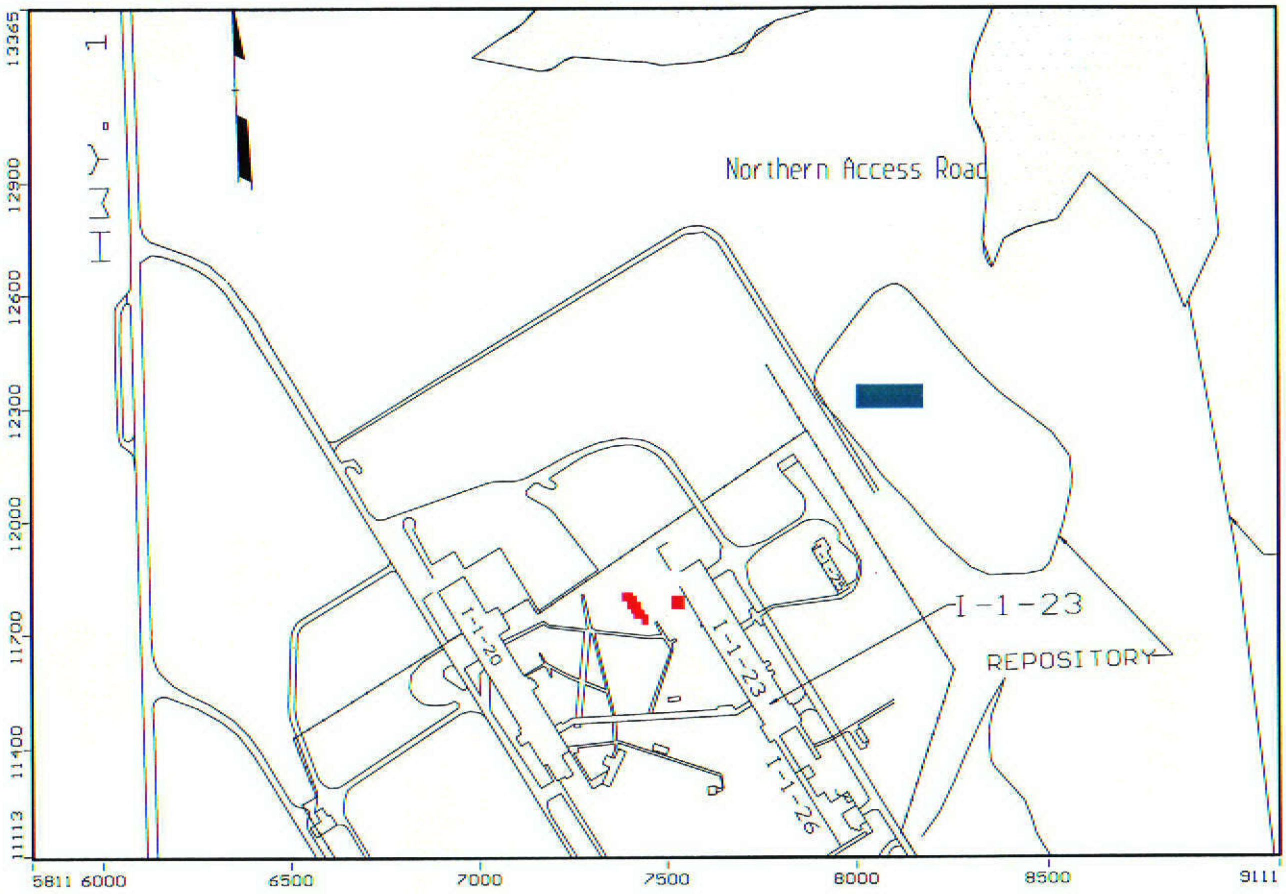
Phone: 608/831-4444



RMT, Inc.
Project: Crab Orchard
Description: Source Areas
Modeller: GK
28 Jul 03

Visual MODFLOW v.3.1.0, (C) 1995–2002
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 6
Current Layer: 1

