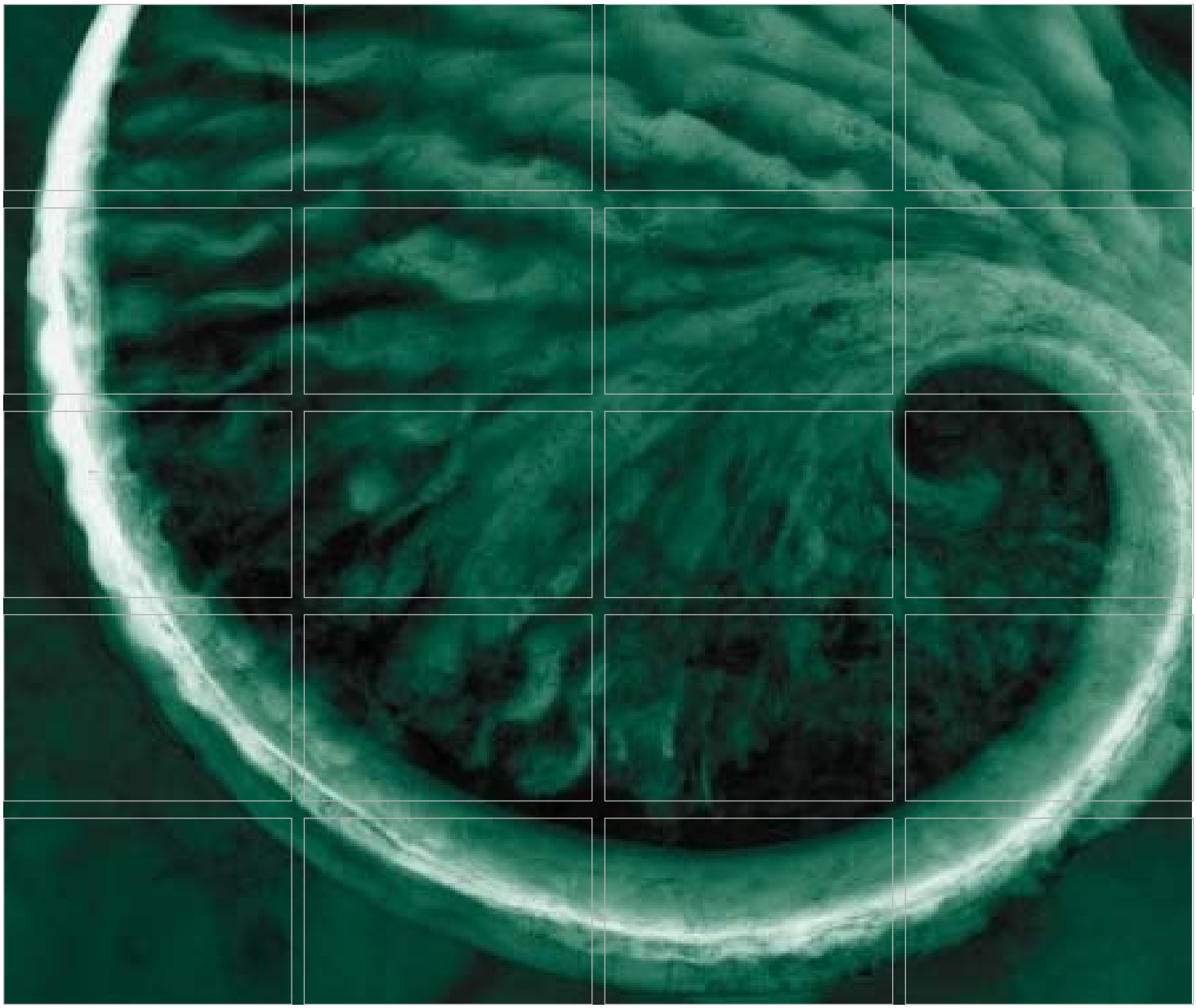


DRAFT Focused Feasibility Study

Groundwater Source Control Interim Remedial Measure
Arkema Chemicals Facility
Portland, Oregon

May 2008

Prepared for:
Legacy Site Services, LLC

www.erm.com

ERM

Delivering sustainable solutions in a more competitive world

Legacy Site Services, LLC

DRAFT Focused Feasibility Study
Groundwater Source Control Interim Remedial Measure
Arkema Chemicals Facility, Portland, Oregon

May 2008

Project No. 0065572

DRAFT

Christopher Underwood, P.E.
Project Engineer

DRAFT

Erik C. Ipsen, P.E.
Partner

ERM-West, Inc.
915 118th Avenue Southeast, Suite 130
Bellevue, Washington 98005
T: 425-462-8591
F: 425-455-3573

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1

1.0 INTRODUCTION 4

1.1 INTERIM REMEDIAL MEASURE OBJECTIVES 5

1.2 SITE BACKGROUND 5

1.3 REVISED REMEDIAL STRATEGY FOR SITE 6

1.4 REPORT ORGANIZATION 7

2.0 SUMMARY OF GROUNDWATER SOURCE CONTROL SCREENING EVALUATION 8

2.1 JOINT SOURCE CONTROL STRATEGY AND SCREENING 8

2.2 POTENTIAL SOURCES 9

2.3 CONSTITUENTS OF POTENTIAL CONCERN 10

2.4 CONCLUSIONS FROM SOURCE CONTROL SCREENING AND WEIGHT-OF-EVIDENCE EVALUATION 11

2.4.1 Lots 1 and 2 12

2.4.2 Lots 3 and 4 12

3.0 PREVIOUS REMEDIAL ACTIONS AND TECHNOLOGY STUDIES 14

3.1 SOIL INTERIM REMEDIAL MEASURES 14

3.1.1 Phase I Soil Removal 15

3.1.2 Phase II Soil Removal 15

3.1.3 Soil Vapor Extraction Interim Remedial Measure 15

3.2 GROUNDWATER INTERIM REMEDIAL MEASURES 16

3.2.1 Hexavalent Chromium Reduction Interim Remedial Measure 16

3.2.2 Air Sparging/Soil Vapor Extraction Interim Remedial Measure 17

3.2.3 In Situ Persulfate Oxidation Interim Remedial Measure 19

3.2.4 Laboratory Biotreatability Study for Enhanced Bioremediation of Perchlorate 19

3.3 GROUNDWATER MODELING 20

3.4 GROUNDWATER BARRIER WALL GEOTECHNICAL ENGINEERING ANALYSIS 22

3.5 SLURRY MATERIALS TESTING 24

3.6 GROUNDWATER TREATABILITY STUDY 27

4.0 DEVELOPMENT OF REMEDIAL ALTERNATIVES 31

4.1 APPLICABLE AND RELEVANT OR APPROPRIATE REQUIREMENTS31

4.2 REMEDIAL ACTION OBJECTIVES 31

4.3 GENERAL RESPONSE ACTIONS 32
4.3.1 Containment Barrier Wall 32
4.3.2 Hydraulic Containment System 33

4.4 TECHNOLOGY SCREENING 34
4.4.1 Groundwater Barrier Wall Technologies 34
4.4.2 Ex Situ Groundwater Treatment Technologies 38
4.4.3 Treated Water Discharge Options 41

4.5 DEVELOPMENT OF REMEDIAL ALTERNATIVES 41
4.5.1 Development of Groundwater Barrier Wall Alternatives 41
4.5.2 Development of Ex Situ Groundwater Treatment Alternatives 47
4.5.3 Development of Treated Groundwater Management Alternatives 49

5.0 EVALUATION OF REMEDIAL ALTERNATIVES 52

5.1 EVALUATION CRITERIA 52
5.1.1 Effectiveness 53
5.1.2 Long-Term Reliability 53
5.1.3 Implementability 54
5.1.4 Implementation Risk 55
5.1.5 Reasonableness of Cost 55

5.2 DETAILED EVALUATION OF REMEDIAL ALTERNATIVES 56
5.2.1 Detailed Evaluation of Groundwater Barrier Wall Alternatives 56
5.2.2 Detailed Evaluation of Ex Situ Groundwater Treatment Alternatives57
5.2.3 Detailed Evaluation of Treated Groundwater Management Alternatives 57

5.3 COMPARATIVE ANALYSIS 58
5.3.1 Comparison of Groundwater Barrier Wall Alternatives 58

5.3.2 Comparison of Ex Situ Groundwater Treatment Alternatives 61
5.3.3 Comparison of Treated Groundwater Management Alternatives 62

5.4 PREFERRED REMEDIAL ALTERNATIVE 63
5.4.1 Preferred Barrier Wall Alternative 63
5.4.2 Preferred Ex Situ Groundwater Treatment Alternative 64
5.4.3 Preferred Treated Water Discharge Alternative 65

6.0 IMPLEMENTATION PLAN AND SCHEDULE 66

6.1 GROUNDWATER BARRIER WALL 66

6.2 GROUNDWATER EXTRACTION AND TREATMENT SYSTEM 67

6.3 IMPLEMENTATION REPORT 68

6.4 PERFORMANCE MONITORING 69

7.0 REFERENCES 70

LIST OF APPENDICES

APPENDIX A – GROUNDWATER MODELING REPORT

APPENDIX B – GEOTECHNICAL EVALUATION REPORT

APPENDIX C – SLURRY MATERIALS TESTING REPORT

APPENDIX D – GROUNDWATER TREATABILITY STUDY REPORT (PROVIDED SEPARATELY, 10 APRIL 2008)

APPENDIX E – COST ESTIMATES FOR GROUNDWATER BARRIER WALL ALTERNATIVES

APPENDIX F – COST ESTIMATES FOR EX SITU GROUNDWATER TREATMENT ALTERNATIVES

APPENDIX G – COST ESTIMATES FOR TREATED WATER DISCHARGE ALTERNATIVES

LIST OF FIGURES (Figures immediately follow the Text)

1-1	*Site Location Map*
1-2	*Site Detail Map*
3-1	*IRM Soil Removal Areas*
4-1	*River Side High Bank Barrier Wall Plan*
4-2	*Full Enclosure Barrier Wall Plan*
4-3	*Conceptual Barrier Wall Details*
4-4	*River Side High Bank Barrier Wall Profile*
4-5	*Full Enclosure Barrier Wall Profile – 1 of 2*
4-6	*Full Enclosure Barrier Wall Profile – 2 of 2*
4-7	*Conceptual Flow Diagram Chemical Precipitation with Anaerobic Biological Treatment*
4-8	*Conceptual Discharge Options*
6-1	*Preliminary Implementation Schedule*

LIST OF TABLES (Tables immediately follow the Figures)

4-1	*Preliminary Project ARARs*
4-2	*Groundwater Containment Technologies and Process Options*
4-3	*Ex Situ Groundwater Treatment Technologies and Associated Target Contaminants*
4-4	*Screening of Ex Situ Groundwater Treatment Technologies*
4-5	*Treated Groundwater Discharge Options*
4-6	*Barrier Wall Construction Details*
4-7	*List of Components of Groundwater Barrier Wall Alternatives*
4-8	*Treated Groundwater Discharge Criteria Summary*
5-1	*Evaluation Summary for Groundwater Barrier Wall Alternatives*
5-2	*Evaluation Summary for Ex Situ Groundwater Treatment Alternatives*
5-3	*Evaluation Summary for Treated Groundwater Discharge Alternatives*

LIST OF ACRONYMS

AS/SVE	Air sparging/soil vapor extraction
Arkema	Arkema Inc.
ARAR	Applicable and relevant or appropriate requirement
CaSx	Calcium polysulfide
COPC	Constituents of potential concern
CPT	Cone penetrometer
Cr[VI]	Dissolved hexavalent chromium
DNAPL	Dense non-aqueous phase liquid
DDT	Dichloro-diphenyl-trichloroethane
ERM	ERM-West, Inc.
FBR	Fluidized bed reactor
FFS	Focused Feasibility Study
FS	Feasibility Study
ft bgs	feet below ground surface
GAC	Granular activated carbon
gpm	gallons per minute
HRT	Hydraulic residence time
IRM	Interim Remedial Measure
JSCS	Joint Source Control Strategy
LSS	Legacy Site Services, LLC
MCB	monochlorobenzene
MCL	Maximum contaminant level
mg/L	milligrams per liter
MPR	Manufacturing process residue
NPDES	National Pollutant Discharge Elimination System
ODEQ	Oregon Department of Environmental Quality
PBR	Packed bed reactor
PCE	tetrachloroethene
POTW	Publicly owned treatment works

LIST OF ACRONYMS (CONTINUED):

RI	Remedial Investigation
SLV	Screening level value
SVE	Soil vapor extraction
SVOC	Semi-volatile organic compound
TOB	Top of bank
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
ZVI	zero valent iron

EXECUTIVE SUMMARY

On behalf of Legacy Site Services LLC, agent for Arkema Inc. (Arkema), ERM-West, Inc. has prepared this *Focused Feasibility Study (FFS) Report* for the former Arkema Chemicals facility in Portland, Oregon (the "Site") pursuant to the Voluntary Agreement for Remedial Investigation/ Feasibility Study (FS), ODEQ (Oregon Department of Environmental Quality) No. ECVC-WMCVC-NWR-97-14. The purpose of the FFS was to evaluate alternatives for a Groundwater Source Control Interim Remedial Measure (IRM) to achieve the following remedial action objectives:

- Establish hydraulic control of constituents of potential concern in groundwater from the primary source areas (Lots 3 and 4) at the Site to the Willamette River;

- Reduce the potential for recontamination of river sediments via the groundwater pathway following the Arkema non-time-critical removal action;

- Allow upland source control measures to proceed on an independent schedule from the non-time-critical removal action without impeding or compromising that work; and

- Implement a remedy, which to the extent practicable, will complement and be compatible with potential final upland remedies for the Site.

The Groundwater Source Control IRM is expected to consist of the following primary components:

1. **Containment barrier wall** to physically separate the affected upland portions and in-water portions of the Site;

2. **Hydraulic control ("groundwater extraction and treatment")** to prevent groundwater containing unacceptable concentrations of constituents of potential concern from moving around, over, or under the containment barrier wall; and

3. **Management of treated groundwater** from the ex situ treatment system described above.

Groundwater modeling, a groundwater barrier wall geotechnical engineering analysis, slurry materials testing, and a groundwater treatability study were completed to support this FFS. Following the completion of this work, technology screening and a detailed evaluation and comparative analysis of the various remedial action alternatives was performed. The recommended alternatives for the primary components of the Groundwater Source Control IRM are summarized as follows:

Groundwater Barrier Wall

The recommended barrier wall component for the Groundwater Source Control IRM is construction of a barrier wall as follows:

- Along the River Side High Bank route (top of the river bank with necessary setback);
- Using either the vibrated beam or conventional slurry wall technology; and
- To a depth to the top of the basalt (approximately 50 to 85 vertical feet below ground surface).

Ex Situ Groundwater Treatment

The recommended ex situ groundwater treatment alternative for the Groundwater Source Control IRM consists of the following:

- Chemical precipitation reactor with aeration, and pH adjustment via sodium hydroxide;
- Solids handling system (i.e., clarifier with polymer feed, sludge holding tank, filter press, and associated equipment);
- pH Adjustment Tank;
- Optional post-clarification solids filter if required;
- Fluidized bed reactor with solids filter for biomass handling, with the option of utilizing either the paced bed reactor or EHC/sand reactor; and
- Two liquid-phase granular activated carbon vessels in series.

Treated Groundwater Management

Based on technical considerations and pending further evaluation, the preferred treated water discharge alternatives include:

- Discharge to the Willamette River; and/or
- Reinjection to shallow groundwater via the anticipated storm water infiltration basin to be constructed on Lots 1 and/or 2 of the Site.

Discharge limits have not yet been established for either option, and will be established as part of the permitting process. The discharge permit limits will need to be established for each option and the final discharge selection made, before the design phases of the groundwater treatment system can commence.

As part of the FFS, a preliminary plan and schedule for implementing the preferred Groundwater Source Control IRM have been developed. The schedule is included as Figure 6-1 of the FFS Report. Tasks associated with implementation include permitting, pre-design investigations, preparation of engineering designs and specifications, contractor and equipment procurement, construction, startup, and ongoing operation and maintenance activities. The schedule highlights those tasks that will be performed by ODEQ and United States Environmental Protection Agency (and possibly other regulatory agencies) that are critical in regards to completing subsequent tasks in accordance with the schedule. Other events beyond the control of Legacy Site Services LLC, ODEQ, and the United States Environmental Protection Agency may also affect the schedule for implementation of the Groundwater Source Control IRM.

1.0 INTRODUCTION

On behalf of Legacy Site Services, LLC (LSS), ERM-West, Inc. (ERM) has prepared this *Focused Feasibility Study Report* (FFS Report) for the Former Arkema, Inc. (Arkema) Chemicals facility in Portland, Oregon (the "Site"). This FFS Report is prepared pursuant to the Voluntary Agreement for Remedial Investigation (RI)/Feasibility Study (FS), DEQ No. ECVC-WMCVD-NWR-97-14 (Voluntary Agreement)

The goal for the Groundwater Source Control Interim Remedial Measure (IRM) is to establish hydraulic control of groundwater constituents of potential concern (COPCs) at the Arkema Site, and maintain an inward groundwater gradient towards the upland portion of the Site away from the Willamette River. This FFS Report summarizes the results of an evaluation of alternatives for a Groundwater Source Control IRM. It has been prepared in accordance with the *Scoping Technical Memorandum* (ERM, December 2006), *Summary of Remedial Technology Alternatives Memorandum* (ERM, 2 January 2008), and associated comments and approvals received from the Oregon Department of Environmental Quality (ODEQ) and United States Environmental Protection Agency (USEPA) (ODEQ, 25 January 2007; ODEQ, 5 February 2008).

As described in the *Scoping Technical Memorandum* (ERM, December 2006), the Groundwater Source Control IRM is expected to consist of the following primary components:

1. **Containment barrier wall** to physically separate the affected upland portions and in-water portions of the Site;

2. **Hydraulic control ("groundwater extraction and treatment")** to prevent groundwater containing unacceptable concentrations of COPCs from moving around, over, or under the containment barrier wall; and

3. **Management of treated groundwater** from the ex situ treatment system described above.

The purpose of this FFS is to evaluate applicable technologies and options for the above components.

1.1 INTERIM REMEDIAL MEASURE OBJECTIVES

The objectives of this Groundwater Source Control IRM are to:

- Establish hydraulic control of COPCs in groundwater from the primary source areas (Lots 3 and 4) at the Site to the Willamette River;
- Reduce the potential for recontamination of river sediments via the groundwater pathway following the Arkema non-time-critical removal action;
- Allow upland source control measures to proceed on an independent schedule from the non-time-critical removal action without impeding or compromising that work; and
- Implement a remedy, which to the extent practicable, will complement and be compatible with potential final upland remedies for the Site.

1.2 SITE BACKGROUND

The Site is located at 6400 N.W. Front Avenue in the Northwest Industrial Area of Portland, Oregon. The facility is bounded by Front Avenue on the north and west, the Willamette River on the east, and an asphalt roofing manufacturer on the south. The plant operated as a chemical manufacturing facility for over 50 years. Manufacturing activities at the facility were terminated in 2001, and the plant was decommissioned and dismantled in 2004. For reference purposes, a site location map and site detail map are included as Figures 1-1 and 1-2, respectively.

In 1998, Arkema entered into the Voluntary Agreement with the ODEQ under the Oregon Voluntary Cleanup Program to address impacts to environmental media associated with the manufacture of dichloro-diphenyl-trichloroethane (DDT) in the Acid Plant Area and sediment in the Willamette River adjacent to the Site. The *Upland Remedial Investigation Report Lots 3 & 4 and Tract A – Revision 1* (RI Report; ERM December 2005) was conditionally approved by ODEQ on 5 June 2006. Detailed information regarding environmental conditions at the Site is provided in the RI Report, which contains a site description, background information, and discussion of the nature and extent of contamination at the Site. The upland Human Health and Ecological Risk Assessments and the Hot Spot Evaluation are currently under development.

In June 2005, Arkema entered into a non-time-critical removal action administrative settlement with USEPA (Early Action).[1] The Statement of Work (SOW) for the Early Action requires, among other things, the preparation and delivery of an Engineering Evaluation/Cost Analysis (EE/CA) Work Plan to identify and provide alternatives for addressing the primary COPCs in the intertidal area and submerged lands on and adjacent to the Site. This removal action is intended to take place before implementation of the remedial action for the harbor-wide cleanup of the Portland Harbor Superfund Site.

1.3 REVISED REMEDIAL STRATEGY FOR SITE

A Joint Source Control Strategy (JSCS)[2] was developed by ODEQ and USEPA to identify, evaluate, and control sources of contamination (that may impact the Willamette River) in a manner that is consistent with the objective and schedule for the Portland Harbor Superfund Site RI/FS. The goal of the JSCS is to achieve timely upland source control to prevent the risk of significant recontamination after the Portland Harbor cleanup is completed. The JSCS recommends that upland source control be substantially completed to the greatest extent practicable before or during early removal actions in order to reduce the potential for recontamination.

Despite the success of several of the alternative, in situ IRM technologies at the Site (see Section 3.0), LSS does not currently believe an in situ remedial approach will be capable of meeting the source control objectives, many of which are not yet defined, in the USEPA-envisioned timeframe for the Early Action. In situ treatment technologies, by their nature, are constrained by reaction kinetics and media interferences which alter their ability to meet rapid and undefined groundwater source control objectives. In addition, the persistent nature of some of the constituents anticipated to require containment/treatment (e.g., dense non-aqueous phase liquid [DNAPL]) are expected to complicate and extend an in situ approach for source control. Because of the Early Action schedule, LSS has been required to pursue an alternative strategy of physical and hydraulic containment to achieve groundwater source control. As a

---

[1] *Administrative Order on Consent for Removal Action*, USEPA Region 10, Docket No. CERCLA 10-20050191 (June 27, 2005)

[2] *Portland Harbor Joint Source Control Strategy prepared by the Oregon Department of Environmental Quality and the United States Environmental Protection Agency* (December 2005) (a framework for making upland source control decisions at the Portland Harbor Superfund Site).

result, this FFS evaluates physical and hydraulic containment technologies only, and does not evaluate in situ or other alternative treatment and containment technologies. The efficacy and practicability of utilizing innovative in situ technologies will be evaluated during start up and operation of the Groundwater Source Control IRM. To the extent that these evaluations are completed in advance of the comprehensive site-wide upland FS, these alternative approaches will be included in the FS for the Site.

1.4 REPORT ORGANIZATION

The remainder of the FFS Report is organized as follows:

- Section 2.0 presents a summary of the potential sources of contamination, COPCs, and areas requiring source control;
- Section 3.0 presents a summary of previous remedial measures implemented at the Site, remedial technology treatability studies and pilot testing, and other studies completed to support the FFS and future remedial design;
- Section 4.0 presents the applicable and relevant or appropriate requirements (ARARs), IRM objectives, and development of groundwater source control alternatives;
- Section 5.0 presents the IRM alternatives evaluation and the preferred remedy; and
- Section 6.0 presents the plan for implementing the IRM including scope of activities and schedule.

2.0 SUMMARY OF GROUNDWATER SOURCE CONTROL SCREENING EVALUATION

This section describes the JSCS, summarizes historical site activities, and presents the results of the groundwater source control screening evaluation relative to site-specific COPCs and areas requiring source control as part of this IRM.