FIGURE B - 8

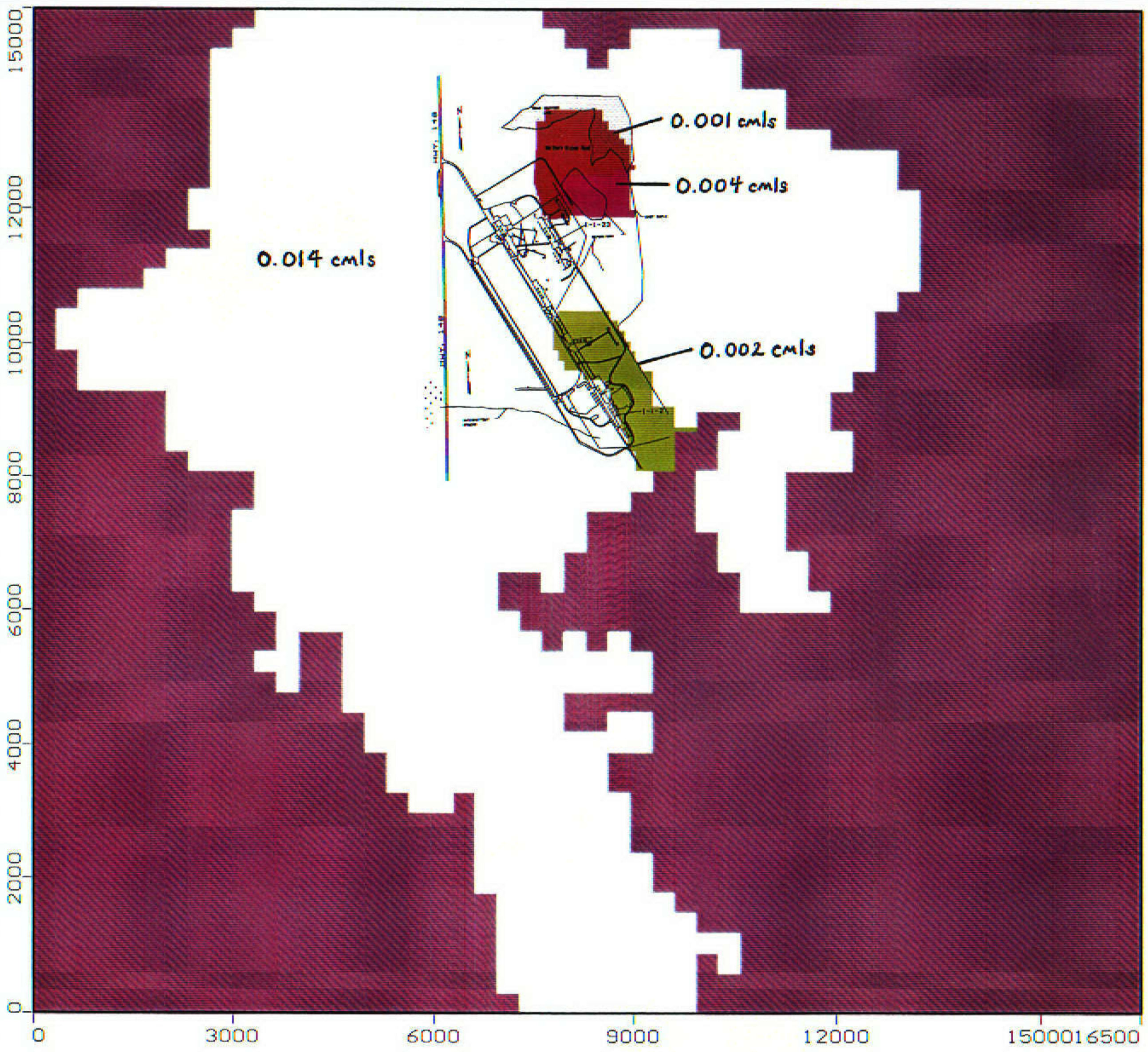
Designated Source Zones
(Constant Concentration Nodes)
I-1-23 and Repository Areas

RMT, Inc.
Project: Crab Orchard
Description: Source Areas
Modeller: GK
28 Jul 03

Visual MODFLOW v.3.1.0, (C) 1995–2002
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 6
Current Layer: 1

FIGURE B - 9

Designated Source Zones
(Constant Concentration Nodes)
I-1-2 Area

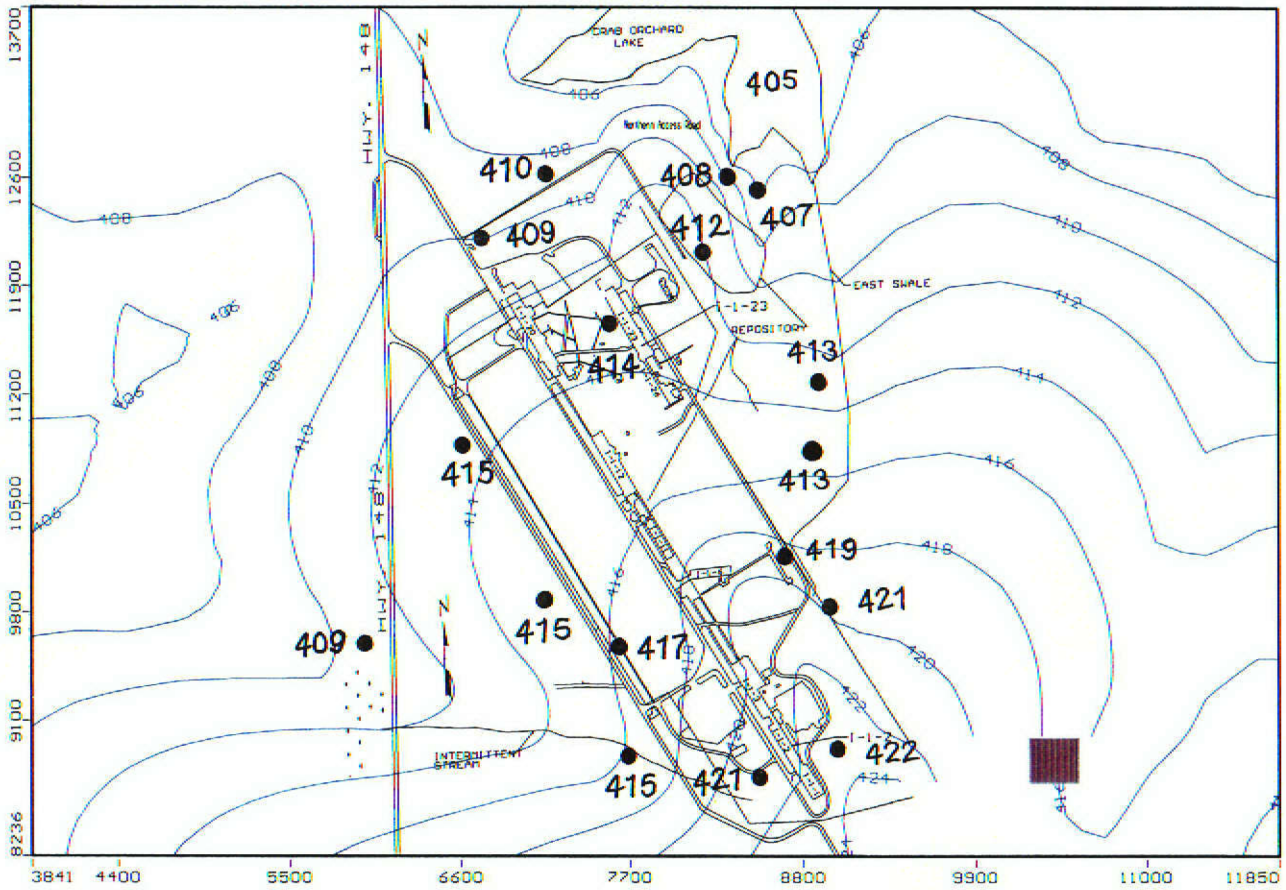


RMT, Inc.
Project: Crab Orchard
Description: K Values – Upper Sand
Modeller: GK
28 Jul 03