2.1 JOINT SOURCE CONTROL STRATEGY AND SCREENING

Finalized in December 2005, the JSCS represents a framework for making upland source control evaluations at the Portland Harbor Superfund Site. The JSCS document does not constitute rulemaking by ODEQ or USEPA, and may not be relied upon to create a right or benefit, substantive or procedural, enforceable in law or equity, by any person, including the ODEQ or USEPA[3]. Nonetheless, the JSCS states:

> *The overarching goal of the JSCS is to identify, evaluate, and control sources of contamination that may reach the Willamette River, in a manner consistent with the objectives and schedule of the Portland Harbor RI/FS. Upland source control should be completed to the extent practicable prior to sediment cleanup in the Portland Harbor Superfund Site.*

The JSCS tool identifies a process whereby concentrations of site constituents are compared to screening level values (SLVs). Exceedance of an SLV does not necessarily indicate the upland source poses an unacceptable risk to human health or the environment, rather it requires further consideration of the need for source control using a weight-of-evidence evaluation. A remedial alternative evaluation (e.g., FFS) is then performed, where complete contaminant migration pathways exist, to address upland sources as deemed necessary by the screening process and the weight-of-evidence evaluation[4]. The results of the screening evaluation completed at the Site are discussed below.

[3] JSCS Title Page
[4] JSCS at p. iii

2.2 *POTENTIAL SOURCES*

Historical site activities and potential sources of COPCs have been previously described in detail in the RI Report. Site activities and potential sources are summarized in this section for convenience.

Chemical manufacturing at the Site occurred on Lots 3 and 4 in the Chlorate Plant and Acid Plant Areas. Inorganic chemicals including sodium chlorate, chlorine, sodium hydroxide, hydrogen, and hydrochloric acid were manufactured at the plant from 1941 until 2001. DDT was manufactured at the Site from approximately 1947 to 1954.

Based on historical activities, potential source areas of COPCs within the Chlorate Plant Area include the following:

- Chlorate Cell Room;
- Chlorate Process Building;
- Chlorate Warehouse; and
- Chlorate Tank Farm.

Likely COPCs from sources within the Chlorate Plant Area include the following:

- hexavalent chromium;
- perchlorate; and
- chloride.

DDT was manufactured in the Acid Plant Area. Discrete areas within the Acid Plant Area that are potential sources of COPCs include the following:

- Former Manufacturing Process Residue (MPR) Pond and Trench;
- DDT Process Building;
- Monochlorobenzene (MCB) Recovery Unit;
- DDT Dry Storage Area;

- Possible DDT Loading Areas; and
- Fill area between the Willamette River and the MPR Pond and Trench.

Based on historical operations, the likely COPCs released from Acid Plant Area activities include the following:

- Organochlorine pesticides (DDT and co-metabolites dichloro-diphenyl-dichloroethane [DDD] and dichloro-diphenyl-dichloroethene [DDE], hereafter referred to collectively as DDx);
- Volatile organic compounds ([VOCs], primarily MCB and chloroform); and
- Perchlorate.

The following additional areas (and COPCs) were investigated as part of the RI and supplemental investigations:

- Salt Pads (chloride);
- Old Caustic Tank Farm (sodium hydroxide, petroleum hydrocarbons, and DDx);
- Former Ammonia Plant (aqueous ammonia);
- Former Transformer Pads (polychlorinated biphenyls [PCBs]);
- BPA Main Substation (PCBs); and
- Storm Water Drain System (pesticides, semi-VOCs [SVOCs], perchlorate, and chloride).

2.3 CONSTITUENTS OF POTENTIAL CONCERN

A groundwater source control screening evaluation was completed by Integral Consulting Inc. (Integral) in April 2007. The results were presented in the *Draft Groundwater Source Control Evaluation* (Integral, 17 April 2007) and appended by Addendum I (Integral, March 2008) (together referred to as the "Source Control Evaluation"). As part of the Source Control Evaluation, groundwater concentrations were compared against JSCS SLVs, including Federal maximum contaminant levels

(MCLs) to identify COPCs. Addendum I included a comparison of the results of the April 2007 site-wide groundwater monitoring event to the July 2007 Revised JSCS SLVs.[5]

For purposes of technology screening completed as part of this FFS, a tentative list of COPCs for Lots 3 and 4 developed from the April 2007 screening evaluation is as follows:

- DDx;
- MCB;
- Other VOCs including benzene, bromodichloromethane, carbon disulfide, carbon tetrachloride, chloroethane, chloroform, chloromethane, methylene chloride, tetrachloroethene, and trichloroethene;
- SVOCs including fluoranthene, pyrene, naphthalene, phenanthrene, and 2-chlorophenol;
- Furan homologues;
- Metals including arsenic, manganese, chromium, hexavalent chromium, cadmium, copper, lead, nickel, mercury, silver, and zinc; and
- Perchlorate, chlorate and chloride.

2.4 *CONCLUSIONS FROM SOURCE CONTROL SCREENING AND WEIGHT-OF-EVIDENCE EVALUATION*

Integral reached the following conclusions as part of the Source Control Evaluation.

[5]It should be noted that the JSCS SLVs are intended to be for screening purposes only and are not considered cleanup goals or discharge targets. "SLVs may be used in two ways: first, they will be used in screening level risk assessments and second, they may be used as helpful comparisons to prioritize source control tasks. The EPA Portland Harbor ROD(s) will establish contaminant specific cleanup levels based on identified applicable or relevant and appropriate requirements (ARARs) or risk-based levels." JSCS at p. iii).

2.4.1 *Lots 1 and 2*

A hydraulically upgradient former pesticide, herbicides, and other heavily chlorinated solvent manufacturing facility, known as the "Rhone-Poulenc Site", has contaminated groundwater under Arkema Lots 1 and 2.[6] The current owner of the property, Star Link Logistics, Inc., (SLLI) is preparing a comprehensive source control evaluation report for the Rhone-Poulenc Site. The SLLI source control evaluation is expected to address the Rhone Poulenc Site groundwater plumes migrating onto Lots 1 and 2, including arsenic detected in well RP-2-31 and constituents detected in the deeper zones of well clusters RP-2, RP-8, RP-9, RP-10, and W-19.

Integral notes in its Addendum I to the Source Control Evaluation that no DDx SLV exceedances were observed in groundwater from downgradient shoreline well clusters RP-02 and W-19, indicating that DDx in groundwater is attenuating and does not exceed SLVs in groundwater adjacent to the river at Lots 1 and 2 (Integral, March 2008). Therefore, source control for Lots 1 and 2 is not considered necessary under this FFS.

2.4.2 *Lots 3 and 4*

Distribution of affected groundwater at the Site corresponds closely to source area locations on Lots 3 and 4 described in Section 2.2 of this FFS. Groundwater in the Acid Plant Area, located on the northern portion of Lot 4, is generally affected by VOCs, SVOCs, DDx, and furans. Groundwater in the Chlorate Plant Area, located on the southern portion of Lot 4, is affected by two inorganics (i.e., chloride and perchlorate) and metals. The two affected areas of groundwater overlap in the vicinity of Dock 2.

The Integral weight-of-evidence evaluation focused on the area of MWA-63, which is outside of the envisioned groundwater barrier wall and hydraulic control system. Low levels of chlorinated VOCs have been detected in one monitoring well (MWA-63) located on Lot 3 outside the area of planned source control (see Figure 1-2). As reported in the *Draft Groundwater Source Control Evaluation* (Integral, April 2007), groundwater data from MWA-63 included some exceedances of the most conservative

[6] DEQ has determined that for Lot 1"the contaminants detected in groundwater are attributable to an off-site source, and application of DEQ's Contaminated Aquifer Policy is appropriate," and for Lot 2, "except for the chemicals DDT, arsenic, and chloride," . . . "application of DEQ's Contaminated Aquifer Policy is appropriate." Letter from Matt McClincy to Larry Patterson dated November 7, 2003.

human health SLVs for chloroform, tetrachloroethene (PCE), and trichloroethene (TCE). In addition, a total of four constituents (chloroform, *cis*-1,2-dichloroethene, PCE, and TCE) detected at MWA-63 exceeded the MCLs.

DDx, PCE, and TCE concentrations detected in the April 2007 groundwater sample collected from MWA-63 decreased substantially compared to the previous monitoring event, and there were no SLV exceedances for chlorobenzene, chromium, perchlorate, 1,2-dichlorobenzene (DCB), or 1,4-DCB.

MCL exceedance quotients were calculated for detected constituents that exceeded the conservative SLVs in MWA-63. The only constituent in groundwater from MWA-63 that exceeded the MCL by a factor greater than 10 was PCE. No known sources of PCE are located on the Site, and the relatively low concentration of PCE in MWA-63 groundwater also indicates that PCE non-aqueous phase liquid is not present. Because of these two important facts, PCE concentrations in MWA-63 will continue to attenuate through dispersion, degradation, volatilization, and other physicochemical processes during transport.

This line of evidence is also supported by data collected during Site sediment investigations. For example, data collected from an in-sediment groundwater sample at WB-18, immediately downstream of Dock 2 and generally downgradient from MWA-63, did not have detectable concentrations of PCE, indicating that natural attenuation is occurring during groundwater transport (Integral, 2003).

The potential impact to the Willamette River water, biota, and sediments from PCE is also highly limited because PCE and the other detected VOCs are not bioaccumulative. PCE also does not tend to partition and accumulate in sediment and is therefore not a recontamination threat to the sediment removal action area being addressed by the Arkema in-water EE/CA.

Based on this analysis, the weight-of-evidence evaluation supports the conclusion that no further active remediation should be considered for MWA-63 at this time. Integral recommends in its Addendum I to the Source Control Evaluation (Integral, March 2008) and ERM concurs that MWA-63 be included in the Groundwater Source Control IRM monitoring program to continue to monitor the decline of PCE concentrations in this part of the Site.

3.0 PREVIOUS REMEDIAL ACTIONS AND TECHNOLOGY STUDIES

3.1 SOIL INTERIM REMEDIAL MEASURES

During RI field activities, evidence of DDx- and MCB-impacted soil was observed in and around the Acid Plant Area. Soils containing DDx and MCB at elevated concentrations were observed within the former MPR Pond and trench (Area A), in an unpaved area approximately 150 feet west of the MPR Pond and trench (Area B), in the unpaved area immediately north of the Acid Plant Area (Area C), and in the area north of the former MCB Recovery Unit Area and south of Warehouse No. 2 (Area D). Elevated DDx and MCB concentrations were primarily identified from near ground surface to approximately 8 feet below ground surface (ft bgs). DDx and MCB were observed at a depth of up to 22 ft bgs in the immediate vicinity of the former Acid Plant Area. Figure 3-1 illustrates the locations of these areas within the Acid Plant Area.

In response to these elevated DDx and MCB concentrations, Arkema implemented multiple IRMs to mitigate potential environmental impacts. The purpose of the IRMs was as follows:

- Remove DDx-affected soil in Areas A, B, C, and D to the extent technically practicable;
- Construct site drainage improvements to ensure proper drainage and reduce ponding of surface water; and
- Install limited paving and a temporary surface cover to reduce transport of DDx and MCB resulting from storm water runoff and erosion of surface soils.

The IRMs targeted DDT concentrations greater than 1,200 milligrams per kilogram. This targeted concentration, while equivalent to ODEQ's default "hot spot" criterion for DDT, was used only as a screening value to identify which surface or near-surface soil might need to be addressed by the IRMs. The prior soil IRMs are described below in this section.

3.1.1 Phase I Soil Removal

The Phase I Soil Removal IRM was performed between September and November 2000, and focused on excavation and off-site disposal of DDx-affected soil from the former MPR Pond and trench areas. Excavations were conducted to a maximum depth of 12 ft bgs. A total of approximately 3,800 tons of soil was excavated and removed as part of the Phase I soil IRM. Grading, paving, and storm water conveyance improvements were installed within the excavated area. Additionally, a temporary surface cover, consisting of a visqueen plastic layer between two layers of geotextile, buried beneath approximately 2 inches of ¾-inch-minus gravel, was constructed in the unpaved area east of the Acid Plant Area. Further details regarding the Phase I Soil IRM activities are presented in the *Interim Remedial Measures Implementation Report* (ERM, 26 February 2001).

3.1.2 Phase II Soil Removal

The Phase II Soil Removal IRM was completed in November 2001, and focused on the area north of the former Acid Plant Area and south of Warehouse No. 2 (Area D). A total of 91 tons of soil was excavated to a maximum depth of 7 ft bgs. Storm water conveyance improvements and asphalt paving were installed to reduce transport of DDx-affected soil in storm water runoff. A detailed description of the Phase II soil IRM activities is presented in the *Phase II Soil Interim Remedial Measure Final Report* (ERM, February 2002).

The Phase I and II IRMs were effective in removing significant quantities of soil containing DDx and MCB, and reduced the potential for transport of these constituents in shallow soils.

3.1.3 Soil Vapor Extraction Interim Remedial Measure

The Phase I and II Soil IRMs were conducted to remove DDx-contaminated soils in and around the Acid Plant Area. A soil vapor extraction system (SVE) was installed in December 2000 to extract MCB mass from subsurface soils, thereby reducing MCB concentrations to allow disposal of the soil as a non-hazardous waste during future excavation activities. The system was expanded periodically over the two and a half years of operation and ultimately included five horizontal extraction wells. The horizontal wells were situated approximately 6 ft bgs. The system was installed, operated, and monitored in accordance

with the *Workplan for Full-Scale Vapor Extraction System* (ERM, 2000) and subsequent work plan addenda approved by ODEQ.

Detailed descriptions of the SVE system installation, operation, and monitoring, including analytical summary tables and laboratory analytical reports are presented in monthly progress reports and the *Confirmation Soil Sampling Summary Report* (ERM, 26 August 2003).

Confirmation sampling results revealed MCB concentrations in soil greater than had been previously observed in the former MCB Recovery Unit Area. Generally, samples with higher MCB concentrations than those previously observed were located around the SVE system extraction wells. Additionally, MCB DNAPL was observed at one of the confirmation borings. The SVE system was not designed to address DNAPL, and, consequently, the system was shut down.

3.2 GROUNDWATER INTERIM REMEDIAL MEASURES

In response to observation of COPCs in ground water at the Site, LSS implemented multiple prior targeted IRMs, including:

- Hexavalent Chromium Reduction IRM;
- Air Sparging (AS)/SVE IRM;
- Persulfate IRM; and
- Laboratory Biotreatability Study for Enhanced Bioremediation of Perchlorate.

These prior groundwater IRMs are summarized below in this section.

3.2.1 Hexavalent Chromium Reduction Interim Remedial Measure

The Hexavalent Chromium Reduction IRM was implemented to treat dissolved hexavalent chromium (Cr[VI]) in the Chlorate Plant Area. This IRM involved in situ reduction of Cr[VI] to trivalent chromium (Cr[III]), thereby decreasing the solubility and toxicity of chromium. The objective of this IRM was to reduce the Cr[VI] concentration in groundwater to the JSCS SLV of 0.011 milligrams per liter (mg/L) in groundwater adjacent to the Willamette River.

The Cr[VI] reduction was achieved by injecting calcium polysulfide (CaSx) into the three uppermost groundwater units (Shallow, Intermediate, and Deep Zones), where previous investigations indicated Cr[VI] was present at elevated concentrations. The IRM was completed in accordance with the *Hexavalent Chromium Reduction Interim Remedial Action Work Plan* (ERM, 28 September 2004). The scope and results of the Cr[VI] reduction IRM are summarized below:

- Injection of CaSx (3 percent and 10 percent by weight) via direct push injection points and permanent wells during two rounds of injections in June and October 2005, respectively;

- Monthly groundwater monitoring for three months following each round of injections and a fourth monitoring event 8 months after the second round of injections;

- A total of 1,387,000 gallons of 3 percent and 120,000 gallons of 10 percent by weight of CaSx was injected into the three uppermost water bearing units at the Site; and

- The average Shallow Zone concentration decreased from 1.306 mg/L to 0.3286 mg/L. The average Intermediate Zone concentration decreased from 0.92 mg/L to 0.14 mg/L. The average Deep Zone concentration decreased from 0.123 mg/L to 0.01 mg/L. Although concentrations in the Shallow and Intermediate Zones did not achieve the targeted JSCS SLV, the average dissolved Cr[VI] concentrations in the Shallow, Intermediate, and Deep Zones were significantly reduced by 75, 85, and 92 percent, respectively, by this IRM.

3.2.2 *Air Sparging/Soil Vapor Extraction Interim Remedial Measure*

After an investigation was conducted in 2002 to characterize the extent of MCB DNAPL, a study involving the installation, operation, and monitoring of a pilot-scale remediation system including AS/SVE technologies was conducted. The pilot study was completed over an approximate five month period in 2003 in the area where the majority of residual-phase DNAPL was observed during the 2002 investigation. Based on the encouraging pilot study results, an AS/SVE IRM was designed and implemented to address the area of known DNAPL. The primary objective of the IRM was to reduce the mass of MCB DNAPL in the Shallow Zone. The AS/SVE system operated continuously between December 2004 and December 2005.

Performance monitoring of the Shallow Zone was conducted three and six months following system startup in March and June 2005, respectively. After reductions of MCB DNAPL concentrations were initially observed during the first two sampling events, significant rebounds of MCB concentration occurred across the treatment area. Based on these results and the In Situ Persulfate Oxidation IRM performance monitoring results (refer to Section 3.2.3), additional investigation was warranted to further characterize the MCB DNAPL.

An MCB DNAPL investigation was conducted in two phases in December 2005 and January/February 2006, respectively. The objective of Phase I of the investigation was to evaluate the effectiveness of the AS/SVE system approximately one year after implementation. To evaluate the ability of the system to remove DNAPL, 17 soil samples were collected from across the treatment area. The objective of Phase II of the investigation was to delineate the lateral extent and vertical distribution of the DNAPL. Phase II of the investigation included collecting soil cores from the bottom of the Shallow Zone in 42 locations in the former Acid Plant Area.

DNAPL was observed at 16 of the 17 borings completed during Phase I. Although the frequency of DNAPL observation was not unexpected, the DNAPL vertical distribution was greater than initially anticipated. Thick zones of DNAPL-impacted soil and thinner zones of saturated DNAPL were observed. The lateral extent of DNAPL observed during Phase II was greater than previously anticipated, extending in a narrow area north of the AS/SVE treatment area. The majority of DNAPL mass was located at the bottom of the Shallow Zone, immediately above the lower silt that separates the Shallow and Intermediate Zones. Smaller amounts of DNAPL were also observed in an upper silt layer within the Shallow Zone at most Phase II sample locations.

Based on the additional DNAPL investigation results, the AS/SVE IRM would not sufficiently remediate the DNAPL source because it was not designed to address the full extent of the DNAPL and the presence of multiple silt lenses in the Shallow Zone prevented effective treatment using AS/SVE. The investigation results indicated that suspending the AS/SVE IRM had little effect on the removal of residual MCB DNAPL. Evaluating additional options for containing and treating the DNAPL was recommended in the *Draft Acid Plant Area DNAPL Sampling Summary Report* (ERM, April 2006). The Sampling Summary Report also recommended suspending the In-Situ Persulfate Oxidation IRM in the area where DNAPL was defined, because dissolved phase MCB treatment would not be fully effective until the DNAPL is addressed.

3.2.3 *In Situ Persulfate Oxidation Interim Remedial Measure*

The In Situ Persulfate Oxidation IRM was implemented in 2005 to remediate dissolved MCB and DDx in the Shallow and Intermediate Zones within the Acid Plant Area, where the historical MPR pond and MCB recovery unit were located. The IRM objectives were to reduce the mass of dissolved MCB and DDx by direct oxidation and subsequently decrease the mobility of DDx due to cosolvency with MCB.

The IRM was to be implemented in accordance with the *In-Situ Persulfate Oxidation Interim Remedial Measure Work Plan* (ERM, 7 July 2005). A sodium persulfate solution was injected into the Shallow and Intermediate Zones via temporary direct-push boreholes during Phase I of the IRM. Between 6 September and 27 September 2005, a total of 5,767 gallons of 2 percent solution was injected at 23 locations, and a total of 70,691 gallons of 15 percent solution was injected at 83 locations.

Monthly groundwater sampling was completed to evaluate the performance of the IRM from October 2005 through January 2006. MCB and DDx concentrations measured in groundwater samples collected during the performance monitoring fluctuated widely. Similar results were observed in performance monitoring data for the concurrently running AS/SVE IRM described in Section 3.2.2. These analytical results, and the results of the DNAPL investigations described in Section 3.2.2, suggested that MCB DNAPL may be present in larger quantities and distributed over a larger area than originally anticipated. Given the uncertain distribution of DNAPL and potential recontamination of treated areas, the In Situ Persulfate Oxidation IRM was suspended in April 2006 pending evaluation of source control alternatives for the residual MCB DNAPL.

3.2.4 *Laboratory Biotreatability Study for Enhanced Bioremediation of Perchlorate*

A laboratory biotreatability study was conducted by SiREM Laboratories of Guelph, Ontario (SiREM; a wholly-owned division of GeoSyntec Consultants) in 2006 to confirm the ability to bioremediate perchlorate in Site groundwater, given the challenging groundwater conditions (e.g., elevated pH and chloride). As a secondary goal, the study assessed the fate of chromium, which is present in groundwater primarily in hexavalent form, under the varying biotreatment conditions. The study evaluated the potential to jointly treat perchlorate and hexavalent

chromium using in situ bioremediation, or to sequence in situ bioremediation of perchlorate with chromium treatment using CaSx reduction, which reduces soluble hexavalent chromium to insoluble trivalent chromium.

Conclusions of the biotreatability study are summarized as follows:

- CPS treatment does not appear to adversely affect or interfere with biodegradation activity.

- The concentration of chloride significantly affects the rate and extent of perchlorate reduction. A chloride concentration below 14,000 mg/L appears to be required to initiate perchlorate reduction.

- Data for citric acid treatments were ambiguous, showing rapid biodegradation under initial test conditions but essentially no biodegradation in a treatment containing CPS. The presence of CPS is not suspected to be the cause of the limited perchlorate biodegradation. Rather, microbial heterogeneity in the soils used to prepare the varying citric acid treatment microcosms is suspected to be the cause. Ethanol and acetate do not promote perchlorate reduction unless microcosms are bioaugmented.

- Bioaugmentation with a perchlorate-reducing microbial culture significantly improves the rate and extent of perchlorate reduction in both the source and downgradient area microcosms, and is likely to be required in those areas to achieve successful enhanced in situ bioremediation at the Site.

Additional information is provided in *Workplan for a Pilot Test of In Situ Bioremediation of Perchlorate in Groundwater at the Former Atofina Chemicals Site, Portland, Oregon* (Geosyntec Consultants, July 2006). The findings of the biotreatability study may be used to support future in situ remedial efforts at the Site.

3.3 GROUNDWATER MODELING

A three-dimensional, numerical groundwater flow model for the Site was developed to support this FFS and the Groundwater Source Control IRM. The design of the groundwater model and methods that were used to calibrate the model to observed groundwater conditions at the facility are

described in the *Draft Groundwater Modeling Report, Arkema Inc., Facility, Portland, Oregon* (ERM, 2007).

The groundwater flow model was used to evaluate the following alternative conceptual groundwater barrier wall designs:

- River Side High Bank Barrier Wall installed to the top of the basalt;
- River Side High Bank Barrier Wall installed into the upper part of the Deep Zone;
- Full Enclosure Barrier Wall installed to the top of the basalt; and
- Full Enclosure Barrier Wall installed into the upper part of the Deep Zone.