Visual MODFLOW v.3.1.0, (C) 1995–2002
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 6
Current Layer: 3

FIGURE B - 10

Hydraulic Conductivity Zones – Upper Sand (Model Layer 3)

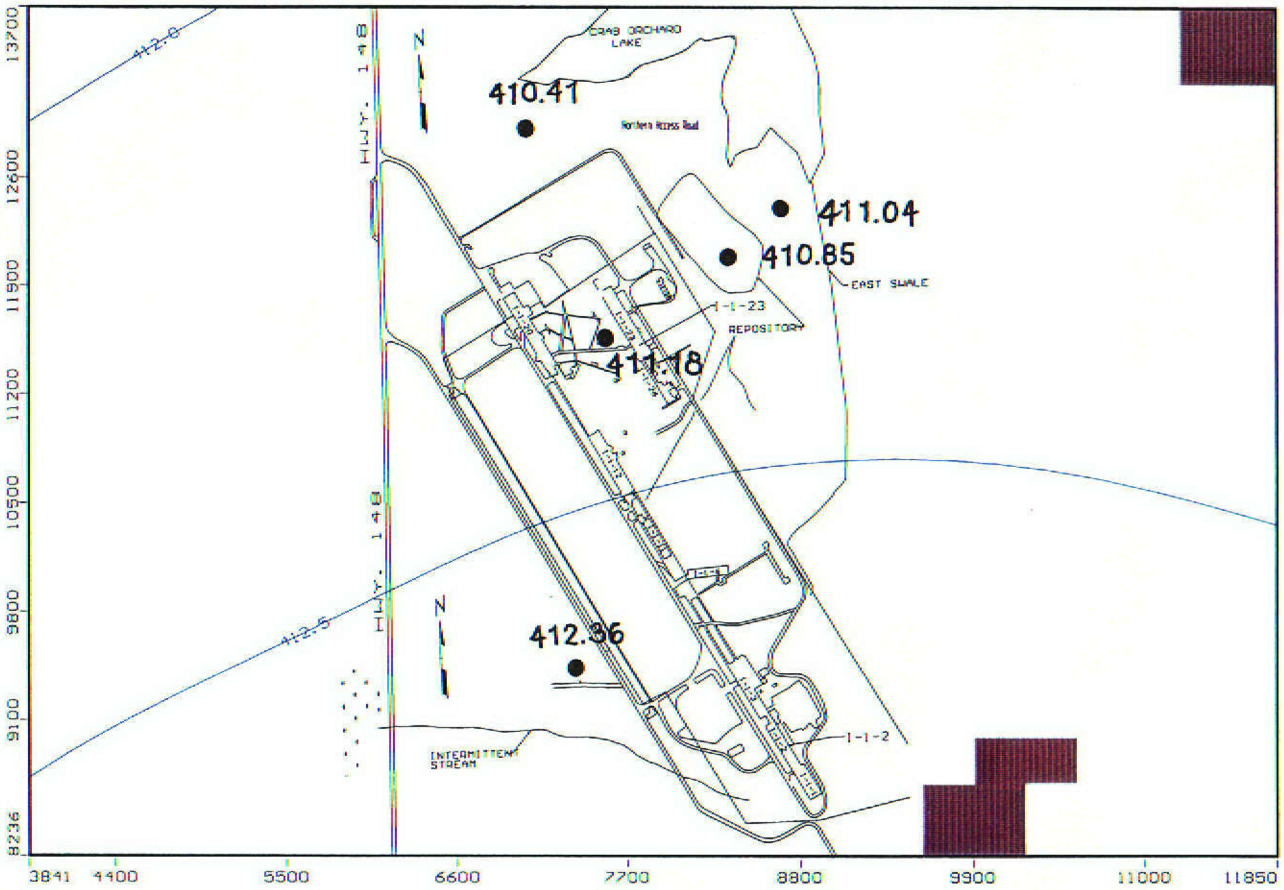


● 409 Measured Hydraulic Head (ft) (August 1998)

RMT, Inc. Project: Crab Orchard (Crab629) Description: Flow Calibration Modeller: Contours in Feet 28 Jul 03	Visual MODFLOW v.3.1.0, (C) 1995–2002 Waterloo Hydrogeologic, Inc. NC: 113 NR: 127 NL: 6 Current Layer: 3

FIGURE B - 11

Flow Calibration, Model Layer 2
(Upper Sand)