The model was used to evaluate the effectiveness of groundwater containment by the alternative conceptual barrier wall designs, and to estimate the number and flow rate of the upgradient withdrawal wells needed for each alternative design. In addition, the model was used to evaluate: 1) the relative effectiveness of a 4-inch thick barrier wall installed using a vibrating beam method and a 3-ft thick barrier wall installed using conventional excavation methods; and 2) the impact of reinjection of treated water on groundwater containment by the alternative conceptual barrier wall designs.

Following are the relevant conclusions of the groundwater model alternatives evaluation:

- The groundwater model simulations of the alternative conceptual barrier wall designs indicate that the four alternative designs would be effective in containing groundwater;
- The number and total combined flow rates of the withdrawal wells in the river side barrier wall simulations (i.e., 17 to 20 withdrawal wells pumping at total combined flow rates of 124 to 130 gallons per minute [gpm], with an estimated design flow rate of 150 gpm based on the preferred pumping scenario) were somewhat greater than the full enclosure barrier wall simulations (i.e., 16 to 18 withdrawal wells pumping at total combined flow rates of 92 to 112 gpm, with an estimated design flow rate of 100 gpm based on the preferred pumping scenario), but not significantly so;

- The model simulations also showed that a 4-inch thick barrier wall installed using a vibrating beam method would be as effective as a 3-foot thick barrier wall installed using conventional excavation methods in containing impacted groundwater; and

- Reinjection of treated water in Lot 2 did not significantly impact containment by the alternative conceptual barrier wall designs in the model simulations. However, reinjection of treated water in Lots 3 and 4 did impact groundwater containment by both the river side and full enclosure barrier wall designs. The impact was greatest for the river side conceptual barrier wall designs, where reinjection of only 5 percent of the treated water in Lots 3 and 4 resulted in incomplete groundwater capture by the barrier walls. For the full enclosure conceptual barrier wall designs, up to 20 percent of the treated water could be reinjected in Lots 3 and 4 without loss of capture.

A brief description of the groundwater model, the methods that were used to evaluate the effectiveness of the alternative conceptual barrier wall designs, and the results of the barrier wall simulations are presented in Appendix A.

3.4 GROUNDWATER BARRIER WALL GEOTECHNICAL ENGINEERING ANALYSIS

The groundwater barrier wall alternatives evaluated in this FFS include possible routing of a barrier wall along the top of the Willamette River bank, otherwise referred to as the River Side High Bank route for purposes of groundwater modeling and identification of barrier wall alternatives (refer to Sections 3.3 and 4.5, respectively). A geotechnical engineering analysis was performed for a possible River Side High Bank barrier wall route to identify the minimum practical offset of the barrier wall from the existing top of bank (TOB) of the Willamette River riverbank to confirm adequate bank stability to support projected construction loads and, following completion of barrier wall construction, static loads for both drained (i.e. low river stage) and rapid drawdown (i.e. following a river high stage flood event) conditions.

Criteria used for acceptable offset included the following:

- Adequate short-term stability during pilot trench excavation and backfill;

- Adequate short-term stability during barrier wall construction; and

- Adequate intermediate bank stability (i.e., following rapid groundwater drawdown resulting from groundwater extraction).

The geotechnical analysis for the River Side High Bank barrier wall route also addresses the Full Enclosure barrier wall route as the two routes are essentially identical in the parts of the routes nearest the river bank where slope stability is most critical. Parts of the Full Enclosure barrier wall route farther from the river bank are less influenced by the stability of the river bank because they are farther away from the critical failure planes that were found to have acceptable stability factor of safety for parts of the barrier wall adjacent to the river bank. A geotechnical analysis was not performed for routing of a barrier wall along the toe of slope (TOS) of the Willamette River bank due to the lack of favorable evaluation of a wide range of evaluation criteria compared to the River Side High Bank route.

The barrier wall geotechnical engineering analysis was based on data obtained during prior site investigations and data obtained during a geotechnical investigation as part of this FFS (see *Scope of Work for Geotechnical Evaluation and Slurry Compatibility Testing in Support of the Groundwater Source Control Interim Remedial Measure* [ERM, March 2007]). Prior data used included monitoring well and soil boring logs and groundwater elevation data. Data obtained during the FFS included four cone penetrometer (CPT) tests and two soil borings advanced along the part of the River Side High Bank route that runs adjacent to the top of the Willamette river bank. The CPT data provided information about the soil type, stratigraphy, and in situ strength characteristics at the locations tested. The soil borings provided Standard Penetration Test data and both disturbed and, in fine soils, undisturbed soil samples for field characterization and subsequent laboratory testing. Descriptions of the field sampling, testing, and geotechnical engineering analysis, results, and conclusions are included in Appendix B.

The geotechnical engineering analysis conclusions are as follows:

- <u>Clearance Trench Offset:</u> It is anticipated that a clearance trench will be required, prior to installation of the barrier wall, to find and, if necessary, remove oversize objects, underground utilities (some utilities may need to be temporarily relocated), and/or monitoring wells that would otherwise be obstructions to construction of the barrier wall. Based upon the geotechnical analysis, the trench can be excavated in the former fill zone to a depth of 25 ft bgs using 2

horizontal to 1 vertical (2H:1V) side slopes and must be located greater than approximately 60 feet from the land side of the TOB. Use of trench support to steepen the trench sidewalls would result in a reduction of this minimum distance from the TOB;

- Vibrated Beam Barrier Wall Offset: A barrier wall constructed using vibrated beam slurry trench techniques to a maximum depth of 60 ft bgs must be located greater than approximately 8 feet from the land side of the TOB. A barrier wall constructed using vibrated beam slurry trench techniques to a maximum depth of 90 ft bgs must be located greater than approximately 10 feet from the land side of the TOB. However, the aforementioned clearance trench offset (60 feet) would prevail in the absence of trench support added to steepen the trench side slopes and to reduce the offset for any barrier wall depth in either of those two depth ranges;

- Slurry Trench Barrier Wall Offset: A barrier wall constructed using conventional slurry trench techniques to a maximum depth of 60 ft bgs must be located greater than approximately 18 feet from the land side of the TOB. A barrier wall constructed using conventional slurry trench techniques to a maximum depth of 90 ft bgs must be located greater than approximately 20 feet from the land side of the TOB. However, the aforementioned clearance trench offset (60 feet) would prevail in the absence of trench support added to steepen the trench side slopes and to reduce the offset for any barrier wall depths in either of those depth ranges; and

- Sheet Pile Barrier Wall Offset: A barrier wall constructed using driven sheet pile to a maximum depth of 60 ft bgs must be located greater than approximately 18 feet from the land side of the TOB. A barrier wall constructed using driven steel sheet pile to a maximum depth of 90 ft bgs must be located greater than approximately 20 feet from the land side of the TOB. However, the aforementioned clearance trench offset (60 feet) would prevail in the absence of trench support added to steepen the trench side slopes and to reduce the offset for any barrier wall depth in either of those depth ranges.

3.5 SLURRY MATERIALS TESTING

Slurry materials testing was implemented to evaluate the ability of candidate slurry wall technologies to achieve sufficiently low permeability

barriers. Testing was completed using samples of affected groundwater and soil from the Site.

Two soil borings advanced along the barrier wall route to collect soil samples for the geotechnical engineering analysis were also used for collecting soil samples for the slurry materials testing. Groundwater samples were collected from monitoring wells in this area. The soil and groundwater samples were shipped to the slurry materials testing laboratory, Sierra Testing Laboratories, Inc. of El Dorado Hills, California.

The Slurry Materials Testing Report presents the testing procedures, results, and conclusions of this work, and is included as Appendix C.

The conclusions of the slurry materials testing are summarized as follows:

- The Atterberg limits and the swell index of the commercial clay slurry products received at the laboratory were in the same range of values published by the commercial manufacturers for those respective products;

- Swell-related properties of clay additives were affected by Site groundwater compared to results of testing with distilled water, although subsequent tests of slurry and slurry backfill mixtures showed that the affect is not consequential to use of slurry to construct the barrier wall;

- Both attapulgite and bentonite clay additive products made clay slurry with slurry index properties that achieved the target viscosity and unit weight acceptance criteria, although both required relatively high clay-water mix ratios to produce effective slurry when exposed to both chloride- and organics-affected groundwater (in comparison to deionized water or unaffected Site potable water);

- Individual soil samples had index properties typical of a range of sandy to clayey soil, with most of the soil samples (collected from the Shallow and Intermediate Zones) found to have index properties typical of a sandy silt or silty sand typical of soil types observed in prior soil borings (i.e., the soil samples are representative of soils expected to be encountered during construction of a barrier wall at the Site);

- Composite soil samples had index properties that were typical of a sandy silt with some clay;

- Mixtures of either of the two composite soil samples with either of the two clay slurries made soil-slurry backfill samples with slump between 4 and 6 inches, unit weight at least 15 pcf more than the unit weight of the slurry, and hydraulic conductivity generally less than 1×10^{-7} cm/sec when tested using Site groundwater as the test permeant, and otherwise suitable for construction of an effective barrier wall using slurry techniques;

- Mixtures of the DNAPL-affected soil sample with the bentonite clay slurry made a soil-slurry backfill sample with a slump of 7 inches, marginally in excess of the 4 to 6-inch target criteria, unit weight at least 15 pcf more than the slurry, and hydraulic conductivity less than 1×10^{-7} cm/sec when tested using organics-affected Site groundwater as the test permeant, and otherwise suitable for construction of an effective barrier wall using slurry techniques that would not be adversely affected by exposure to Site DNAPL; and

- Cured mixtures of either of the two composite soil samples with the clay-cement additive made a cured soil-slurry backfill sample with hydraulic conductivity less than the 1×10^{-7} cm/sec target criteria when tested using affected Site groundwater as the test permeant and suitable for construction of a plastic concrete barrier wall using a vibrated beam slurry technique.

Commercial attapulgite and bentonite products mixed separately with Site potable water were both found capable of producing clay-water slurry that achieved target acceptance criteria for viscosity and unit weight.

Commercial attapulgite and bentonite slurry mixed separately with chloride- and organics-affected soil samples achieved target acceptance criteria for slump and unit weight, and achieved the target hydraulic conductivity when tested using correspondingly affected groundwater as the test permeant.

Commercial clay-cement (i.e., Liquid Earth Support, Inc. "Impermix") additive mixed separately with chloride- and organics-affected soil samples and cured more than 45 days prior to testing achieved target acceptance criteria for hydraulic conductivity when tested using correspondingly affected groundwater used as test the permeant.

3.6 GROUNDWATER TREATABILITY STUDY

Groundwater extraction and treatment are an essential part of the proposed IRM. Due to the variety of constituents present in Site groundwater, multiple technologies are required to treat the groundwater. As such, a groundwater treatability study was conducted to support this FFS and design of the Groundwater Source Control IRM. The goal of this study was to evaluate the feasibility of several treatment technologies and develop design parameters and cost information for full-scale implementation of potentially feasible technologies. The treatability study was performed by Adventus Americas, Inc. (Adventus), under the direction of ERM, KC Environmental, Inc., and LSS, at their testing facility in Mississauga, Ontario, Canada.

As described in the *Groundwater Treatability Study Work Plan* (ERM, April 2007), groundwater samples were collected from monitoring wells at the Site by ERM between 29 and 31 March 2007. The wells were selected to provide groundwater from across the length of the proposed barrier wall, such that a blended composite sample would be representative of the potential influent to the full-scale groundwater treatment system. Groundwater samples were collected from the wells using a submersible pump, placed in DOT-approved 55-gallon drums, and shipped to Adventus' testing facility. Treatability testing commenced during April 2007 and was completed in February 2008. A copy of the summary report for the groundwater treatability study is included as Appendix D (provided to ODEQ and USEPA under separate cover on 10 April 2008).

The treatability study scope of work included the following testing:

- Chemical Reduction Testing to evaluate the ability of this technology to treat chlorate and perchlorate;

- Chemical Precipitation Testing to evaluate the ability of this technology to treat iron and metals considered COPCs;

- Anaerobic Biological Treatment Testing to evaluate the ability of this technology to treat chlorate and perchlorate;

- Ion Exchange Testing (optional, pending results of Anaerobic Biological Treatment Testing) to evaluate the ability of the technology to treat chlorate and/or perchlorate potentially remaining in treated effluent from the anaerobic biological treatment process; and

- Proprietary Biological Treatment Testing to evaluate the ability of this technology to treat iron, metals considered COPCs, chlorate, perchlorate, VOCs, SVOCs, and DDx.

Other treatment technologies considered for use in the full-scale treatment process included air stripping and liquid-phase carbon adsorption. No treatability testing was conducted for these technologies since they are proven technologies and can be designed without completing such testing.

Details on the specific testing protocols are provided in the *Groundwater Treatability Study Work Plan*. The following is a brief summary of the testing protocol and results:

- **Chemical Reduction** – Batch testing was conducted during April/May 2007 using three different grain sizes of zero valent iron (ZVI). Some reduction in chlorate was observed for the finest grained ZVI, but otherwise ZVI was ineffective for chlorate treatment. In addition, no reduction in perchlorate was observed for any of the grain sizes evaluated, proving ZVI to be ineffective for perchlorate treatment. Based on these results, column testing for ZVI was placed on hold pending the results of anaerobic biological treatment testing. Given the success of the anaerobic biological treatment testing, additional column testing for ZVI was considered unnecessary and not completed.

- **Chemical Precipitation Testing** – Initially, chemical precipitation testing was to include separate testing for hydroxide precipitation and iron co-precipitation via addition of a supplemental iron source (e.g., ferrous sulfate). However, given the relatively high iron concentrations in the groundwater treatability samples, iron co-precipitation occurred during precipitation testing without addition of a supplemental iron source. Jar testing for chemical precipitation was conducted from May to August 2007. The testing results indicated that sodium hydroxide (NaOH) was preferable to lime ($Ca[OH]_2$) as a precipitant for metals. Based on the testing results, aeration, pH adjustment to 8.0 using NaOH, polymer addition, and settling was selected as the treatment method for removing iron from groundwater. Filtration was not required following settling, as iron concentrations in treated groundwater were below the target of 1 to 2 mg/L recommended for anaerobic biological treatment testing. No conclusions could be drawn for other metals considered to be COPCs,

as potential discharge limits have yet to be defined for the Groundwater Source Control IRM.

- **Anaerobic Biological Treatment Testing** – Both fluidized bed reactors (FBRs) and packed bed reactors (PBRs) were tested. The FBRs included two reactors in series with one containing sand as the fluidized media and the second containing granular activated carbon (GAC) as the fluidized media. The PBR included a single reactor filled with Adventus' proprietary biological treatment media, AQUAMEND®. Testing was initiated in August 2007 in recycle mode, which was necessary to acclimate the microorganisms. Continuous mode testing commenced in October 2007. Testing initially included establishing and maintaining anaerobic conditions in the reactors, and achieving the optimal substrate (high fructose corn syrup selected for purposes of the treatability testing) and nutrient (nitrogen and phosphorus) balance to stabilize reactor performance. Once stable conditions were achieved, the hydraulic residence time (HRT) for each reactor was adjusted downward to a target level of three hours. Overall, both the FBRs and PBRs proved capable of treating chlorate and perchlorate to non-detectable concentrations at an HRT of three hours for both low (i.e., 1,500 mg/L) and high (i.e., 8,000 mg/L) chloride conditions[7]. In addition, testing indicated that (1) a single FBR was capable of treating chlorate and perchlorate to non-detectable concentrations, suggesting that the use of two FBRs in series is not required to achieve treatment goals for these compounds, (2) sand or GAC are suitable fluidized media for the FBR to achieve the treatment goals for these compounds, and (3) ion exchange will not be required as a polishing treatment step.

- **Ion Exchange Testing** – Ion exchange was identified as an optional polishing step for removal of chlorate and/or perchlorate should anaerobic biological treatment not support consistent and complete removal of these compounds. Based on the success of the anaerobic biological treatment testing, the ion exchange testing was considered unnecessary and not completed.

[7] The approximate 1,500 mg/L "low" chloride concentration corresponds to the blended groundwater treatability study sample collected from wells across the entire treatment area. The approximate 8,000 mg/L "high" chloride concentration corresponds to a mixture of six parts of the blended groundwater treatability study sample with one part of a groundwater treatability study sample collected from a well in the vicinity of the former salt pads.

- **Proprietary Biological Treatment Testing** – This testing was intended to evaluate the performance of two of Adventus' proprietary treatment products (i.e., EHC® and AQUAMEND) as the basis for an alternate treatment system. If successful, the alternate treatment system would be used as a replacement to the other, more traditional process trains proposed for groundwater treatment. Testing commenced during August 2007 in recycle mode, which was necessary to acclimate the microorganisms. Continuous mode testing commenced during September 2007. Testing evaluated two processes that included the following:

  - EHC reactor → Sand column → Waterloo Emitter (oxygenation step) → Aerobic AQUAMEND reactor

  - EHC reactor → Sand column → Anaerobic AQUAMEND reactor → Anaerobic AQUAMEND reactor

  Overall, the EHC reactor in combination with the sand column proved capable of treating chlorate and perchlorate to non-detectable concentrations at an HRT of approximately six hours for both low (i.e., 1,500 mg/L) and high (i.e., 8,000 mg/L) chloride conditions. However, the subsequent aerobic and anaerobic AQUAMEND reactors proved to only be partially effective for treatment of other COPCs.

In summary, chemical precipitation and anaerobic biological treatment (including FBRs, PBRs, and EHC reactors) are viable treatment technologies for removal of metals, and perchlorate and chlorate, respectively, from groundwater and will be considered further in this FFS. The other treatment technologies were either unnecessary (i.e., ion exchange as a polishing step) or ineffective (chemical reduction using ZVI). Depending on the concentration of iron present in groundwater pumped from the recovery wells, a supplemental iron source may need to be added for the full-scale groundwater treatment system if the treatment system is not achieving the applicable discharge criteria yet to be determined. Modifications to the chemical precipitation system to include the addition of ferrous sulfate (or other source of iron) would consist of a ferrous sulfate (or other source of iron) feed tank, pump, and corresponding controls.

4.0 DEVELOPMENT OF REMEDIAL ALTERNATIVES

Remedial alternatives for the Groundwater Source Control IRM were developed based on prior site characterization, field sampling and testing, treatability testing, and technical analysis of candidate technologies, as described below.

4.1 APPLICABLE AND RELEVANT OR APPROPRIATE REQUIREMENTS

A preliminary list of statutes and regulations that may be considered ARARs for the project is included in Table 4-1. These and other potential ARARs can be generally categorized as chemical-specific, action-specific, or location-specific.

The list of ARARs in Table 4-1 includes rules and regulations typically relevant for in-water actions. These have been included for completeness, and to ensure consistency with the in-water early action planned for the Site.

ARARs for each of these categories will be finalized and selected in consultation with ODEQ and USEPA during implementation of the Groundwater Source Control IRM.

4.2 REMEDIAL ACTION OBJECTIVES

As stated in Section 1.1, the remedial action objectives (RAOs) of this Groundwater Source Control IRM are as follows:

- Establish hydraulic control of COPCs in groundwater from the primary source areas (Lots 3 and 4) at the Site to the Willamette River;
- Reduce the potential for recontamination of river sediments via the groundwater pathway following the Arkema non-time-critical removal action;
- Allow upland source control measures to proceed on an independent schedule from the non-time-critical removal action without impeding or compromising that work; and

- Implement a remedy, which to the extent practicable, will complement and be compatible with potential final upland remedies for the Site.

Cleanup goals for the upland portion of the Site will be developed through the comprehensive site-wide upland FS process, to be completed separately from this IRM. As such, the goal for the Groundwater Source Control IRM is to establish hydraulic control of COPCs in groundwater from the primary source areas pending completion of final upland remedies for the Site.

4.3 GENERAL RESPONSE ACTIONS

The general response actions proposed to satisfy the remedial action objectives of the Groundwater Source Control IRM include engineering controls and groundwater treatment. Specifically, the Groundwater Source Control IRM will consist of the following general response actions:

- **Containment** via a barrier wall to physically separate the upland and in-water portions of the Site and reduce the amount of groundwater pumping needed to maintain hydraulic control of COPCs;

- **Hydraulic control** using groundwater extraction to prevent COPCs present in on-site groundwater from moving around, under, or over the containment barrier wall; and

- **Groundwater treatment system** to address COPCs in groundwater extracted from the containment area.

These general response actions are discussed in more detail in the following sections.

4.3.1 Containment Barrier Wall

Although groundwater modeling suggests hydraulic capture could be achieved without the barrier wall and would be sufficient to create groundwater containment, LSS will construct a barrier wall to provide additional containment of groundwater flow from the areas of the Site requiring source control toward the Willamette River. In addition, a barrier wall will serve to reduce the volume of extracted groundwater required to achieve hydraulic containment. The barrier wall is expected to contain groundwater within Lot 4 and a portion of Lot 3 (i.e., from the southeastern property boundary to the northwestern most No. 2 dock).

The barrier wall will extend from above the top of the Shallow Zone to an appropriate confining layer. The barrier wall will not be "keyed" into the basalt bedrock (i.e., excavated into the bedrock) because such excavation is unnecessary to contain affected groundwater. The low permeability silts and clays that comprise the Deep Zone above the basalt bedrock will provide an appropriate zone into which to complete the barrier wall based on groundwater modeling completed as part of the FFS (see Appendix A).

The layout and extent of the barrier wall described in this FFS was selected to contain groundwater in the areas of the Site where the source of impacts exist. The planned barrier wall will extend from the southern-most portion of the Site to MWA-63, the well which is considered the northern extent of groundwater impacts associated with Arkema's former manufacturing areas (Lots 3 and 4) of the Site. The detailed rationale and justification for this barrier wall route is presented in the Groundwater Source Control Evaluation (Integral, April 2007) and Addendum I (Integral, March 2008). A summary of the screening evaluation is provided in Section 2.0.

Additional discussion, review, and evaluation of barrier wall alternatives are provided in the following sections of this FFS.

4.3.2 Hydraulic Containment System

The purpose of the hydraulic containment system is to maintain a hydraulic gradient inward/away from the river by extracting groundwater from locations upgradient of the barrier wall. The system will include the following primary elements:

- Groundwater extraction wells;
- Conveyance piping;
- Groundwater treatment train capable of reducing contaminant concentrations to discharge limits that will be determined through the applicable permitting and approval process; and
- Treated effluent water discharge system.

Extraction wells will be placed along the barrier wall and at other locations as necessary to maintain groundwater capture and a hydraulic gradient away from the river. Groundwater modeling performed to support this FFS provided a preliminary number of extraction wells,

optimum locations, screened intervals, and pumping rates required to achieve the desired hydraulic containment for conducting this FFS. Based on the results of this groundwater modeling, the design flow rates selected for the groundwater treatment system are 100 gpm and 150 gpm for the Full Enclosure and River Side barrier wall routes, respectively. However, ERM recommends that groundwater pumping tests be performed as part of a pre-design investigation to refine and reduce the uncertainty associated with the permeability values used for modeling purposes, which can have a significant effect on the required pumping rate. Additional groundwater modeling will be conducted using the pumping test data to refine and better predict the required groundwater pumping rate to achieve hydraulic control, design the extraction wells and their layout, and ultimately size the treatment system.

4.4 TECHNOLOGY SCREENING

The *Scoping Technical Memorandum* (ERM, December 2006) prepared for the Groundwater Source Control IRM included a preliminary technology screening to identify remedial technologies to be evaluated as part of the FFS. As the presumptive approach for this IRM is a containment barrier wall coupled with a hydraulic containment system, only technologies relevant to these two general response actions were considered. The following is a summary of the technology screening, updated for purposes of this FFS.

4.4.1 Groundwater Barrier Wall Technologies

Screening of groundwater barrier wall technologies included identification of the general range of capabilities and limitations posed to the success of each technology, including, as appropriate, the following:

- Compatibility with potential future river bank grading, remediation, and/or capping;
- Transmissive zone thicknesses and hydraulic conductivity;
- Groundwater and surface water (including the river and on-site surface drainage) levels, flow paths, and flow velocity;
- Topography of the barrier wall route, including the adjacent river bank, excavation work platform(s), and slurry mix pad(s);

- Resistance to seismic loads (all three technologies are generally equally resistant to seismic loads, so resistance to seismic loads is not a distinguishing characteristic of any of the technologies);

- Limitations, or lack of limitations, on loads imposed on adjacent surfaces after construction;

- Potential to generate local ground vibration during construction that might adversely affect vibration-sensitive equipment located in off-site facilities near the Site;

- Presence, type, extent, ability to remove, and need to maintain, replace, or restore to service existing overhead, surface, and subsurface excavation obstructions;

- Range of initial and end dates of preferred construction season(s) and associated river stage, groundwater levels, and climatic conditions suitable for construction; and

- Availability of specialty equipment, personnel, and supplies.

Groundwater barrier wall options considered during the FFS addressed three site-specific characteristics: 1) location, 2) construction technology, and 3) total depth.

4.4.1.1 *Barrier Wall Location*

Three options for barrier wall location were selected for screening as part of the FFS, as follows:

- River Side High Bank Route, located on the river side of the groundwater source zone and on the land side of the top of the river bank;

- Full Enclosure Route, which includes much of the River Side High Bank route plus additional extent to provide full enclosure of the groundwater source zone; and

- River Side Low Bank Route, located on the river side of the groundwater source zone between the river bank toe of slope and the shore line.

Based on the results of the screening process, the River Side Low Bank Route is removed from further consideration, primarily because it has been determined to be technically impracticable. Factors supporting this determination are as follows:

- Susceptibility to relatively frequent flooding that would instantaneously compromise the ability of the barrier wall to achieve the remedial action objective pertaining to hydraulic control of COPCs;

- Additional permitting and approvals associated with work to be completed in close proximity to the river may include, but not be limited to, the Federal Water Pollution Control Act/Clean Water Act (CWA) dredge and fill provisions under Section 404 (33 USC Section 1344) Program, water quality certification provisions under Section 401 (33 USC Section 1341), Rivers and Harbors Appropriations Act for construction of structures such as berms and pilings (33 USC Sections 10 and 403), and Removal Fill Laws and Regulations (ORS 196.795 through 196.990; OAR Chapter 141, Division 85);

- Exceptionally poor access along the low part of the route, requiring construction of one or two substantial access ramps and staging support facilities;

- Difficulties associated with construction of the barrier wall along the steep slope of the river bank, including unknown long-term slope stability;

- Increased construction duration;

- Increased potential for adverse effects on worker safety;

- Increased potential for release of affected residuals to the river during construction;

- Requirement for significant work platform improvement and removal in the low part of the route;

- Difficulty in setting temporary controls for slurry/soil runoff into the river during construction, with the close proximity to the river providing little or no buffer zone;

- Requirement for temporary or permanent removal and/or replacement of the dock piers, potentially causing dock instability);

- Increased susceptibility to river erosion and seismic damage due to proximity to the river;
- Increased susceptibility to adverse affects and/or damage from dredging; and
- Excessive costs associated with construction of the barrier wall.

Additional discussion of the River Side High Bank and Full Enclosure Routes is provided in Section 4.5.1.1.

4.4.1.2 *Barrier Wall Construction Technology*

Available groundwater containment technologies are listed in Table 4-2 with preliminary screening comments on feasibility, effectiveness, implementability, and cost of each technology. Based on the preliminary technology screening in Table 4-2, the following groundwater barrier wall technologies are retained for detailed evaluation, as further described in Section 4.5.1.2:

- Vibrated beam slurry groundwater barrier wall;
- Conventional slurry trench groundwater barrier wall; and
- Sealed steel sheet pile groundwater barrier wall.

4.4.1.3 *Barrier Wall Total Depth*

Two options for barrier wall depth were selected for screening as part of the FFS, as follows:

- Total depth within the Deep Zone; and
- Total depth at the top of the basalt.

For the Deep Zone option, the total depth (i.e., bottom) of the barrier wall would extend into, but not through, the Deep Zone. Based on the results of the screening process, the Deep Zone option is removed from further consideration. Factors supporting this determination are as follows:

- ODEQ requirement that the portion of barrier wall located downgradient of the Acid Plant Area extend to the top of the basalt

further reduces potential benefits associated with terminating the barrier wall within the Deep Zone;

- Relatively low thickness of Deep Zone at various locations along the barrier wall route results in minor reductions in overall depth and total surface area of barrier wall;

- Relatively minor cost savings are realized relative to extending the total depth of the barrier wall to the top of the basalt; and

- Potential difficulties in establishing the total depth for completion of the barrier wall into the Deep Zone.

Additional discussion of the total depth at basalt option is provided in Section 4.5.1.3.

4.4.2 *Ex Situ Groundwater Treatment Technologies*

Table 4-3 summarizes the ex situ groundwater treatment technologies selected for screening in the FFS along with the expected effectiveness for their target COPCs. The selected technologies and target COPCs for consideration in the FFS include the following:

- Air stripping (VOCs);

- Aerobic biological treatment (primarily VOCs, and will achieve some treatment for SVOCs and metals);

- Anaerobic biological treatment (primarily perchlorate and chlorate, and will achieve some treatment for DDx, VOCs, SVOCs);

- Chemical oxidation (DDx, VOCs, and SVOCs);

- Chemical precipitation (metals);

- Chemical reduction (DDx, VOCs, possible metals depending on the form, and will achieve some treatment for perchlorate and chlorate);

- Ion exchange (perchlorate, and possible metals depending on form); and

- Liquid-phase carbon adsorption (DDx, VOCs, SVOCs, and possible metals depending on form).

Aerobic biological treatment was not initially included the *Technical Scoping Memorandum* (ERM, December 2006) for further consideration, as it was not expected to be effective for many of the COPCs and was thought to provide little benefit from a cost perspective for those selected site-specific compounds it may effectively treat. However, after further internal evaluation, aerobic biological treatment was evaluated as part of the groundwater treatability study as part proprietary biological treatment testing, and was considered during the technology screening process.

Table 4-4 provides a screening of the effectiveness, implementability, and relative cost of each technology option, and reflects the results of the groundwater treatability studies completed to support this FFS. Technical findings from the groundwater treatability studies include the following:

- Based on groundwater treatability studies, a chemical reduction/ZVI reactor is not considered effective for pretreatment of chlorate and perchlorate and is removed from further consideration;

- Based on groundwater treatability studies, chemical precipitation using sodium hydroxide and aeration is effective for removal of iron, but the ability of this technology to remove metals considered to be potential COPCs could not be fully assessed since NPDES discharge limits have yet to be defined for the Groundwater Source Control IRM;

- Based on groundwater treatability studies and presence of relatively high iron concentrations in the groundwater treatability samples, iron co-precipitation may be required to remove metals to levels below potential discharge limits;

- Based on the solids loading expected in the effluent from the precipitation reactor, a solids filter may be inadequate and prone to frequent backwashing/fouling and a clarifier with an associated sludge handling system will likely be required;

- Based on the groundwater treatability studies, the FBR, PBR, and EHC/sand reactor were proven effective for anaerobic biological treatment of perchlorate and chlorate;

- Considering that aeration is required for removal of metals early in the process train, downstream air stripping will provide little additional treatment for residual VOCs (which can be removed more cost-

effectively by liquid-phase GAC) and is removed from further consideration;

- Based on published literature and prior experience, liquid-phase GAC is expected to be effective for treatment of DDx, VOCs, and SVOCs;

- Based on groundwater treatability studies, ion exchange is not expected to be required for treatment of perchlorate and chlorate since anaerobic biological treatment was able to effectively remove perchlorate and chlorate to laboratory detection limits, and is removed from further consideration;

- Based on groundwater treatability study results, the alternate treatment processes are not expected to be effective as standalone process trains for treatment of extracted groundwater and reducing COPC concentrations to levels below potential discharge limits, and are removed from further consideration; and

Air emission control technologies were initially considered for treating air stripper offgas. However, the anticipated air emission rate of VOCs is below levels requiring air emission control based on groundwater data and a review of the applicable regulations (OAR 340-216-0020(1) and Table 1, Part B, Category 75), so no further evaluation of air emission control technologies was completed as part of this FFS. Further assessment of the requirement for air emission control for the groundwater treatment system will be completed as part of the permitting and design phases of the project.

Based on the results of the screening process, the following technologies were retained for further evaluation as components of the ex situ groundwater treatment alternative:

- Chemical precipitation;

- Anaerobic biological treatment via FBR, PBR, and EHC/sand reactor; and

- Liquid-phase carbon adsorption.

Section 4.5.2 presents additional discussion of these treatment technologies.

4.4.3 Treated Water Discharge Options

Four possible treated water discharge options are considered as part of this FFS. Table 4-5 summarizes the following discharge options to be considered for this project:

- Discharge to the Willamette River;
- Reinjection to shallow groundwater;
- Discharge to a publicly owned treatment works (POTW); and
- Reinjection to deep groundwater.

Discharge to the storm water sewer was preliminarily included as a potential management alternative. However, this is no longer considered a separate discharge alternative because water discharged to the storm water sewer would ultimately be discharged to the Willamette River and be subject to National Pollutant Discharge Elimination System (NPDES) discharge requirements.

4.5 DEVELOPMENT OF REMEDIAL ALTERNATIVES

The Groundwater Source Control IRM will include a combination of groundwater containment, ex situ groundwater treatment, and discharge of treated water. This section describes the alternatives selected for evaluation as part of this FFS.

4.5.1 Development of Groundwater Barrier Wall Alternatives

Criteria important to development of a cost-effective, technically practicable groundwater barrier wall include the following:

- Location;
- Construction technology; and
- Total depth.

These criteria are described below in this section.

4.5.1.1 *Location*

Options for location of the barrier wall include River Side High Bank and Full Enclosure routes. Additional details are as follows:

- The *River Side High Bank Route* would be located on the river side of the groundwater source zone and on the land side of the river bank TOB (see Figure 4-1). This route is generally level, has good access, and is much less susceptible to flooding than the River Side Low Bank route. In addition, this route would require no modification of the river bank or the dock piers.

- The *Full Enclosure Route* would include much of the River Side High Bank route plus additional extent to provide full enclosure of the groundwater source zone (see Figure 4-2). Similar to the River Side High Bank route, the Full Enclosure route is generally level, has good access, is much less susceptible to flooding than the River Side Low Bank route, and would require no modification of the river bank or the dock piers.

4.5.1.2 *Construction Technology*

Options for barrier wall construction technology include a Vibrated Beam Slurry Wall, a Slurry Trench Slurry Wall, and a Sealed Steel Sheet Pile Barrier Wall. General construction details and conceptual drawings for these technologies are provided in Table 4-6 and Figure 4-3, respectively. Additional details are provided below in this section.

A *Vibrated Beam Slurry Wall* would be constructed by a combination of jetting and vibration of a steel frame into the formation at the base of a shallow (i.e., approximately 2 ft bgs) slurry reserve and containment trench to the target depth. Conceptual design considerations include the following:

- **Route Clearance**: Surface structures (i.e., concrete foundations, slabs, structures, etc.) would need to be removed, intersecting sewers would need to be sealed, and subsurface obstructions larger than approximately 4 inches would need to be removed in the zone in which the barrier wall would be constructed.

- **Work Platform**: A relatively level excavation work platform approximately 20 feet wide would be needed for construction. No slurry backfill mix platform would be needed because no soil, other

than the route clearance trench and the slurry reservoir trench, would be excavated.

- **Profile Slope Limits**: The slurry trench needs to be relatively level along its length to maintain an adequate reserve and containment in the slurry reservoir trench. Consequently, the slurry wall cannot be constructed along slopes steeper than approximately two percent.

- **Steep Slope Techniques**: Where the slope is steeper, such as at the river bank, the slurry wall would need to be constructed in stages. A single stage should be adequate to allow construction of the barrier wall from the river bank toe of slope to the TOB. However, the cost of that construction would necessarily be greater than an equivalent level route, to account for fill placed to make the excavation work platform, the slurry mix platform, and the additional slurry wall, the removal of unaffected fill otherwise in the river channel, removal and disposal of potentially affected material excavated from the unused upper part of the slurry wall, and capping the sloped surface.

- **Barrier Wall Material**: The barrier wall would be a mixture of clay-cement slurry and native soil that ordinarily produces a slow-setting plastic-concrete grout. Samples of Site soil, a clay-cement additive, Site potable water, and affected Site water were mixed, cured and tested to demonstrate that the material can be effective at the site (see Section 3.5 and Appendix C).

- **Depth Limits**: Vibrated beam slurry walls have been constructed at similar sites to depths over 100 ft bgs, well in excess of the depth needed for a barrier wall at the Site. That depth was found to be feasible at the Site based on a geotechnical engineering analysis (see Section 3.4 and Appendix B).

- **Construction Residuals**: Construction of a vibrated beam slurry wall would generally produce a relatively small volume of affected residuals in addition to the route obstruction clearance trench and the slurry reservoir trench. No soil would be excavated from the slurry wall.

- **Vibration**: A vibrated beam slurry wall would be advanced to total depth from the surface using a combination of slurry injection plus static and vibratory loads imposed by the construction tool. The primary frequency and amplitude of the vibration can be varied to reduce potential adverse effect on subsoil stability (i.e., liquifaction)

and to vibration-sensitive receptors, such as fabrication equipment reported to be at the Siltronic facility.

A *Slurry Trench Slurry Wall* would be constructed by excavating a trench maintained open by slurry to the target depth, mixing the soil excavated from the trench with slurry to make backfill with appropriate unit weight and slump, and backfilling the trench with the slurry backfill. Conceptual design considerations include the following:

- **Route Clearance**: Surface structures (i.e., concrete foundations, slabs, structures, etc.) would need to be removed, intersecting sewers would need to be sealed, and subsurface debris larger than approximately 24 inches would need to be removed in the zone in which the barrier wall would be to be constructed.

- **Work Platform**: A relatively level excavation work platform approximately 20 feet wide would be needed, and a relatively level slurry backfill mix platform approximately as wide as the barrier wall is deep (i.e. approximately 60 to 90 feet wide) would be needed adjacent to the excavation platform.

  Alternatively, if sufficient space is not available for a slurry backfill work platform adjacent to the excavation work platform, the excavation spoil could be loaded and hauled to a remote slurry backfill mix platform. Under that scenario, mixed slurry backfill would be loaded and hauled to the slurry trench to allow placement of the slurry backfill, although ordinarily at substantially increased cost (including the effects of decreased production, increased worker safety hazard, and potential for spill of affected materials due to the additional handling of loose or liquids-containing materials on slick unpaved surfaces).

- **Profile Slope Limits**: The slurry trench would need to be relatively level along its length to maintain an adequately low freeboard to the slurry surface to support the open slurry trench until backfilled. Consequently, the slurry wall could not be constructed along slopes steeper than approximately one percent.

- **Steep Slope Construction**: Where the slope is steeper, such as at the river bank, the slurry wall would need to be constructed in stages. A single stage would be adequate to allow construction of the barrier wall from the river bank toe of slope to the TOB. However, the cost of that construction would necessarily be greater than an equivalent level

route to account for fill placed to make the excavation work platform, the slurry mix platform, and the additional slurry wall, the removal of unaffected fill otherwise in the river channel, removal and disposal of potentially affected material excavated from the unused upper part of the slurry wall, and capping the sloped surface.

- **Barrier Wall Material**: The barrier wall would be made of a mixture of fine clay (i.e., bentonite or attapulgite) slurry and soil excavated from the slurry trench. The resulting slurry backfill does not set and cure to a strength in excess of, if matching, the surrounding soil (i.e., it is not a pozzolan like the plastic-concrete grout usually used to construct a vibrated beam slurry wall). Testing of mixtures of clay slurry and samples of Site soils are described in Section 3.5 and Appendix C.

- **Depth Limits**: Conventional slurry trench slurry walls have been constructed at similar sites to depths over 100 ft bgs, well in excess of the depth needed for a barrier wall at the Site. That depth was found to be feasible at the Site based on a geotechnical engineering analysis (see Section 3.4 and Appendix B).

- **Construction Residuals**: Construction of a slurry trench slurry wall would generally produce a relatively small volume of affected residuals. All soil excavated from the slurry wall would be used to make slurry backfill.

- **Vibration**: A slurry trench slurry wall would be advanced to total depth from the surface using a conventional tracked hydraulic excavator with an excavation bucket mounted on an extended boom. That type of excavation normally produces negligible vibration. The vibration would not be a significant concern to vibration-sensitive receptors, such as fabrication equipment reported to be at the Siltronic facility.

A *Sealed Steel Sheet Pile (SP) Barrier Wall* would be constructed by driving steel sheet pile from the surface to the total depth using an impact or vibratory hammer, and then injecting sealant into the piling joints. Conceptual design considerations include the following:

- **Route Clearance**: Surface structures (e.g., concrete foundations, slabs, structures, etc.) would need to be removed, intersecting sewers would need to be sealed, and subsurface debris larger than approximately four-inch size would need to be removed in the zone in which the barrier wall would be constructed.

- **Work Platform**: A relatively level excavation work platform approximately 20 feet wide would be needed.

- **Profile Slope Limits**: While the work platform needs to be relatively level, the surface into which the sheet piles would be driven can have much more slope than that for either a VB or ST slurry wall. Areas adjacent to the work platform are needed to stage the sheets, although the range through which the driving crane can pick up sheets would allow more flexibility in placement of the support areas than for the slurry backfill mix platform. Consequently, the sheet pile wall should be able to be constructed along slopes as steep as the river bank with little, if any, need for excavation or fill along that part of the route.

- **Joints**: To reduce potential for migration of potentially affected ground water or infiltrating river water through sheet pile joints, special sealed joints would be used. The special joint would be sealed with a compatible sealant after driving the associated sheet pile sections to the final depth.

- **Depth Limits**: Sheet pile barrier wall have been constructed at similar sites to depths over 100 ft bgs, well in excess of the depth needed for a barrier wall at the Site.

- **Construction Residuals**: Construction of a sheet pile barrier wall would be expected to produce a relatively small quantity of affected residuals other than the affected material excavated from the underground obstruction clearance trench.

- **Vibration**: A SP slurry wall would be advanced to total depth from the surface using vibratory loads imposed by a hammer or a vibratory drive head. The primary frequency and amplitude a vibratory drive head could be varied to reduce potential adverse effect on subsoil stability (i.e., liquifaction) and to vibration-sensitive receptors, such as fabrication equipment reported to be at the Siltronic facility, to some extent.

It is expected that potential vibration impacts to surrounding commercial operations will need to be considered during design of the barrier wall. The results from on-going vibration studies at the Gasco and Siltronic sites will be evaluated and considered during design to select construction activities that reduce impacts to these surrounding commercial operations. These results were not available at the time of

preparation of this FFS and therefore could not be utilized in the evaluation of barrier wall construction technologies.

4.5.1.3 *Total Depth*

The *T.D. at Basalt* option would set the total depth of the barrier wall at the top of the basalt. The depth of a barrier wall constructed to total depth at the basalt (T.D. at Basalt depth) is estimated to range from approximately 50 to 85 vertical feet for both the River Side High Bank and Full Enclosure barrier wall routes.

A profile for the River Side High Bank route is shown on Figure 4-4. A profile for the Full Enclosure route is shown on Figures 4-5 and 4-6.

The combination of the two locations, the three construction technologies, and the one depth results in six alternatives. Refer to Table 4-7 for a summary of these alternatives. These alternatives were further evaluated as described in Section 5.2.1.

4.5.2 *Development of Ex Situ Groundwater Treatment Alternatives*

In conjunction with the barrier wall, groundwater will be extracted from pumping wells to maintain hydraulic control of affected groundwater, and the groundwater will be treated prior to discharge. Based on the results of the groundwater treatability studies and subsequent treatment technology screening (as discussed in Sections 3.6 and 4.4.2, respectively), an ex situ groundwater treatment process train alternative was developed for further evaluation during the FFS. A conceptual flow diagram of this ex situ groundwater treatment alternative is provided as Figure 4-7. Specifically, this alternative consists of the following treatment process train:

- **Chemical Precipitation Reactor** – Conversion of metals by conventional hydroxide precipitation via aeration and the addition of sodium hydroxide;

- **Flocculation and Clarification** – Removal of precipitates through the addition of a polymer and subsequent clarification with an associated sludge handling system used for solids management;

- **pH Adjustment Tank** – If necessary, adjustment of pH to target level for anaerobic biological treatment via addition of sulfuric (or other) acid;

- **Solids Filter** – Removal of residual metal hydroxides and/or other particulates; pretreatment step for reduction of solids loading to anaerobic bioreactors;

- **FBR** – Removal of chlorate, perchlorate, and other contaminants amenable to anaerobic biological treatment; organic substrate and nutrients added to stimulate biological activity for FBR; reactor media for FBR is sand or GAC;

- **Solids Filter** – Removal of excess biomass and/or other particulates; pretreatment step for reduction of solids loading to GAC; and

- **GAC** – Removal of DDx, VOCs, and SVOCs, and potential residual organic carbon (measured as TOC) from the FBR.

Refer to Section 5.2.2 for a detailed evaluation of this ex situ groundwater treatment alternative. In addition to the evaluation criteria outlined in Section 5.1, selection of the preferred treatment alternative will be driven by results of future design work.

As part of the screening and evaluation of treatment alternatives, some consideration was given to potential benefits of segregating and pre-treating groundwater extracted from the former Acid Plant and Chlorate Plant Areas. However, following review of groundwater data and considering the current and potential future distribution of COPCs (e.g., VOCs, metals, perchlorate) in groundwater following startup and operation of the groundwater treatment system, this approach does not offer any significant cost and/or operational advantages and will not be considered further. Based on the proximity and partial overlap of the two impacted areas, a single treatment system will be used to treat groundwater extracted from wells in both the Acid Plant and Chlorate Plant Areas.

Also, as requested by ODEQ, an additional evaluation of alternatives for treatment of chloride was completed. Groundwater treatment to remove chloride is not proposed for the following reasons:

- The combination of relatively high chloride concentration (estimated to be approximately 1,500 mg/L initially and decreasing over time) and relatively low flow rate of water (approximately 100 to 150 gpm based on preliminary groundwater modeling) does not lend itself to using current desalinization technologies designed for lower chloride concentrations and higher flow rates.

- Constructing and operating a desalinization treatment system is costly primarily due to managing the high concentration reject water from a reverse osmosis (RO) treatment system. For example, an RO unit treating groundwater at a flow rate of 150 gpm may have a rejection rate of 25% and result in generating 54,000 gallons per day of reject water. Assuming a favorable transportation and disposal cost at a commercial wastewater treatment facility for this waste of $0.25 per gallon, the annual cost for disposal of the reject water is nearly $5,000,000. Other cost drivers include the high energy costs associated with operating desalinization treatment units.