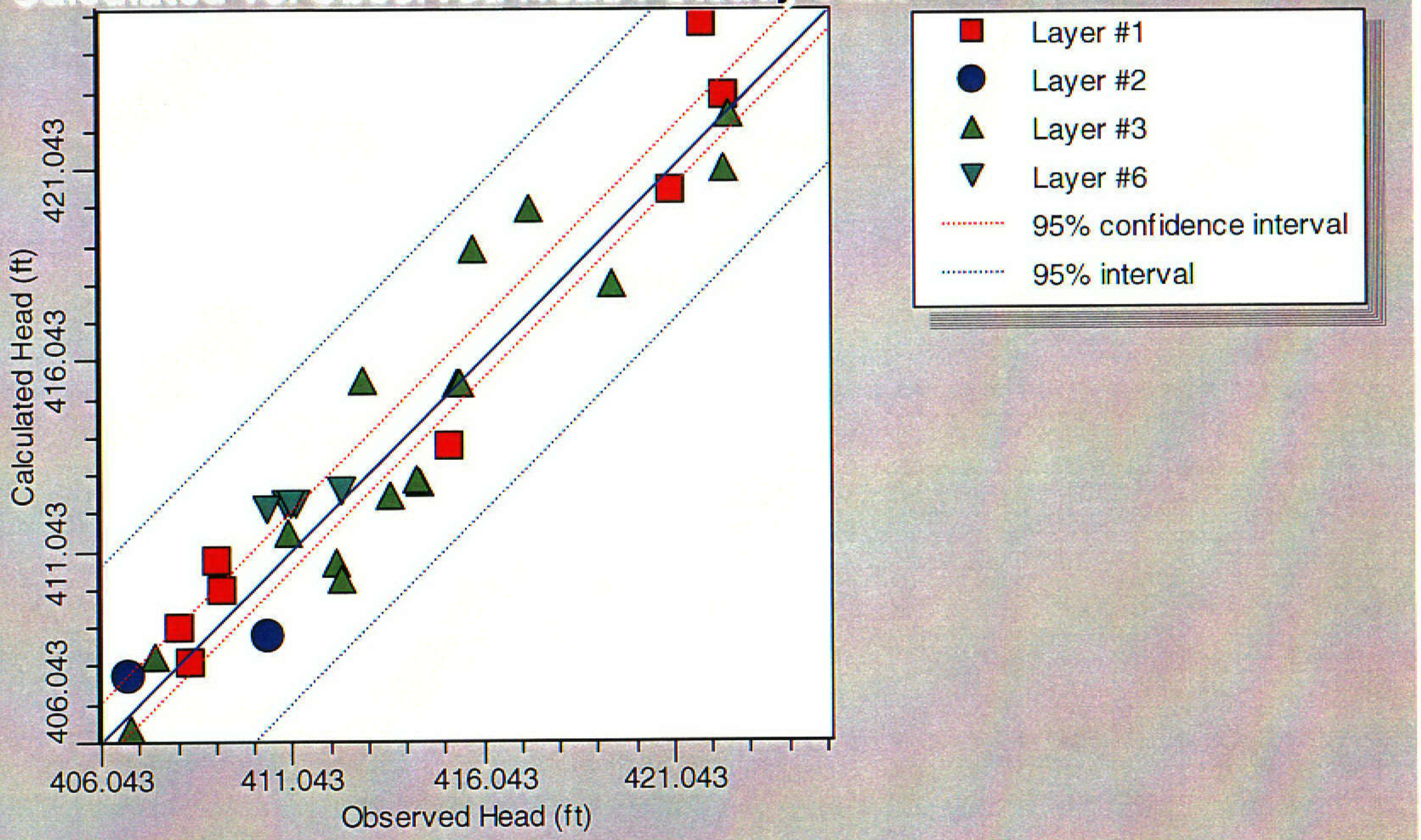
● 412 Measured Hydraulic Head (ft) (August 1998)

RMT, Inc. Project: Crab Orchard (Crab629) Description: Flow Calibration Modeller: Contours in Feet 28 Jul 03	Visual MODFLOW v.3.1.0, (C) 1995–2002 Waterloo Hydrogeologic, Inc. NC: 113 NR: 127 NL: 6 Current Layer: 6

FIGURE B - 12

Flow Calibration, Model Layer 5
(Lower Sand)

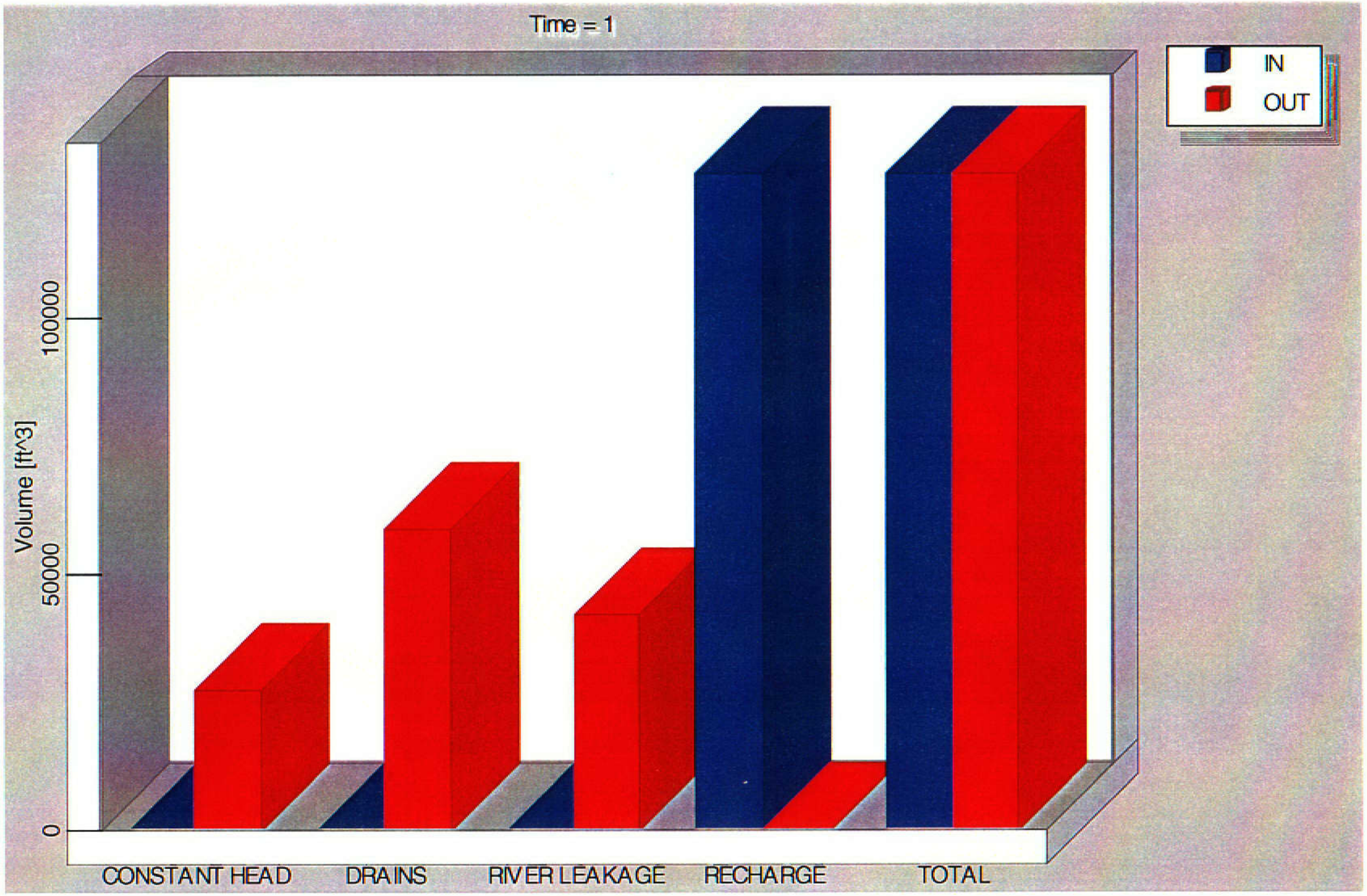
Calculated vs. Observed Head : Steady state