- Using the above example, transporting 54,000 gallons of reject water off site per day is not practical or sustainable over the long operating life projected for the Groundwater Source Control IRM. This volume results in approximately 11 tanker truckloads per day being hauled off site to a commercial wastewater treatment facility.

- Any of the potential discharge options will reduce chloride concentrations when the discharged effluent is blended with surface water, groundwater, storm water, or POTW sewer water. Initial effluent concentrations are expected to be similar to average groundwater concentrations across the Site.

- Treating groundwater to remove chloride provides little to no benefit to human health and the environment considering the limitations of desalinization technology, the excessive energy consumption to operate the treatment equipment and associated adverse environmental affects, the volume of reject water generated, and the potentially adverse effects of transporting the material from one location to another.

4.5.3 Development of Treated Groundwater Management Alternatives

Four treated water discharge alternatives are being evaluated during the FFS for management of the groundwater that has been extracted and treated, as follows:

- Discharge to the Willamette River via existing storm water Outfall #4 and an in-river diffuser;

- Reinjection into the shallow aquifer via shallow injection wells, trenches, and/or infiltration basin/gallery;

- Discharge to the POTW; and

- Reinjection into a deep saline aquifer via deep injection wells.

Conceptual diagrams of the discharge alternatives are included as Figure 4-8, and Table 4-5 provides a summary of the technical and regulatory considerations for each alternative. Additionally, Table 4-8 provides a summary of the preliminary possible discharge criteria for each of these treated water discharge alternatives. The values listed in Table 4-8 are for preliminary comparison purposes only. Final discharge limits will be determined through the applicable permitting and approval process based upon the selected discharge option.

The four discharge alternatives are described in more detail as follows:

- **Discharge to the Willamette River**: Treated groundwater would be discharged directly to the Willamette River by connecting to the conveyance line for Outfall #4 or utilizing existing on-site storm water sewers and the installation of a diffuser, assuming there is adequate capacity to handle the anticipated flow rate. Permitting requirements for this alternative would include revision of the current NPDES permit for the Site to include process water discharge (permit currently only addresses storm water discharge). Final discharge limits for this alternative would ultimately be determined through the NPDES permitting process.

- **Reinjection into Shallow Aquifer**: Three shallow reinjection alternatives are being evaluated as part of the FFS: (1) five shallow injection wells with one shallow infiltration trench, (2) five shallow injection wells with three shallow infiltration trenches, and (3) discharge of treated groundwater to the proposed storm water infiltration basin to be constructed on Lots 1 and 2 of the Site. The majority of the treated groundwater is anticipated to be reinjected outside the capture zone of the groundwater extraction and treatment system, due to the reinjection limitations described in Section 3.3. However, some portion of the treated water may be amended with a suitable material (e.g., carbon substrate) and reinjected within the capture zone to promote in situ treatment of COPCs in the Acid Plant and Chlorate Plant Areas. Proceeding with the shallow injection discharge alternative is dependent upon the approval of a UIC permit by ODEQ. The preliminary discharge criteria for shallow reinjection are anticipated to be MCLs. Final discharge limits will be based on the applicable State water quality permit.

- **Discharge to the POTW**: Treated groundwater would most likely be discharged to the 60-inch diameter sewer interceptor that runs parallel to NW Front Avenue along the western boundary of the Site. Based on the size of the pipe and the anticipated discharge flow rates, the sewer will likely have adequate capacity to discharge the treated water. However, the POTW will need to analyze the sewer network and approve the tie-in location. An annual industrial discharge permit would need to be maintained and a disposal fee would apply. Currently, some existing discharge limits are set for Site COPCs. However, specific discharge limits for other Site COPCs (e.g., chloride) or other parameters (e.g., TDS) would need to be determined in discussions with the POTW during the permitting process.

- **Reinjection into Deep Saline Aquifer**: Treated water would be injected via a series of injection wells into the deep saline aquifer located beneath the Site. The deep aquifer would need to be characterized to better assess acceptance of anticipated flow rate into the formation. Viability of this discharge alternative is dependent upon the approval of an Underground Injection Control (UIC) permit by ODEQ. The UIC regulations are covered under OAR 340-044. The preliminary discharge criteria for deep reinjection are anticipated to be MCLs. Final discharge limits will be based on the applicable State water quality permit.

In addition to treated groundwater, other discharges from the treatment processes will also need to be considered, which may include dewatered solids from a chemical precipitation process, biosolids generated by biological treatment processes, and spent GAC. Solids will likely be sent to a landfill, but the need for any pre-treatment of the solids (e.g., solidification/ stabilization) prior to off site disposal will be evaluated as part of the design process.

5.0 EVALUATION OF REMEDIAL ALTERNATIVES

In this section, each remedial alternative is evaluated both individually and compared to other alternatives to evaluate which alternative or alternatives best satisfy specific evaluation criteria. The purpose of the individual assessment is to evaluate the extent to which each remedial action alternative satisfies the selection criteria. The comparative assessment provides a relative evaluation of the remedial action alternatives to determine which alternative best balances the selection factors and provides the best comprehensive remedial approach.

Remedial alternatives developed in Section 4.5 were evaluated and compared to identify a preferred alternative. This section describes the evaluation of remedial alternatives, including:

- Description of evaluation criteria;
- Evaluation of each alternative;
- Comparison of alternatives; and
- A description of the preferred alternative.

5.1 EVALUATION CRITERIA

Under Oregon's environmental cleanup law, the feasibility of each remedial action alternative is to be assessed based on a balance of five selection factors including effectiveness, long-term reliability, implementability, implementation risk, and reasonableness of cost (OAR 340-122-0090(3)).

Because the remedial alternatives developed in this FFS are being considered as components of the Groundwater Source Control IRM for the Site and are not proposed as source area treatments per se, although the extraction and treatment system will provide some level of source area treatment, these alternatives were not evaluated specifically against the selection criteria of protectiveness (OAR 340-122-0090(2)) and preference to treat hot spots of contamination (OAR 340-122-0090(4)). However, all of the alternatives evaluated in this FFS are considered to be "protective" because they include a combination of the protective actions specified in

OAR 340-122-0090(2) and are therefore assumed to meet the protectiveness selection criterion. The hot spot evaluation for the Site will be completed during the FS.

The following sections provide a brief description of each of the balancing factors to be considered during the remedial alternative evaluation.

5.1.1 *Effectiveness*

The effectiveness criterion assists in determining the ability of the remedial action alternative to meet the required level of protection of human health and the environment. The effectiveness criterion evaluates the performance of the alternative through implementation of the remedial action and achievement of RAOs. Additional long-term effectiveness of the alternative is evaluated under the long-term reliability criterion (Section 5.1.2). The effectiveness of an alternative is both a qualitative (e.g., adequacy of engineering and institutional controls) and a quantitative (e.g., magnitude of risk from treatment residuals) analysis.

The effectiveness criteria that are used, as appropriate, for assessment of remedial alternatives include the following:

- Magnitude of risk from treatment residuals or untreated waste taking into consideration any risk reduction through on-site management of exposure pathways;
- Adequacy of engineering and institutional controls necessary to manage the risk from treatment residuals or untreated waste;
- Extent to which remedial action protects or restores existing and reasonably likely future beneficial uses of water;
- Adequacy of technologies to meet treatment objectives; and
- Time required to achieve treatment objectives.

5.1.2 *Long-Term Reliability*

The long-term reliability criterion provides an evaluation of an alternative's ability to provide an adequate level of protection over the long term after implementation. Long-term reliability focuses on the magnitude of residual risk after RAOs are achieved. This criterion also

evaluates the adequacy and reliability of engineering or institutional controls. Long-term reliability is generally a qualitative evaluation.

Evaluation of remedial alternatives shall consider the following, as appropriate:

- Reliability of technologies to meet treatment objectives (yet to be defined for the Groundwater Source Control IRM);
- Reliability of engineering and institutional controls to manage risk from treatment residuals and untreated hazardous substances, including characteristics of hazardous substances, long-term effectiveness in preventing contaminant migration, and managing risks of potential exposure;
- General understanding of necessary long-term management (e.g., operation, maintenance, monitoring).

5.1.3 Implementability

The implementability criterion provides an assessment of remedial alternatives during the construction and implementation phases through the stage where the remedial objectives are met. Implementability considerations include technical and administrative feasibility, as well as availability of services and materials, and generally comprise a qualitative analysis. Technical feasibility considerations include construction, operation, and reliability of a technology as well as monitoring considerations. Administrative considerations can include coordination with multiple offices or agencies.

The ease or difficulty of implementing a remedial alternative is evaluated by considering the following, as appropriate:

- Potential difficulties and unknown factors associated with construction and implementation of a technology, engineering control, or institutional control (including scheduling);
- Ability to monitor effectiveness of remedial action;
- Ability to comply with federal, state, and local requirements and coordination with agencies; and

- Availability of required services, materials, and equipment (including off-site treatment, storage, and disposal services).

5.1.4 *Implementation Risk*

Implementation risk, also known as short-term risk, is generally a qualitative analysis of the risks or impacts to human health and the environment that may occur due to the implementation of a remedial measure. The risk associated with implementing a remedial alternative shall be evaluated based on the following criteria, as appropriate:

- Potential impacts on the community;
- Potential impacts on workers;
- Potential impacts on the environment; and
- The length of time until the remedial action is complete.

5.1.5 *Reasonableness of Cost*

The reasonableness of cost is generally a two part, qualitative assessment of remedial alternatives. A cost estimate is first prepared for each remedial alternative. Typically, the cost estimates are prepared within a +50% to -30% accuracy range. A present worth analysis is then completed to incorporate costs over various time periods by discounting all anticipated future costs to a common base year. This allows alternatives to be compared on the basis of an overall cost for the entire alternative if the total costs were invested in the base year.

Second, a cost sensitivity analysis should be completed to evaluate how the anticipated costs may vary based on changes of any major factors of the remedial alternative (e.g., effective life of alternative, volume of contaminated material, etc.). The degree to which the costs are proportionate to the benefits between the various remedial alternatives should also be considered. In general, those alternatives that meet the required level of protectiveness of human health and the environment at a lower cost will have a greater reasonableness of cost.

Evaluation of a remedial alternative shall be completed based on the following criteria, as appropriate:

- Cost of remedial action including capital costs, annual operation and maintenance, periodic review requirements, and net present value;
- Extent to which costs are proportionate to benefits to human health and the environment with respect to risk reduction or risk management;
- Extent to which costs are proportionate to benefits regarding protection or restoration of existing and reasonably likely future beneficial uses of water (with respect to hot spots); and
- Degree of sensitivity and uncertainty of costs.

5.2 *DETAILED EVALUATION OF REMEDIAL ALTERNATIVES*

A detailed evaluation of remedial alternatives was performed using the remedy selection balancing factors described in Section 5.1. The results of these evaluations are provided in the following sections.

5.2.1 *Detailed Evaluation of Groundwater Barrier Wall Alternatives*

As described in Section 4.5.1, six barrier wall alternatives were developed to address the following range of options:

- Location;
- Construction technology; and
- Total depth.

Each of the six alternatives developed in Section 4.5.1 was evaluated using the balancing factors described in Section 5.1. The evaluation of each of the six barrier wall alternatives, including the complimentary and contrary effects of the various combinations of location, construction technology, and total depth for each of the remedy selection balancing factors is summarized in Table 5-1. Concept cost estimates for each of the alternatives, as well as alternatives that were eliminated during the FFS screening process, are included in Appendix E.

In general, the River Side High Bank barrier wall route was found to be equally effective and as compatible with future in water actions, such as bank regrading, capping, and dredging and/or capping sediments, as the

Full Enclosure barrier wall route alternatives at considerably lower cost. Therefore, the River Side High Bank route was found to be most cost effective of the routes.

In general, the vibrated beam slurry wall construction technology was found to be equally effective and compatible with potential future in water actions as the slurry trench slurry wall and the sheet pile barrier wall alternatives. As the present value of the vibrated beam slurry wall is less than the other construction technologies, the vibrated beam slurry wall is the most cost effective construction technology.

In general, the most cost-effective barrier wall alternative was found to be the River Side High Bank route using vibrated beam slurry wall construction technology constructed to the T.D. to Basalt depth. However, both the vibrated beam and conventional slurry wall techniques will be retained for further evaluation prior to final selection.

5.2.2 *Detailed Evaluation of Ex Situ Groundwater Treatment Alternatives*

Table 5-2 summarizes the evaluation of the groundwater treatment alternative selected based on the results of the groundwater treatability studies against the remedy selection balancing factors. Budgetary cost estimates for the alternative, as well as alternatives that were eliminated during the FFS screening process, are included in Appendix F.

5.2.3 *Detailed Evaluation of Treated Groundwater Management Alternatives*

Table 5-3 summarizes the evaluation of the groundwater management alternatives against the remedy selection balancing factors. Budgetary cost estimates for the alternatives are included in Appendix G. Based on the results of the evaluation, each of the technologies was retained for further evaluation as potential components of the remedial alternatives for the Site. Technical and regulatory considerations that will determine the final selection of the treated groundwater management alternative include the following:

- The current NPDES permit would require revision to allow discharge of treated groundwater to the Willamette River;
- Site-specific discharge criteria for the discharge to river alternative will not be identified until the NPDES permitting process is complete;

- The results of the shallow reinjection modeling indicate that the aquifer is capable of accepting flows generated by the groundwater extraction and treatment process without compromising the capture zone of the Groundwater Source Control IRM;

- Site-specific discharge criteria for the POTW alternative will not be identified until the permitting process is complete;

- An annual permit will be required for POTW discharge, subjecting the POTW discharge to annual uncertainty;

- POTW discharge fees (based on price per water unit [100 cubic feet or 748 gallons]) are expensive, and the fees can be expected to increase;

- Deep aquifer injection is currently prohibited by State regulations, and while these regulations may be reviewed in the near future, the permitting process to achieve an exemption from the prohibition is expected to be lengthy (estimated at five years);

- Deep aquifer characteristics are currently unknown, and would need to be confirmed prior to discharge system design;

- Potential for biofouling or solids build-up exists for shallow and deep injection wells; and

- Final discharge limits, established through applicable permitting processes, will be a critical decision factor to determine actual the implementability of each alternative.

The treatment concepts presented in Section 4.5.2 and Figure 4-7 are capable of treating groundwater to the shallow reinjection, POTW, and deep reinjection discharge options. However, since the discharge limits for NPDES-controlled discharges to the river are not yet defined, this discharge option cannot be fully assessed at this point.

5.3 COMPARATIVE ANALYSIS

5.3.1 Comparison of Groundwater Barrier Wall Alternatives

Characteristics common to, and distinguishing, multiple alternatives were evaluated for each of the alternatives.

5.3.1.1 *Evaluation of Alternatives Based on Location*

The two locations developed were the River Side High Bank barrier wall route and the Full Enclosure barrier wall route. An evaluation of the common and distinguishing characteristics is as follows:

- **Effectiveness**: Both locations were found to be effective in containing affected groundwater based on the results of groundwater modeling.

- **Long-Term Reliability**: Both locations were found to have good long term reliability because the proposed routes are in areas not susceptible to river erosion, are less susceptible to seismic damage because they are further from the river, and have been shown by the geotechnical analysis to provide adequate slope stability. Also, both locations are expected to be compatible with potential future in water actions, such as bank regrading and capping, and dredging and/or capping of sediments.

- **Implementability**: Both locations were found to have reasonable implementability because the proposed routes are in relatively level areas with suitable access.

- **Implementation Risk**: Both locations were found to have reasonable implementation risk because the proposed routes are in relatively level areas with suitable access for implementation of temporary controls during construction.

- **Reasonableness of Cost**: The River Side High Bank route location was found to have a more reasonable cost relative to the Full Enclosure route location because of the shorter length and smaller vertical area.

The differences in present value for the River Side High Bank and the Full Enclosure barrier wall route location alternatives range from $7,600,000 for the vibrated beam slurry wall to $14,600,000 for the sheet pile barrier wall, which exceed the estimated cost savings in treatment and disposal costs realized by a reduction in design flow rate from 150 gpm to 100 gpm (present value estimated to be in the range of $2,000,000 to $4,000,000). Thus, the Full Enclosure barrier wall route alternatives are not cost-effective compared to the River Side High Bank route alternatives.

5.3.1.2 *Evaluation of Alternatives Based on Construction Technology*

The three construction technologies developed were a vibrated beam slurry wall, a slurry trench slurry wall, and a sheet pile barrier wall.

- **Effectiveness**: The slurry materials testing described in Appendix C verified that mixtures of commercial bentonite and Site soil, attapulgite and Site soil, and "Impermix" clay-cement mixed with Site soil are capable of producing a stable adequately low permeability barrier wall. Steel sheet pile manufacturer data show that rates of corrosion of steel sheet pile in contact with water with elevated total dissolved solids (i.e., chloride) concentration and/or the relatively mild variation in pH of groundwater (measured between approximately 5 s.u. and 8 s.u.) and affected soil (measured between approximately 3 s.u. and 10 s.u.) are expected to be low enough to not be a significant concern regarding protectiveness of a sheet pile barrier wall. Further, based on data in the *Piling Handbook* (Arcelor RPS, Alzette, Luxembourg, January 2005), normal commercial steel sheet piling for salt water conditions and "aggressive" soils at industrial sites is projected to corrode between approximately 3.25 and 3.75 millimeters (mm) in 50 years. This amount of corrosion is much less than the minimum thickness of sheet piling (normally greater that 7 mm) needed to achieve a driven depth in the range desired to construct the barrier wall. Therefore, no failure of a barrier wall constructed using normal commercial steel sheet piling is projected for the useful life of the barrier wall. Thus, each construction technology was found to be effective based on the results of slurry materials testing and, for the sheet pile alternatives, manufacturer data. Therefore, construction technology is not a basis for favoring an alternative evaluated for effectiveness.

- **Long-Term Reliability**: Each construction technology was found to be reliable in the long term based on the results of testing compatibility of slurry materials mixed with samples of Site soils, including for the slurry trench slurry wall technology, DNAPL-affected soil, and when exposed to samples of affected ground water from the Site and, for the sheet pile alternatives, manufacturer data. Therefore, construction technology is not a basis for favoring an alternative evaluated for long-term reliability.

- **Implementability**: The vibrated beam technology would be somewhat susceptible to problems with small (i.e., larger than approximately 4 inches) debris and would cause some limited vibration in surrounding areas, but is otherwise generally evaluated as having good implementability. The vibrated beam technology has one contractor using the technology in the US, but the organization is a well-established, stable and diversified business, offering little concerns with availability of the technology when needed. The slurry

trench technology is less susceptible to problems with small debris, would cause very little vibration, and is generally evaluated as having good implementability. The sheet pile technology is relatively susceptible to problems with small (i.e., approximately 4 inches) debris and can exhibit significant vibration, but is otherwise generally evaluated as having good implementability.

- **Implementation Risk**: Each construction technology was considered to have reasonable implementation risk. The sheet pile barrier wall technology has less potential for spills, but potential for destabilizing subsoils due to vibration during placement of the sheet pile would be greater than other alternative technologies.

- **Reasonableness of Cost**: The vibrated beam and the slurry trench technologies would be nearly equivalent in cost. The sheet pile technology would be much more expensive due in large part to the current high demand for steel products and the typically lower productivity of that technology compared to the other technologies.

5.3.1.3 Evaluation of Alternatives Based on Total Depth

The depth used for the development of barrier wall alternatives was total depth to the top of basalt (T.D. to Basalt). This depth fulfills the criteria set forth in the five remedy balancing factors.

5.3.2 Comparison of Ex Situ Groundwater Treatment Alternatives

The ex situ groundwater treatment alternative for the Groundwater Source Control IRM is a treatment train that includes: a chemical precipitation reactor with aeration and pH adjustment; a clarifier and associated solids handling system; a pH Adjustment Tank; a post-clarification solids filter (if required); a FBR; a solids filter for biomass handling and removal of residual particulates; and two liquid-phase GAC vessels in series.

The groundwater treatment alternative retained for evaluation fulfills the criteria set forth in the five remedy balancing factors. Currently, a FBR has been selected as the preferred anaerobic biological treatment option based on demonstrated performance during the groundwater treatability study, number of full-scale FBR applications for perchlorate treatment, and long-term performance considerations. However, the PBR and EHC/sand reactor will be retained for further evaluation prior to final selection.

For comparative purposes, budgetary costs were developed for a groundwater extraction and treatment system designed to accommodate 150 gpm, which corresponds to the flow rate required to achieve hydraulic control (as predicted by groundwater modeling) for the River Side High Bank barrier wall route. As discussed in Section 5.3.1.1, the differences in present value for the River Side High Bank and the Full Enclosure barrier wall route location alternatives exceed the estimated cost savings in treatment and disposal costs realized by a reduction in design flow rate from 150 gpm to 100 gpm. Thus, development of budgetary costs for a flow rate of 100 gpm, which corresponds to the flow rate required to achieve hydraulic control (as predicted by groundwater modeling) for the Full Enclosure barrier wall route, was not considered to be warranted.

5.3.3 Comparison of Treated Groundwater Management Alternatives

A comparative assessment of the four treated water discharge alternatives indicates all alternatives generally meet the criteria set forth in the five remedy balancing factors. Based on the results of the comparative analysis, discharge to the Willamette River and reinjection to the shallow aquifer appear to be the most viable options. A summary of the comparative analysis of the discharge alternatives based on the remedy balancing factors is as follows:

- **Effectiveness**: Each of the four discharge alternatives will meet required levels of protection of human health and the environment. Reinjection to the deep aquifer would limit the risk of exposure to human health and the environment because the deep, saline aquifer is not a drinking water source.

- **Long-Term Reliability**: Discharge to the Willamette River and reinjection to the shallow aquifer via the storm water infiltration basin have favorable long-term reliability due to the relatively low amount of maintenance and relatively low potential for operating problems. Both the shallow and deep well injection systems would require regular operation and maintenance due to the potential for biofouling and solids plugging to occur. The long-term performance of shallow and deep well reinjection systems is difficult to predict and would require additional testing for better characterization. Long-term performance could diminish and lead to temporary shut-downs of the groundwater extraction and treatment system while wells are being maintained and/or replaced. The long-term reliability of the POTW alternative is subject to annual permit renewal.

- **Implementability**: Discharge to the Willamette River and the POTW are the simplest options to implement due to the reduced design and construction effort that would be required. Shallow reinjection via the storm water infiltration basin may require some additional field testing, but is still relatively easier to implement than the shallow and deep well reinjection alternatives. The shallow and deep well reinjection alternatives would require additional testing, subsurface characterization, and more components to design and construct.

- **Implementation Risk**: The shallow and deep well aquifer reinjection scenarios are dependent on aquifer acceptance of flows generated during treatment. The shallow reinjection scenario using the infiltration basis and shallow wells has been modeled and results show that anticipated flow rates could be accepted by the shallow aquifer outside of the hydraulic capture zone. In contrast, the deep well reinjection scenario is currently prohibited by State regulations (see Section 4.5.3). The regulations may be revised in the future, but could require a lengthy permit process.

- **Reasonableness of Cost**: The net present worth of the Willamette River discharge and the shallow and deep aquifer reinjection scenarios are on the same order of magnitude. Direct discharge to the river and discharge to a potential future storm water infiltration basin are the least expensive alternatives. The POTW discharge alternative is significantly higher due to unit-based water disposal fees, currently quoted by the Portland Bureau of Environmental Services (BES) as $5.86/100 cubic feet.

5.4 PREFERRED REMEDIAL ALTERNATIVE

5.4.1 Preferred Barrier Wall Alternative

Based on the evaluation of barrier wall alternatives, the recommended barrier wall component for the Groundwater Source Control IRM is construction of a barrier wall as follows:

- Along the River Side High Bank route,

- Using either the vibrated beam or conventional slurry wall technology,

- To a depth to the top of the basalt.

Additional details on the implementation plan and schedule for this alternative are provided in Section 6.1.

5.4.2 *Preferred Ex Situ Groundwater Treatment Alternative*

Based on the screening and evaluation of groundwater treatment alternatives, the recommended ex situ groundwater treatment alternative for the Groundwater Source Control IRM consists of the following:

- Chemical precipitation reactor with aeration, and pH adjustment via sodium hydroxide;
- Solids handling system (i.e., clarifier with polymer feed, sludge holding tank, filter press, and associated equipment);
- pH Adjustment Tank;
- Optional post-clarification solids filter if required;
- FBR with solids filter for biomass handling, with the option of utilizing either the PBR or EHC/sand reactor; and
- Two liquid-phase GAC vessels in series.

As stated in Section 5.3.2, given the success of the three bioreactor configurations (i.e., FBR, PBR, and EHC/sand reactor) during treatability testing, further evaluation of the three alternatives will be completed as part of the design phase of the project. Additional details on the implementation plan and schedule for this alternative are provided in Section 6.2.

In the event metals considered to be COPCs are present in the influent groundwater of the full-scale treatment system at concentrations exceeding potential discharge limits, the ability of the conventional hydroxide precipitation to remove these metals to concentrations below the applicable discharge limits will be further evaluated. If it is not effective, the hydroxide precipitation system may be supplemented with iron addition to the system to effect an iron co-precipitation process. The treatment equipment is essentially the same and conversion would only require the addition of a ferrous sulfate storage tank, feed pump, and associated controls. Sufficient space in a potential treatment equipment pad or building will be provided in the design to accommodate the potential tank.

5.4.3 Preferred Treated Water Discharge Alternative

Selection of the preferred management alternative(s) will be generally driven by technical and regulatory considerations outlined in Tables 4-5 and 4-8. Pretreatment goals and other waste handling requirements associated with groundwater treatment will be determined by ongoing development and review of ARARs for the management alternatives. The technical feasibility of the deep reinjection alternative will be further evaluated by review of published information pertaining to the deep saline aquifer present beneath the Site, while the shallow reinjection scenario will be evaluated further as part of ongoing groundwater modeling.

Based on current considerations and pending further evaluation, the preferred treated water discharge alternatives include:

- Discharge to the Willamette River, and
- Reinjection to shallow groundwater via the proposed storm water infiltration basin to be constructed on Lots 1 and 2 of the Site.

Based on regulatory, technical practicability, and cost considerations, discharge to POTW and reinjection to deep groundwater have been eliminated from further consideration at the present time.

6.0 IMPLEMENTATION PLAN AND SCHEDULE

A plan and schedule for implementation of the preferred alternatives that comprise Groundwater Source Control IRM are described below.

6.1 GROUNDWATER BARRIER WALL

Implementation of the barrier wall component of the Groundwater Source Control IRM includes the following:

- **Permitting** – preparing applications for and obtaining the required permits and other approvals required for construction of the barrier wall (e.g., negotiation with City of Portland regarding the Greenway Overlay Zone and potential impacts due to design and construction, and other permits determined to be required);

- **Pre-Design Investigation** – verifying the barrier wall route, topographic surveying to verify surface grades and obstructions (if not available from prior surveys), and additional CPT or soil borings (if needed to identify stratigraphy not available from prior CPT and soil borings);

- **Pre-Final Design** – preparing design drawings, technical specifications, CQA plan, and related design package submittals (e.g., Pre-Design Investigation results, design bases and criteria, supporting design analyses and calculations) and submitting this package to ODEQ and USEPA for review, comment, and approval;

- **Final Design** – revising the pre-final design package to incorporate ODEQ and USEPA comments and potential new information that may become available during ODEQ's and USEPA's review;

- **Contractor Bidding** – preparing bid documents incorporating the Final Design, contractor bidding, evaluation and clarification of bids, contractor selection, and contract execution; and

- **Construction** – including mobilization, site preparation, pre-wall construction trenching to clear obstructions and underground utilities, wall installation, capping of the wall, restoration, construction of piezometers to measure performance, and demobilization.

The sequence and duration of these activities is shown on Figure 6-1. The schedule highlights those tasks that will be performed by ODEQ and USEPA (and possibly other regulatory agencies), and these highlighted tasks are critical in regards to completing subsequent tasks in accordance with the schedule. Other items out of the control of LSS, ODEQ, and USEPA may also affect the schedule.

6.2 *GROUNDWATER EXTRACTION AND TREATMENT SYSTEM*

Implementation of the groundwater extraction and treatment system will consist of the following:

- **Permitting** – preparing applications for and obtaining the required permits and other approvals required for construction and operation of the groundwater extraction and treatment system (e.g., discharge/NPDES permit depending on preferred option and acceptability of the option, negotiation with City of Portland regarding the Greenway Overlay Zone and potential impacts due to design and construction);

- **Pre-Design Investigation** – conducting groundwater pumping tests to obtain data to reduce the uncertainty associated with sensitive groundwater model input parameters (e.g., permeability) and conducting additional groundwater modeling to verify the required groundwater pumping rate, extraction well layout, and extraction well design;

- **Pre-Final Design** - preparing design drawings, technical specifications, operation and maintenance (O&M) plan, and related design package submittals (e.g., Pre-Design Investigation and groundwater modeling results, design bases and criteria, supporting design analyses and calculations) and submitting this package to ODEQ and USEPA for review, comment, and approval;

- **Equipment Procurement** – preparing equipment performance specifications and requests for bids, equipment vendor bidding, evaluation and clarification of bids, equipment vendor selection and purchase order issuance, fabrication drawing preparation and review (if any necessary), fabrication, and delivery;

- **Final Design** - revising the pre-final design package to incorporate ODEQ and USEPA comments and potential new information that may become available during ODEQ's and USEPA's review;

- **Contractor Bidding** – preparing bid documents incorporating the Final Design, contractor bidding, evaluation and clarification of bids, contractor selection, and contract execution;

- **Construction** – including mobilization, site preparation, installation of extraction wells and piping, placement and connection of groundwater treatment components, connection of utilities, installation of discharge piping and tie-in to discharge point, restoration, and demobilization;

- **Startup** – including pre-startup process hazards review, bump testing equipment and checking controls/interlocks to verify they operate as designed and making any necessary adjustments, treatment performance verification beginning at low flow rates and gradually increasing flow until required flow rate is achieved and adequate biological population is developed, equipment performance optimization, troubleshooting, and O&M Plan revisions based on actual observations; and

- **Operation and Maintenance** – commencing routine O&M following startup and consisting of routine system checks and maintenance, documenting system operating parameters and information required for permits, treatment system performance monitoring (influent and effluent monitoring) and optimization, troubleshooting, and repairs as necessary.

A preliminary implementation schedule is provided as Figure 6-1. The schedule highlights those tasks that will be performed by ODEQ and USEPA (and possibly other regulatory agencies), and these highlighted tasks are critical in regards to completing subsequent tasks in accordance with the schedule. Other items out of the control of LSS, ODEQ, and USEPA may also affect the schedule.

6.3 IMPLEMENTATION REPORT

Following the construction completion, the implementation report will be prepared and submitted to ODEQ and USEPA for review, comment, and approval. The report will include a summary of the construction activities, as-built drawings, design changes and reasons for the changes,

startup results, revised O&M Plan, summary of performance, groundwater performance monitoring plan, and progress reporting.

6.4 PERFORMANCE MONITORING

Performance monitoring will be implemented following construction and startup to measure the effectiveness of the groundwater source control IRM. This monitoring will be completed in accordance with the O&M Plan and groundwater performance monitoring plan included with the implementation report.

7.0 REFERENCES

ERM 2000 *Workplan for Full-Scale Vapor Extraction System*, Environmental Resources Management, September, 2000)

ERM 2003 *Confirmation Soil Sampling Summary Report*, Environmental Resources Management, 26 August 2003.

ERM 2004 *Hexavalent Chromium Reduction Interim Remedial Action Work Plan*, Environmental Resources Management, 28 September 2004).

ERM 2005 *In-Situ Persulfate Oxidation Interim Remedial Measure Work Plan*, Environmental Resources Management, 7 July 2005.

ERM 2006a *Draft Acid Plant Area DNAPL Sampling Summary Report*, Environmental Resources Management, April 2006.

ERM 2006b *Scoping Technical Memorandum*, Environmental Resources Management, December 2006.

ERM 2007 *Groundwater Treatability Study Work Plan,* Environmental Resources Management, April 2007.

ODEQ 1998 *Final Guidance for Conducting Feasibility Studies*, Oregon Department of Environmental Quality, 1 July 1998.

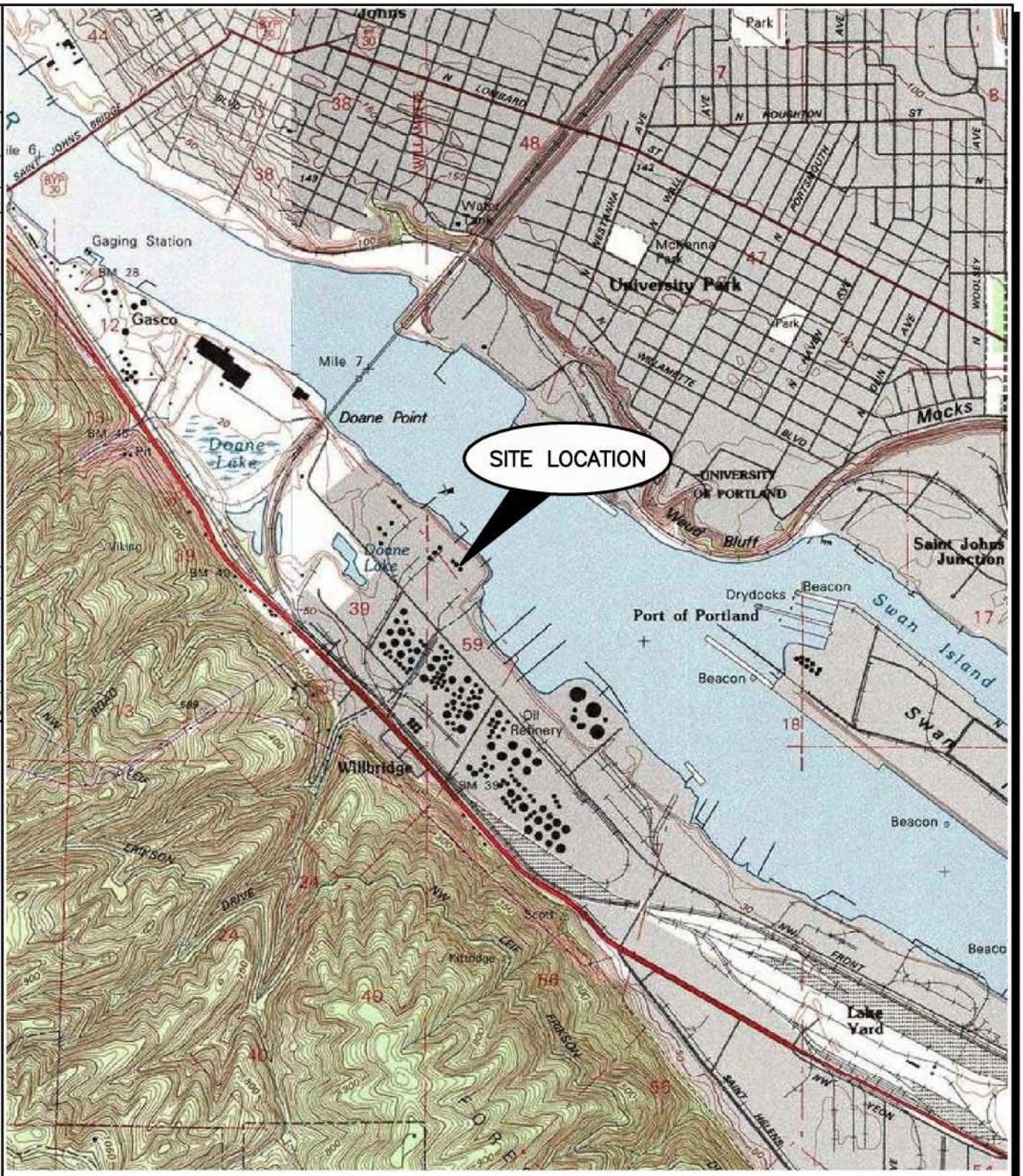
ODEQ 2008 Oregon Administrative Rules, Chapter 340 Department of Environmental Quality, Division 122 Hazardous Substance Remedial Action Rules, Selection or Approval of the Remedial Action (OAR 340-122-0090)

ODEQ 2008 Oregon Administrative Rules, Chapter 340 Department of Environmental Quality, Division 216 Air Contaminant Discharge Permits (OAR 340-216-0020(1)

Figures

DRAFT

Project No. 0057055.30
Date: 11/01/07
Drawn By: R. Olson
CAD File: g:\0057055\30\site location.dwg



SCALE 1:24,000

1 1/2 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

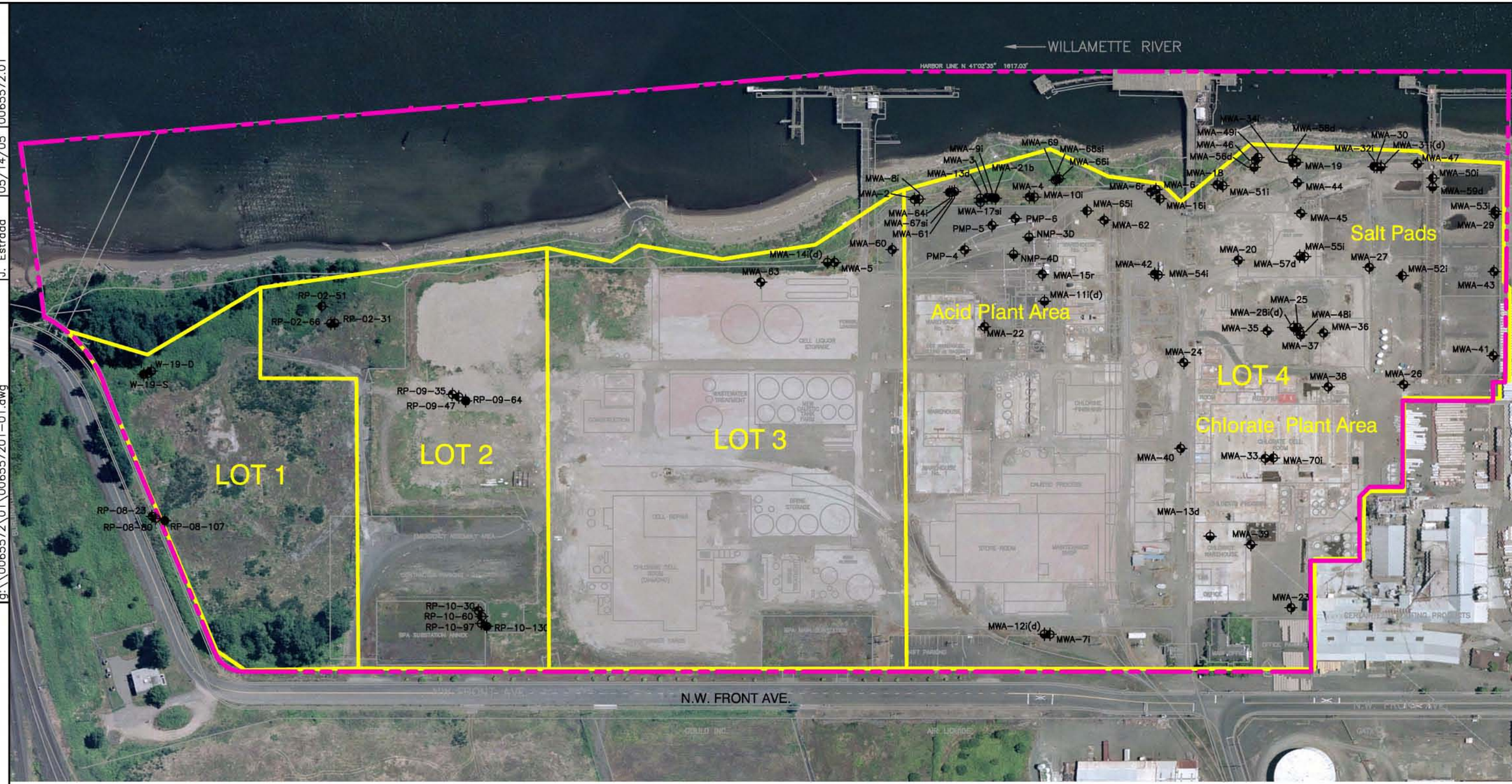
N

Figure 1-1
Site Location Map
Groundwater Source Control IRM
Arkema, Inc.
Portland, Oregon

References:
TOPO!® Software
U.S.G.S. 7.5 Minute Series (Topographic) Quadrangle,
Linnton, OR Version: 1990; Current: 1990
Portland, OR WA Version: 1990; Current: 1990

ERM 11/07

Project No. 0065572.01
Date: 05/14/05
Drawn By: J. Estrada
CAD File: g:\0065572\01\006557201-01.dwg



LEGEND

- Monitoring Well, Shallow Zone
- Monitoring Well, Shallow–Intermediate Zone
- Monitoring Well, Intermediate Zone
- Monitoring Well, Deep Zone
- Monitoring Well, Gravel Zone
- Monitoring Well, Basalt
- Property Boundary
- Lot Boundary

TRUE NORTH
PLANT NORTH
0 200
FEET

Figure 1-2
Site Detail Map
Groundwater Source Control IRM
Arkema Inc.
Portland, Oregon

ERM 05/08

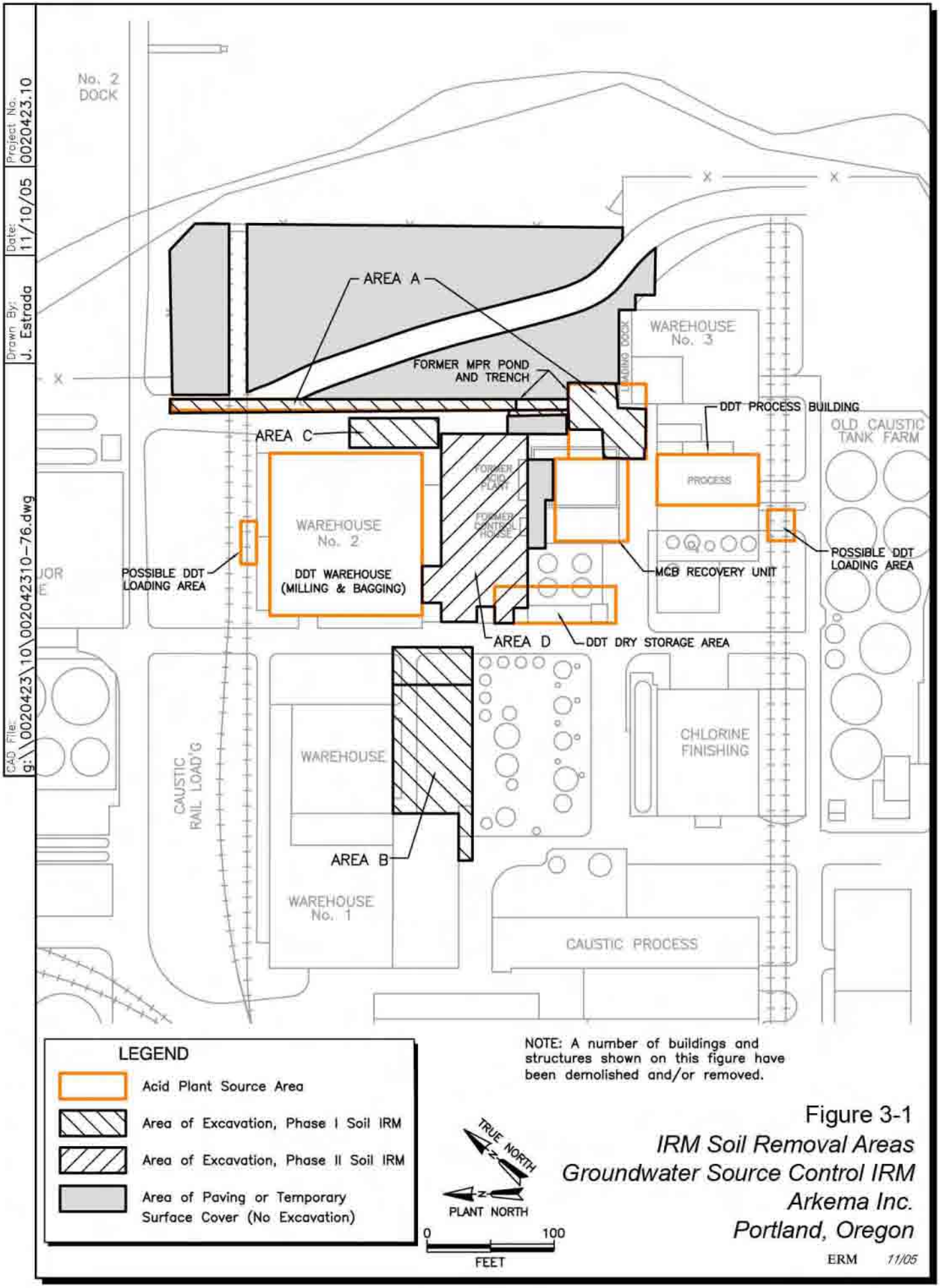
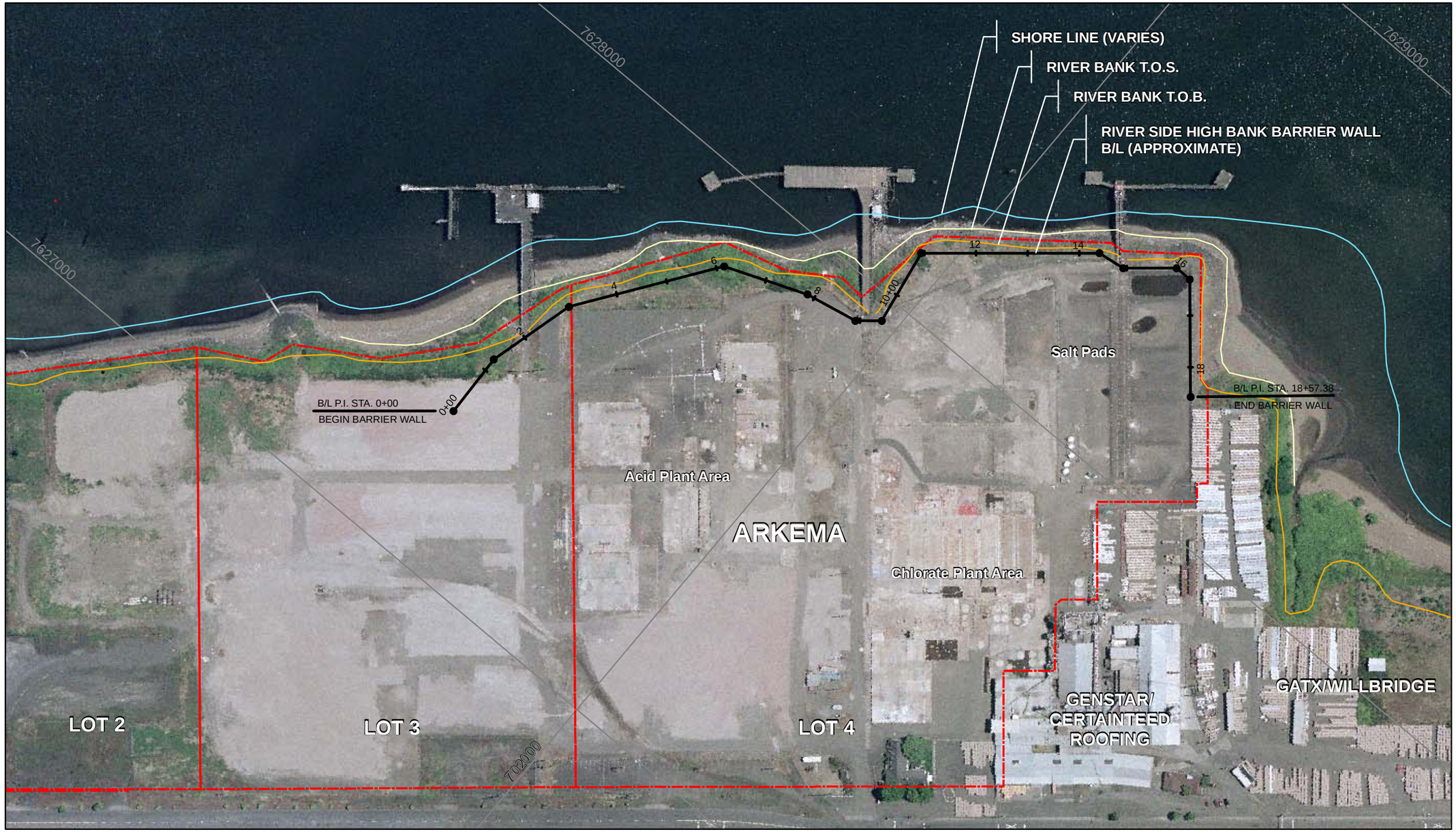