Num. of Data Points : 31
Max. Residual: 3.139 (ft) at MW-11/A
Min. Residual: 0.001 (ft) at MW-33/A
Residual Mean : 0.302 (ft)
Abs. Residual Mean : 1.233 (ft)

Standard Error of the Estimate : 0.265 (ft)
Root Mean Squared : 1.482 (ft)
Normalized RMS : 9.362 (%)
Correlation Coefficient : 0.955

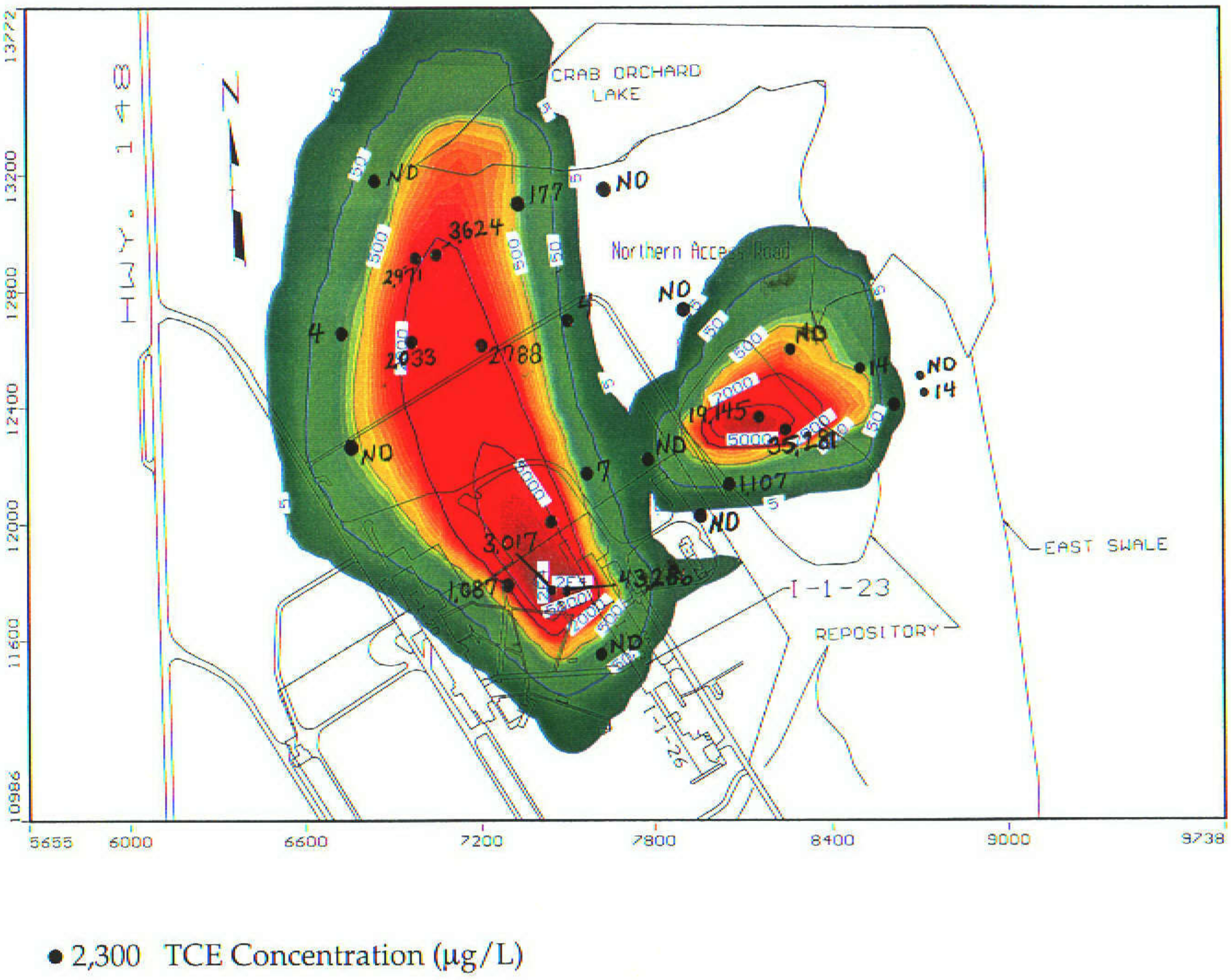
Figure B-13



Mass Balance Summary

I:\WPMSN\00-04781\12\BFigures.ppt

Figure B-14

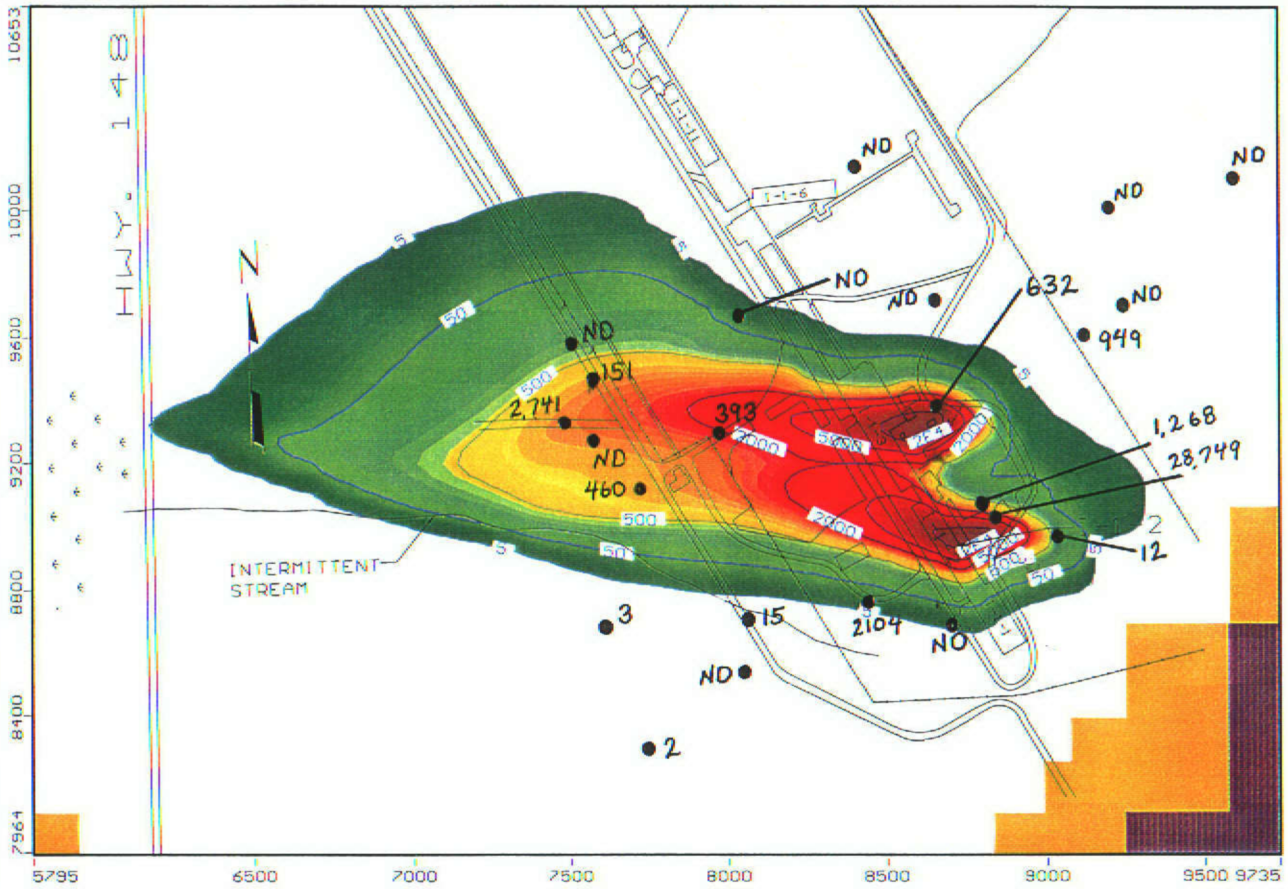


RMT, Inc.
Project: Crab Orchard (Crab629)
Description: Transport Calibration
Modeller: TCE Contours in ppb
28 Jul 03

Visual MODFLOW v.3.1.0, (C) 1995-2002
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 6
Current Layer: 3