Figure 3-1
IRM Soil Removal Areas
Groundwater Source Control IRM
Arkema Inc.
Portland, Oregon

Project No. 0065572
Date: 02/12/08
Drawn By: T. Cota
GIS File:



Aerial Photography - July, 2005

LEGEND
- Barrier Wall
- River Bank T.O.B.
- River Bank T.O.S
- Shore Line
- Approximate Lot Boundary

N

0 200 400
Feet

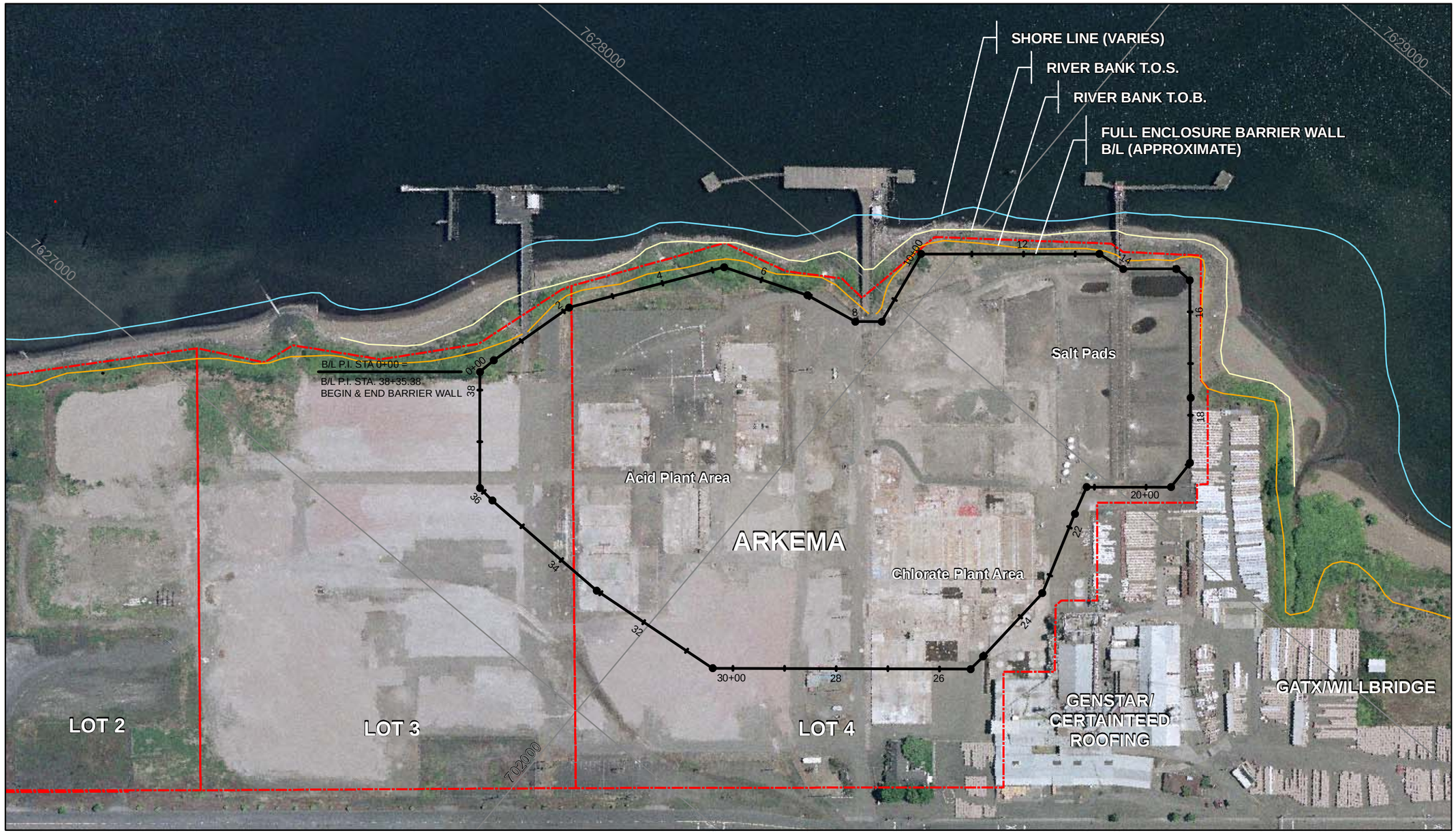
ABBREVIATIONS AND ACRONYMS

B/L	BASELINE
P.I.	POINT OF INTERSECTION
STA.	STATION (100-FOOT STATION BASIS)
T.O.B.	TOP OF BANK
T.O.S.	TOE OF SLOPE

Figure 4-1
River Side High Bank Barrier Wall Plan
Groundwater Source Control IRM
Arkema, Inc.
Portland, Oregon

ERM 02/08

Project No. 0065572
Date: 02/12/08
Drawn By: T. Cota
GIS File:



Aerial Photography - July, 2005

LEGEND
- Barrier Wall
- River Bank T.O.B.
- River Bank T.O.S
- Shore Line
- Approximate Lot Boundary

N

0 200 400
Feet

ABBREVIATIONS AND ACRONYMS: SEE FIGURE 4-1.

Figure 4-2
Full Enclosure Barrier Wall Plan
Groundwater Source Control IRM
Arkema, Inc.
Portland, Oregon

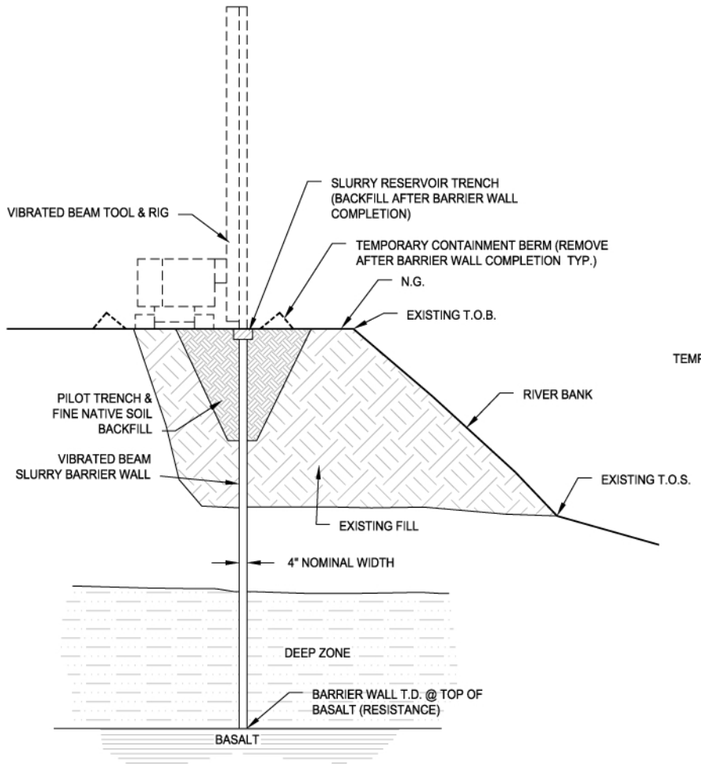
ERM 02/08

Project No.

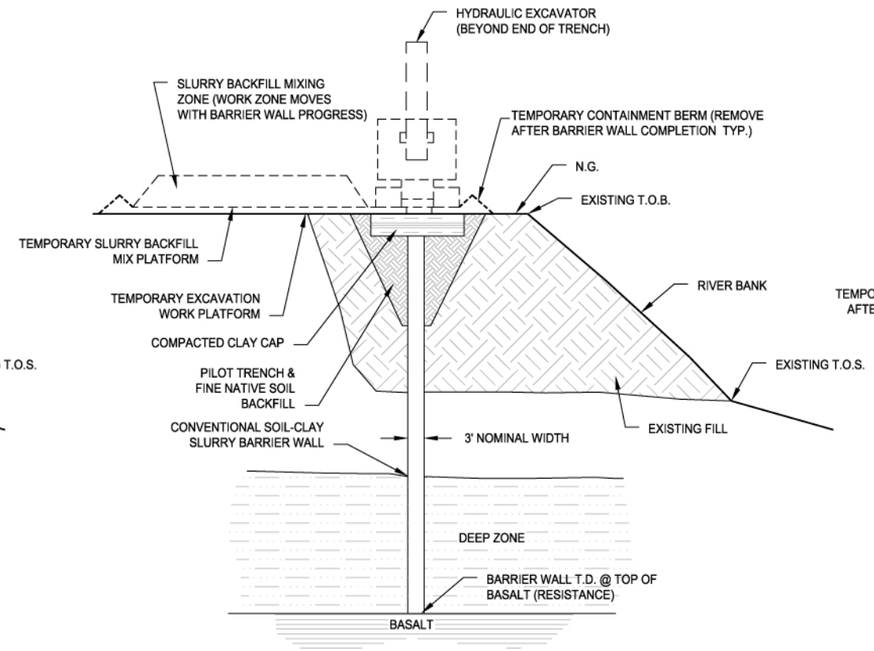
Date: 5-13-08

Drawn By: MLB

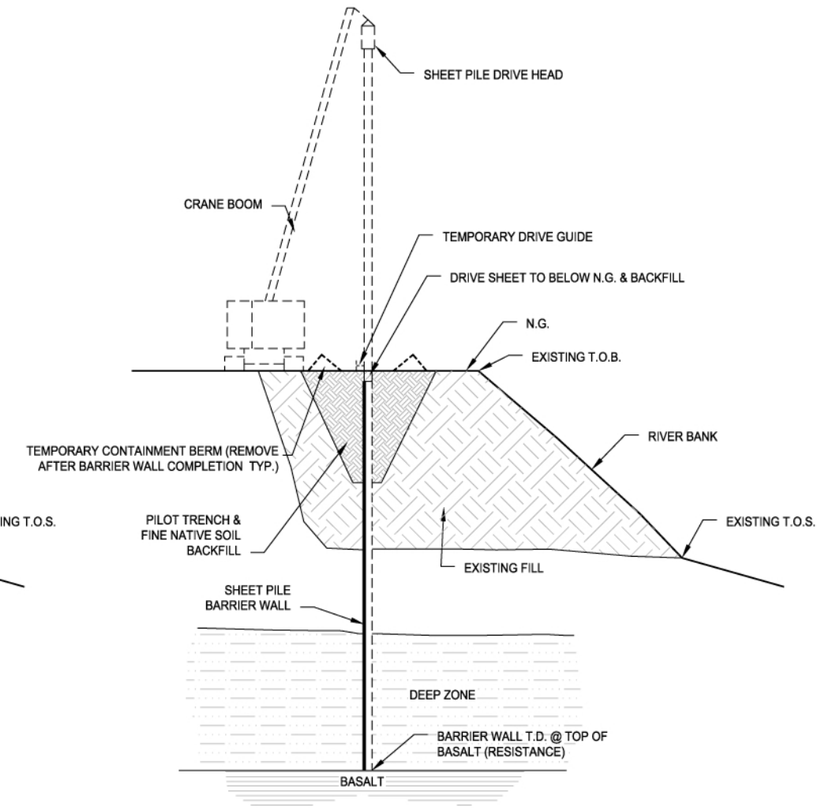
CAD File: G:\CAD\Drawings\Arkema-Portland\0065572\203.dwg



TYPICAL SECTION - VIBRATED BEAM SLURRY BARRIER WALL



TYPICAL SECTION - CONVENTIONAL SLURRY TRENCH BARRIER WALL



TYPICAL SECTION - SEALED STEEL SHEET PILE BARRIER WALL

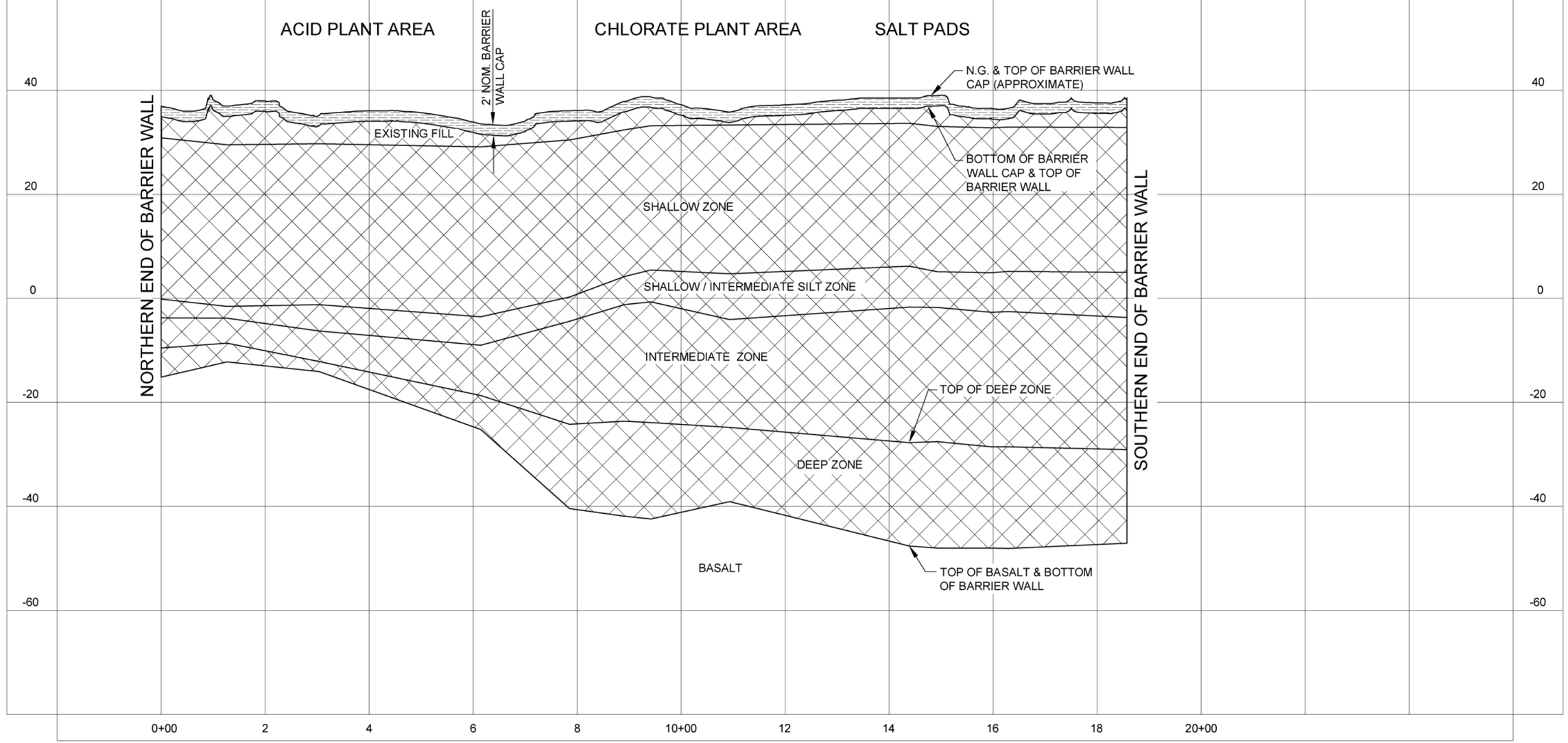
LEGEND

N.G.	NATURAL GRADE
T.O.S.	TOE OF SLOPE
T.O.B.	TOP OF BANK
T.D.	TOTAL DEPTH
TYP.	TYPICAL

NOT TO SCALE

Figure 4-3
Conceptual Barrier Wall Details
Groundwater Source Control IRM
Arkema Inc.
Portland, Oregon

ERM *10/30/07*



PROFILE ALONG RIVER SIDE HIGH BANK BARRIER WALL B/L

LEGEND

BARRIER WALL CAP (SCHEMATIC THK. & GRADE SHOWN)

BARRIER WALL

NOTES:

1. HORIZONTAL DATUM: 100-FOOT STATIONS ALONG BARRIER WALL B/L.

2. VERTICAL DATUM: FEET, NORTH AMERICAN VERTICAL DATUM, 1988.

3. N.G. SURFACE ELEVATION PROFILE: THE N.G. SURFACE PROFILE WAS OBTAINED FROM A DTM CREATED USING SURFACE CONTOURS FROM THE SITE BASE MAP ON THE LAND SIDE OF THE RIVER BANK T.O.B. AND USING SLOPE BREAK LINES (I.E. T.O.B., T.O.S., SHORE LINE, AND INTERMEDIATE BREAK LINES) FROM THE SITE BASE MAP ON THE RIVER SIDE OF THE RIVER BANK T.O.B. ALONG THE FULL ENCLOSURE BARRIER WALL B/L ROUTE; SEE FIG. 4-2. THE ACTUAL N.G. PROFILE MAY VARY FROM THAT SHOWN.

4. ZONE CONTACT PROFILE: THE ZONE CONTACT PROFILES ARE INTERPOLATED BASED ON A ZONE CONTACT SURFACE MODEL PREPARED USING "SURFER" SOFTWARE BASED ON INTERPRETED CONTACT DEPTH DESCRIBED IN BORING LOGS AND THE SURFACE ELEVATION STATED AT THOSE BORING LOGS. THE ACTUAL CONTACT ELEVATIONS MAY VARY FROM THOSE SHOWN BASED ON THE ACTUAL DEPTH OF THE CONTACTS FOUND DURING CONSTRUCTION.

ABBREVIATIONS AND ACRONYMS

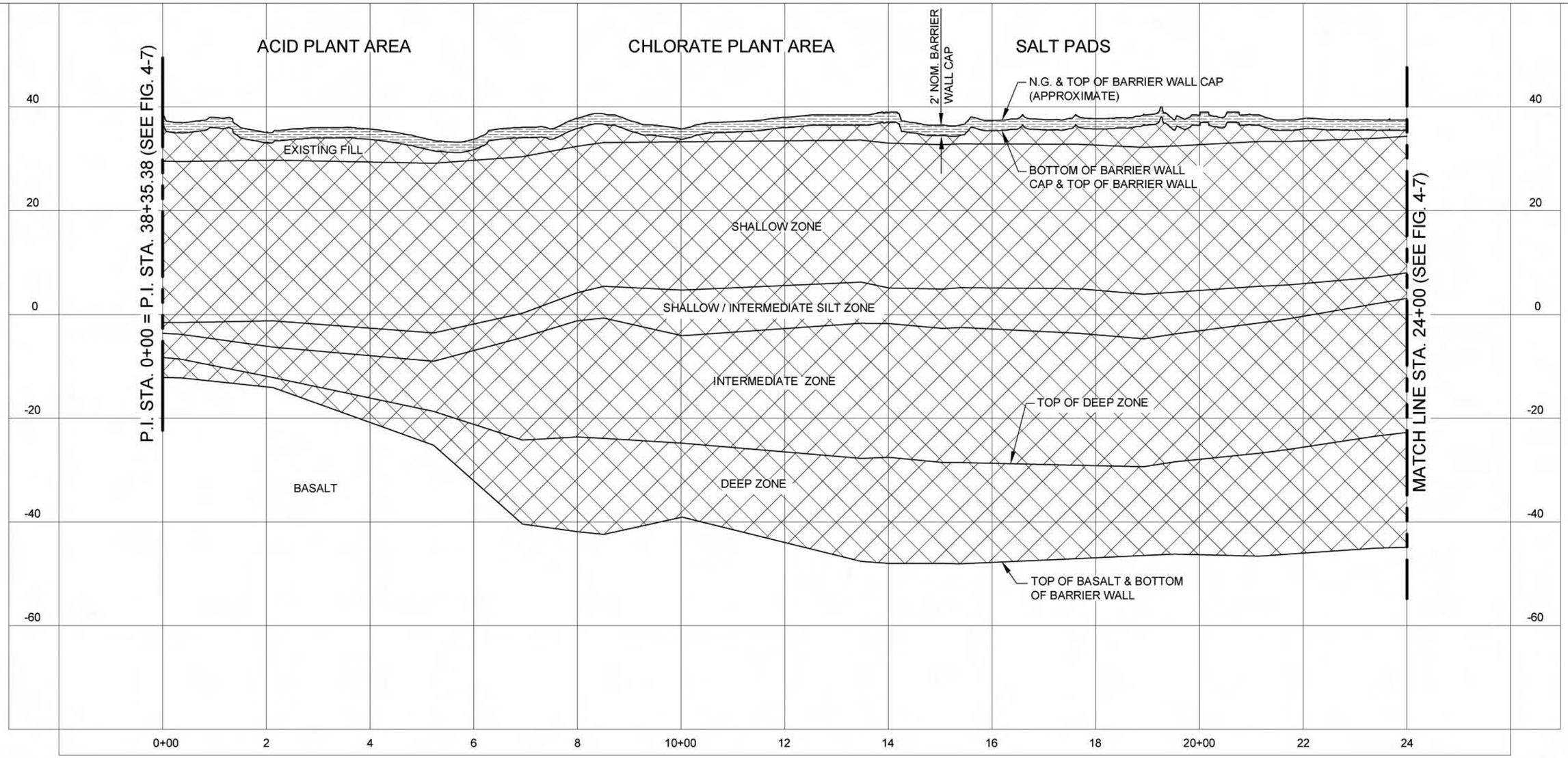
ALT.	ALTERNATIVE
B/L	BASELINE
DTM	DIGITAL TERRAIN MODEL
FIG.	FIGURE
N.G.	NATURAL GROUND
NOM.	NOMINAL
P.I.	POINT OF INTERSECTION
STA.	STATION (100-FOOT STATION BASIS)
T.D.	TOTAL DEPTH
THK.	THICKNESS
T.O.B.	TOP OF BANK
T.O.S.	TOE OF SLOPE

Figure 4-4

River Side High Bank Barrier Wall Profile
Groundwater Source Control IRM
Arkema Inc.
Portland, Oregon

ERM *5/14/08*

Project No. 0065572
Date: 5/14/08
Drawn By: CAK
CAD File: H:\DWG\E08\0065572_topo.dwg



PROFILE ALONG FULL ENCLOSURE BARRIER WALL B/L

LEGEND

BARRIER WALL CAP (SCHEMATIC THK. & GRADE SHOWN)

BARRIER WALL

NOTES: SEE FIG. 4-4.