FIGURE B - 15

Transport Model Calibration
I-1-23 and Repository Areas

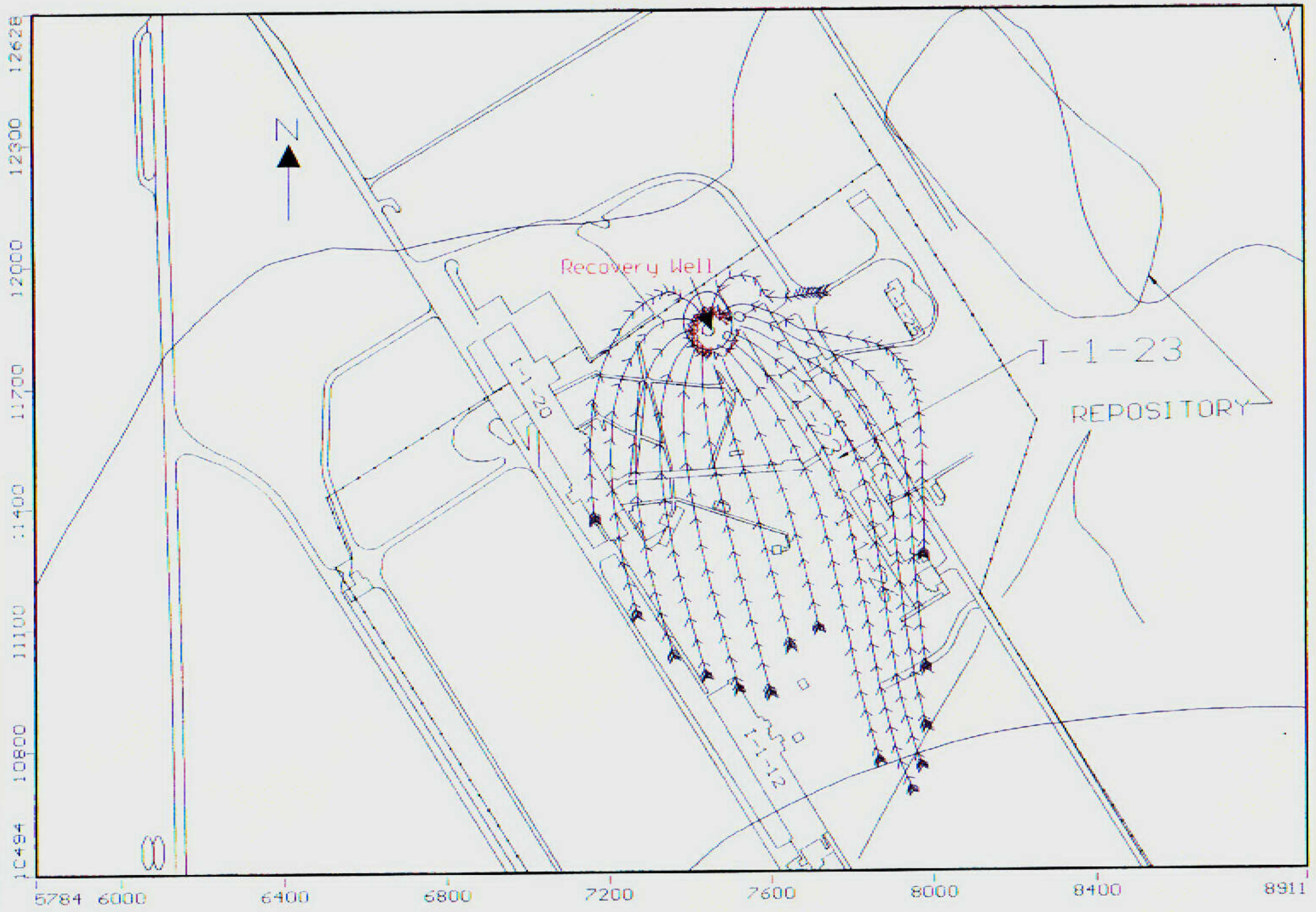


RMT, Inc.
Project: Crab Orchard (Crab629)
Description: Transport Calibration
Modeller: TCE Contours in ppb
28 Jul 03

Visual MODFLOW v.3.1.0, (C) 1995–2002
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 6
Current Layer: 3

FIGURE B - 16

Transport Model Calibration
I-1-2/I-1-3 Plume

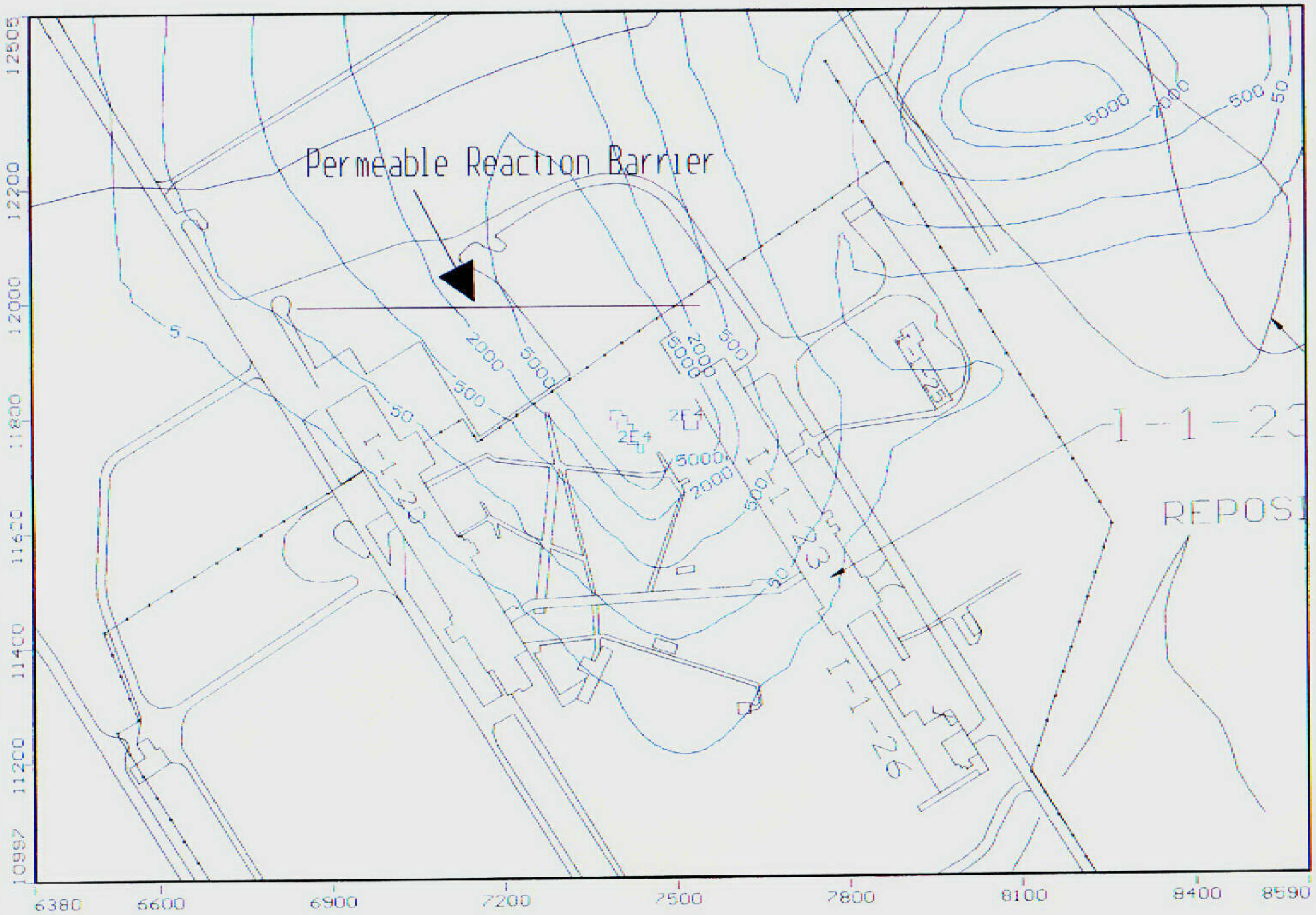


RMT, Inc.
Project: Crab643 Capture Zone
Description: 10gpm pumping
2 Jul 04

Visual MODFLOW v.3.1.0, (C) 1995-2002
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 6
Current Layer: 3

Capture Zone of Extraction Well, 10 gpm, I-I-23

Figure B-17

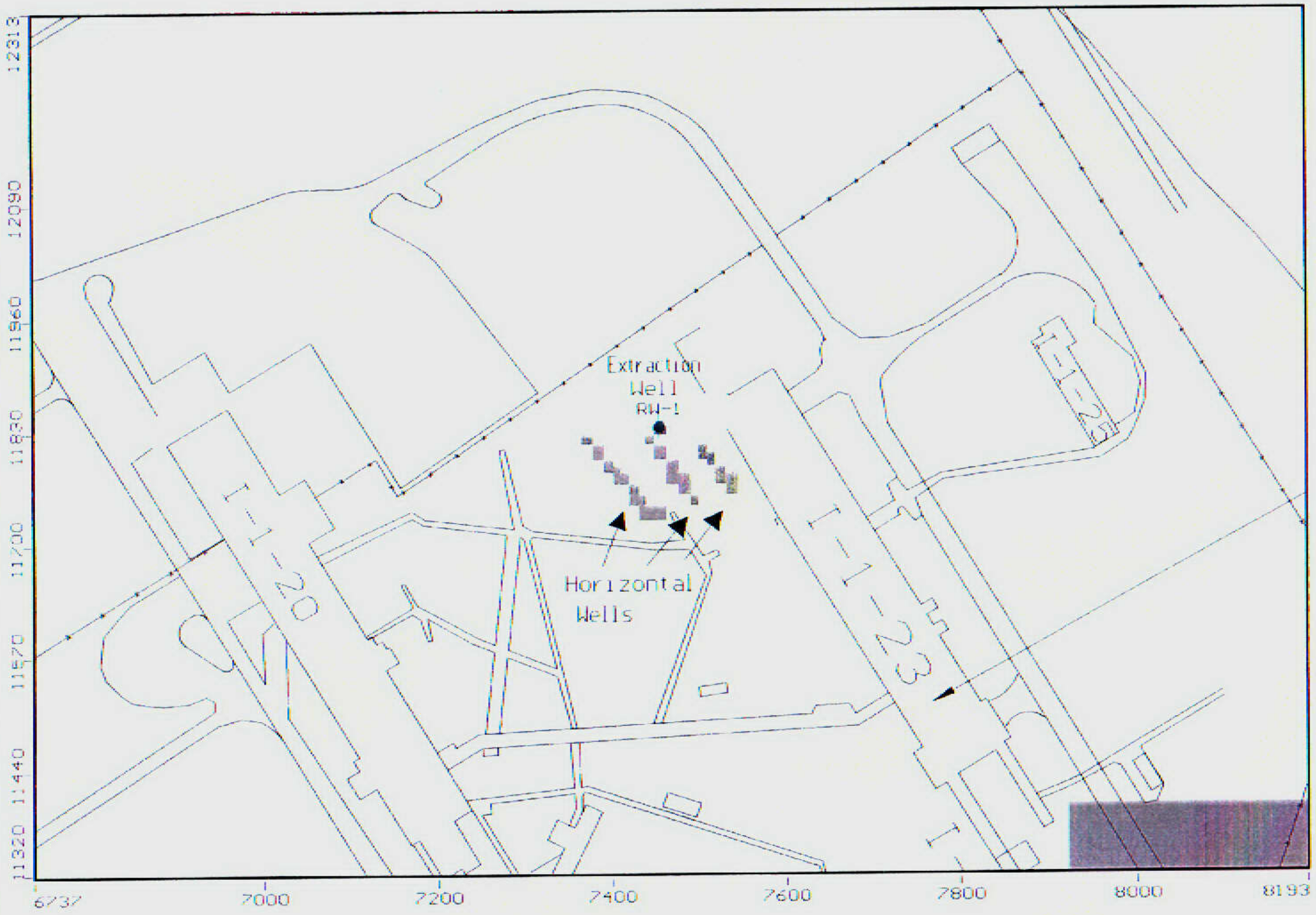


RMT, Inc.
Project: Crab642 PRB
Description: TCE Concentrations
Modeller: t=5 yr (values in ug/L)
29 Jun 04

Visual MODFLOW v.3.1.0, (C) 1995-2002
Waterloo Hydrogeologic, Inc.
NC: 121 NR: 139 NL: 6
Current Layer: 3

PRB Location, I-1-23

Figure B-18



RMT, Inc.
Project: Crab646 Hor. Wells
Description: Vertical Well
29 Jun 04

Visual MODFLOW v.3.1.0, (C) 1995–2002
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 6
Current Layer: 3

Location of horizontal wells, simulated as drains, Alternative C, I-1-23

Figure B-19

RMT, Inc.
Project: Crab646
Description: Pumping Hor. Wells
29 Jun 04

Visual MODFLOW v.3.1.0, (C) 1995-2002
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 6
Current Layer: 3

Water table depression around horizontal wells, Alternative C, I-1-23

Figure B-20