ABBREVIATIONS AND ACRONYMS : SEE FIG. 4-4.

Figure 4-5

Full Enclosure Barrier Wall Profile - 1 of 2

Groundwater Source Control IRM

Arkema Inc.

Portland, Oregon

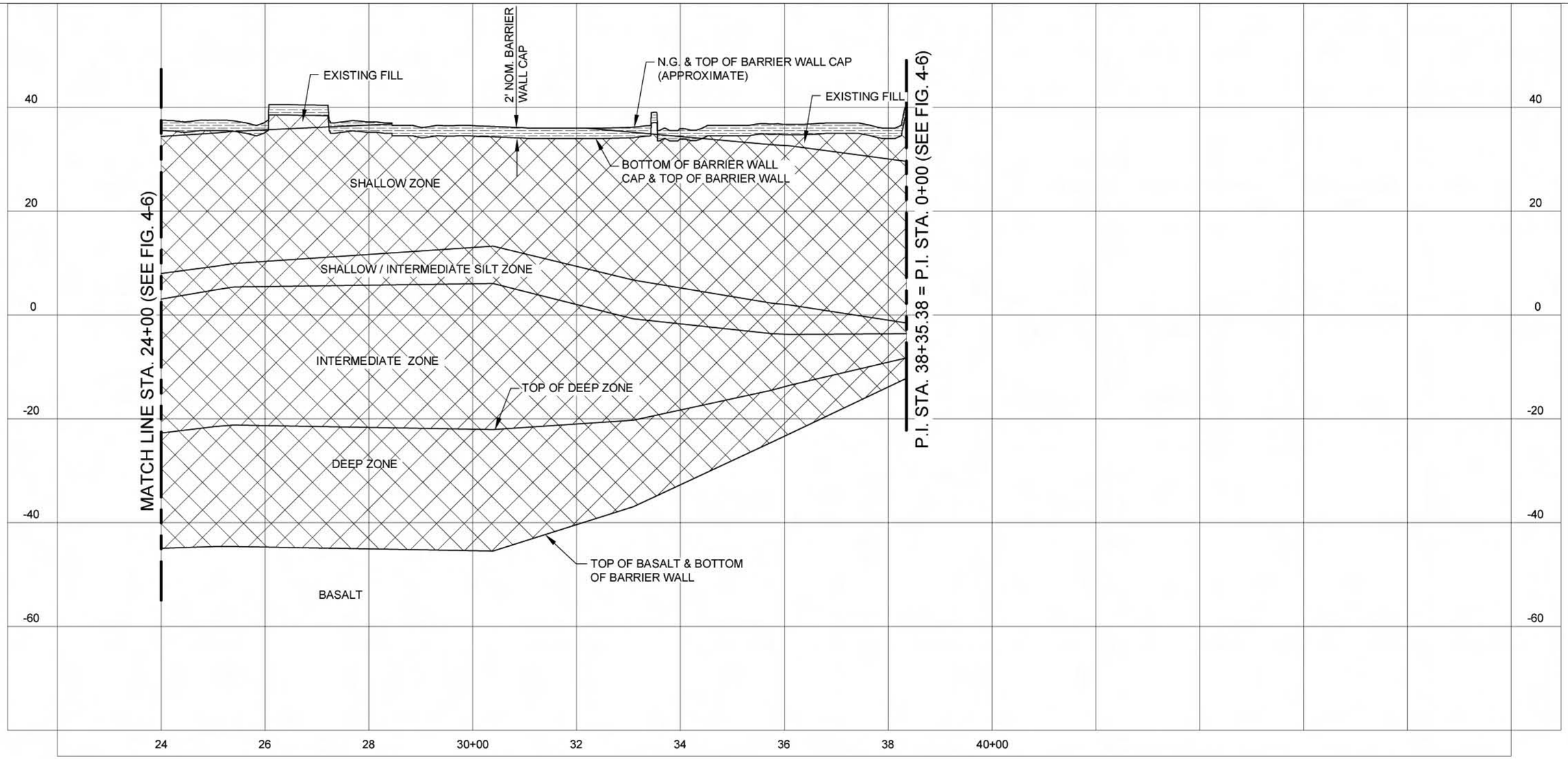
ERM *5/14/08*

Project No. 0065572

Date: 5/14/08

Drawn By: CAK

CAD File: H:\DWG\E08\0065572_topo.dwg



PROFILE ALONG FULL ENCLOSURE BARRIER WALL B/L

LEGEND

BARRIER WALL CAP (SCHEMATIC THK. & GRADE SHOWN)

BARRIER WALL

NOTES: SEE FIG. 4-4.

ABBREVIATIONS AND ACRONYMS : SEE FIG. 4-4.

Figure 4-6

Full Enclosure Barrier Wall Profile - 2 of 2

Groundwater Source Control IRM

Arkema Inc.

Portland, Oregon

ERM *5/14/08*

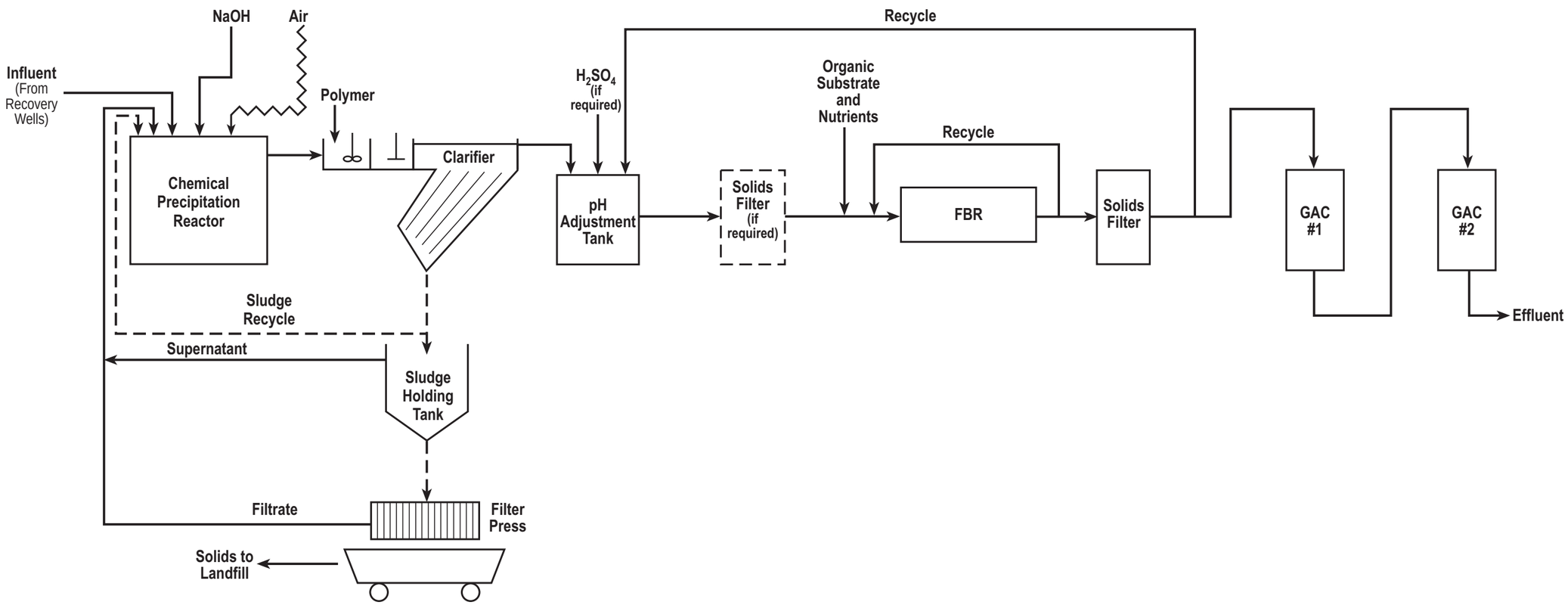
Project No. 0065572

Date: 5/14/08

Drawn By: CAK

CAD File: H:\DWG\E08\0065572_topo.dwg

Drawn By: AP/CU 5-14-08 Project: Arkema 0065572.01.0001



LEGEND

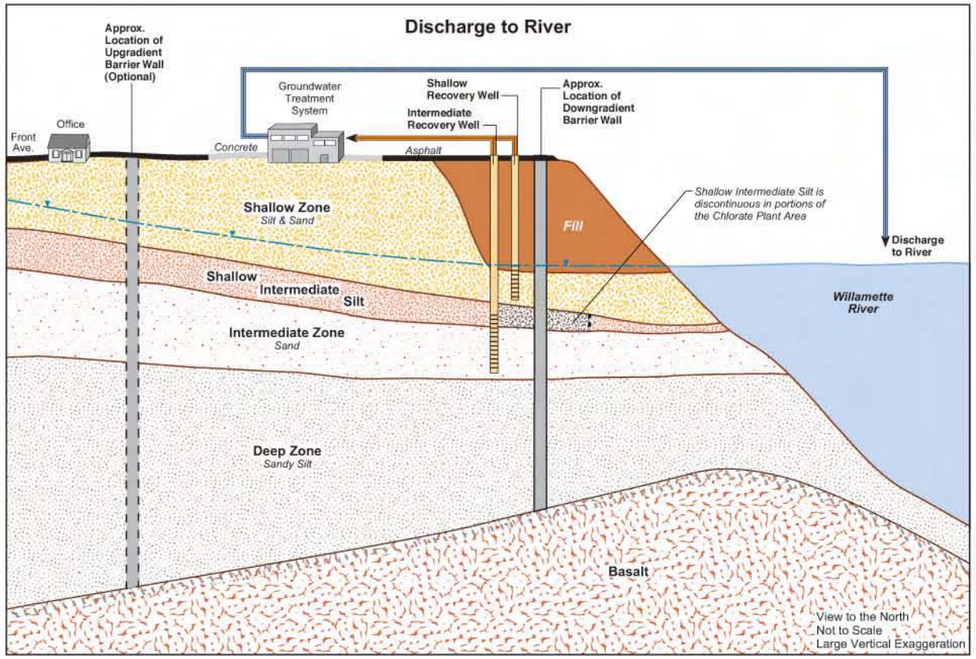
Groundwater
Sludge
Air

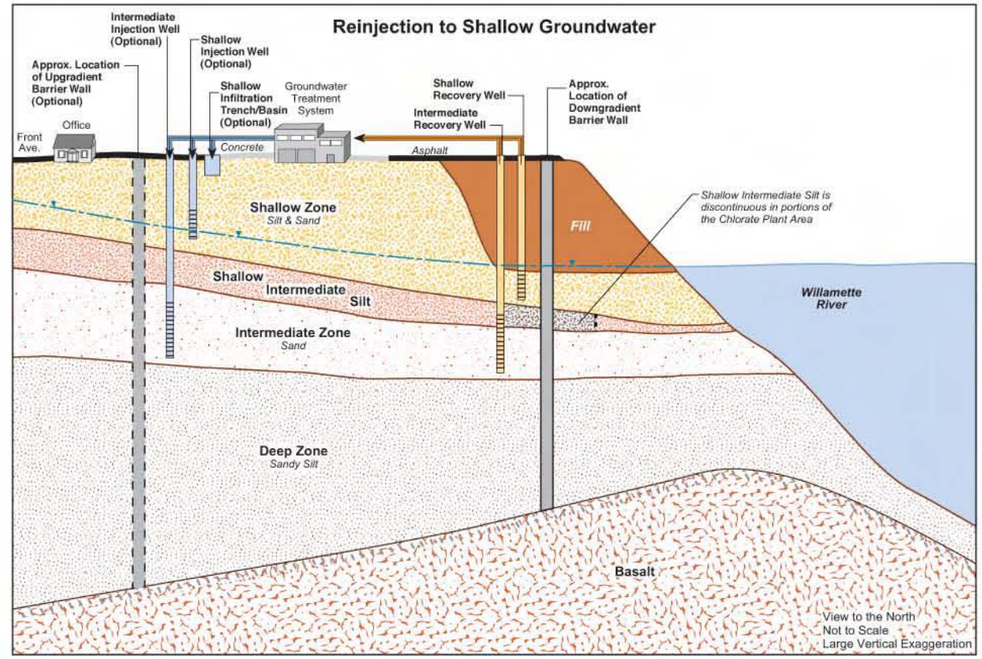
FBR - Fluidized Bed Reactor
GAC - Granular Activated Carbon

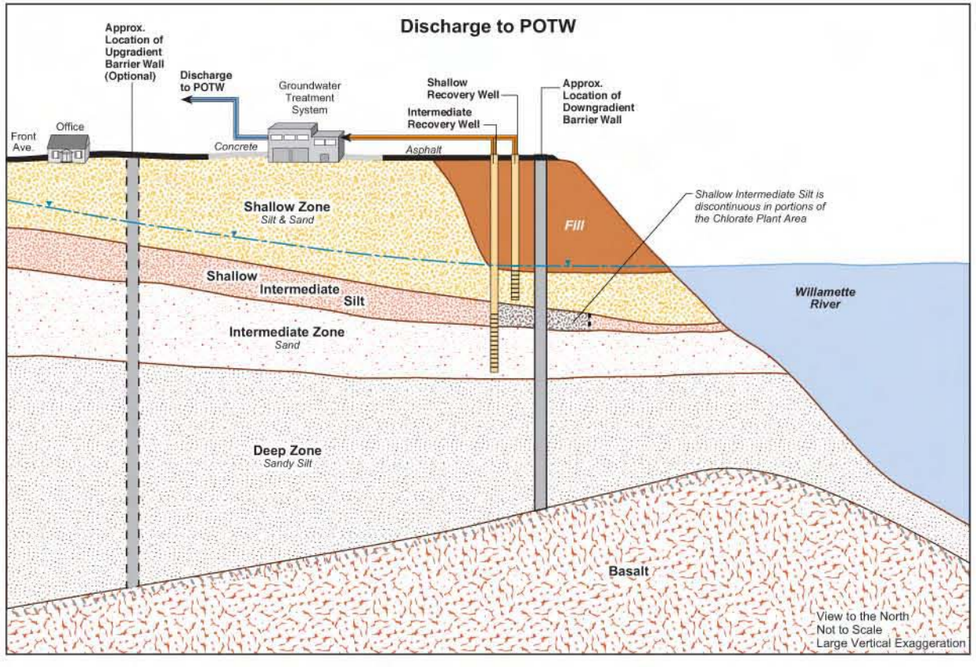
Figure 4-7
Conceptual Flow Diagram
Chemical Precipitation with
Anaerobic Biological Treatment
Groundwater Source Control IRM
Arkema Inc.
Portland, Oregon

ERM

Drawn By: EK/CU 10-22-07 rev. EK 5-13-08 Project: Arkema 0065572.01.0001







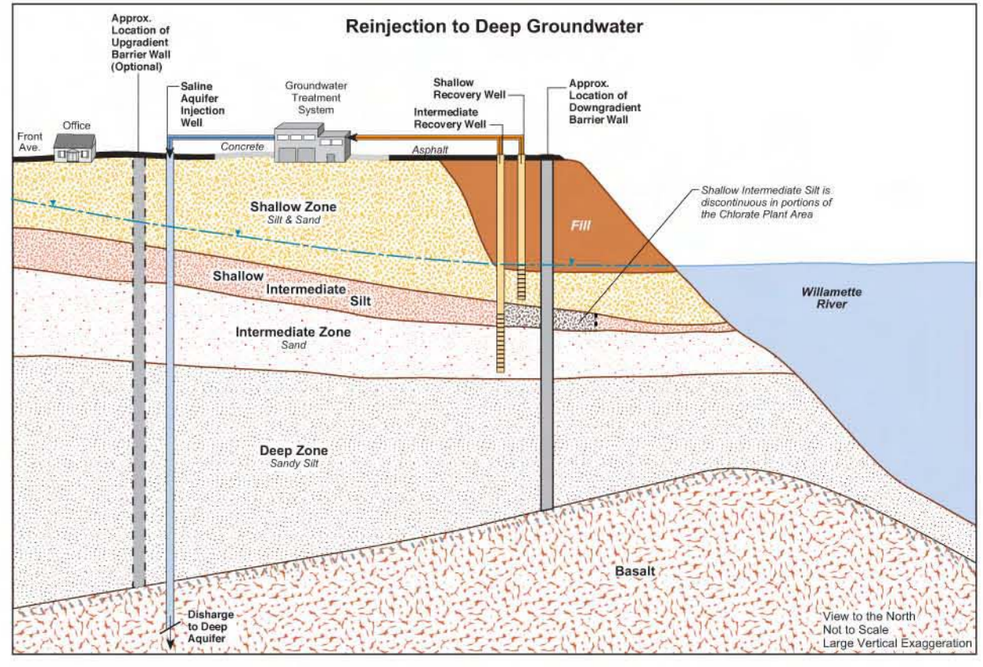
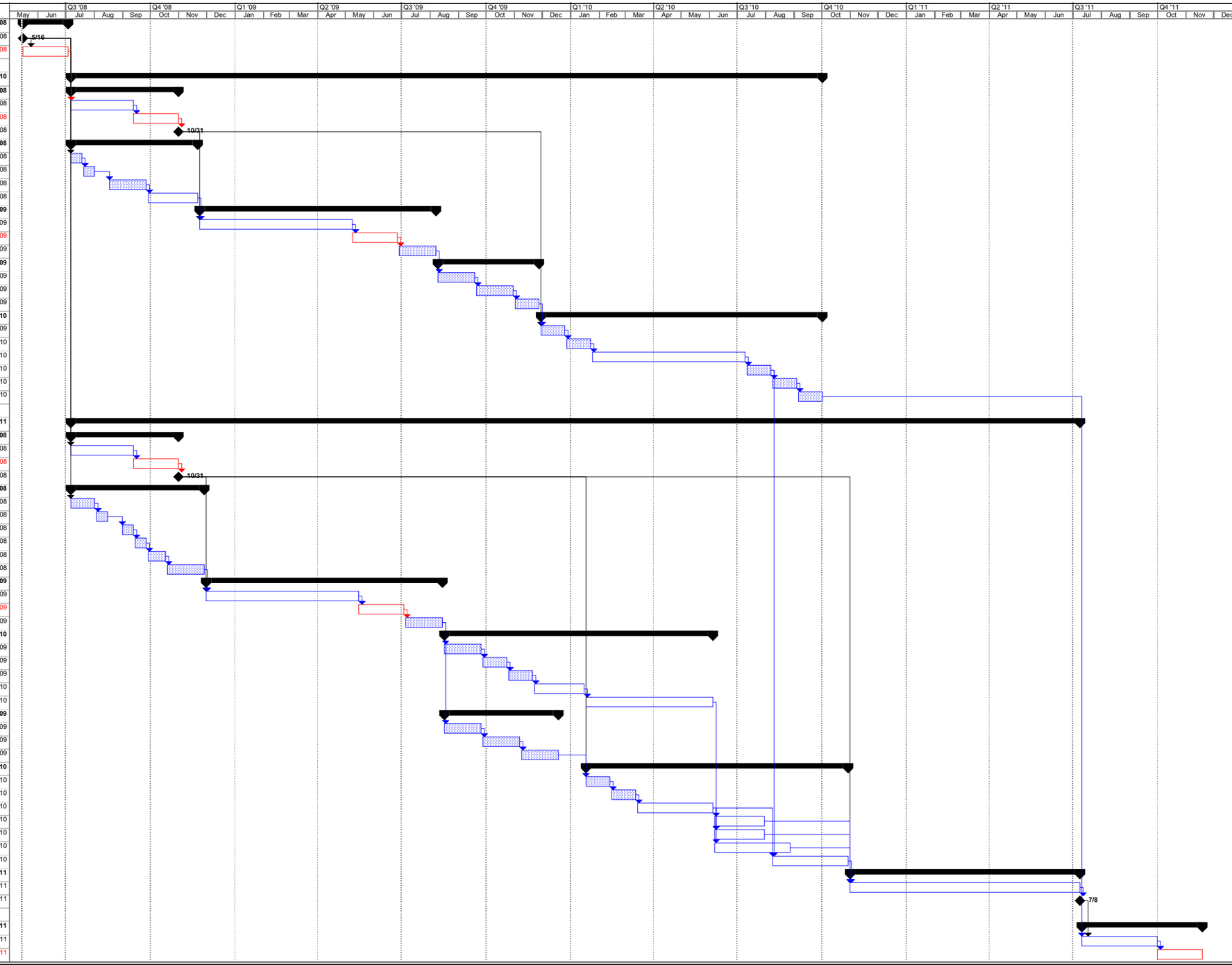


Figure 4-8
Conceptual Discharge Options
Groundwater Source Control IRM
Arkema Inc.
Portland, Oregon

ERM

FIGURE 6-1
Preliminary Implementation Schedule
Groundwater Source Control Interim Remedial Measure
Arkema Chemicals Facility - Portland, Oregon

ID	Task Name	Duration	Start	Finish
1	**Focused Feasibility Study Report**	**35 days**	**Fri 5/16/08**	**Fri 7/4/08**
2	Submit to ODEQ/EPA	0 days	Fri 5/16/08	Fri 5/16/08
3	ODEQ/EPA Review and Approval	49 edays	Fri 5/16/08	Fri 7/4/08
4				
5	**Groundwater Barrier Wall**	**585 days**	**Mon 7/7/08**	**Fri 10/1/10**
6	**GWBW Permitting**	**85 days**	**Mon 7/7/08**	**Fri 10/31/08**
7	Application Preparation	50 days	Mon 7/7/08	Fri 9/12/08
8	ODEQ/EPA Review	49 edays	Fri 9/12/08	Fri 10/31/08
9	Permits Issued	0 days	Fri 10/31/08	Fri 10/31/08
10	**GWBW Pre-Design Investigation**	**100 days**	**Mon 7/7/08**	**Fri 11/21/08**
11	PDI Scoping	10 days	Mon 7/7/08	Fri 7/18/08
12	Surveyor and Driller Contracting	10 days	Mon 7/21/08	Fri 8/1/08
13	Route Survey Field Work/Data Evaluation	30 days	Mon 8/18/08	Fri 9/26/08
14	Route CPT and Borings Field Work/Data Evaluation	40 days	Mon 9/29/08	Fri 11/21/08
15	**GWBW Design**	**185 days**	**Mon 11/24/08**	**Fri 8/7/09**
16	Pre-Final Design Preparation and Submittal	120 days	Mon 11/24/08	Fri 5/8/09
17	ODEQ/EPA review and approval	49 edays	Fri 5/8/09	Fri 6/26/09
18	Final Design Preparation	30 days	Mon 6/29/09	Fri 8/7/09
19	**GWBW Bidding and Contracting**	**80 days**	**Mon 8/10/09**	**Fri 11/27/09**
20	Bid Package Preparation	30 days	Mon 8/10/09	Fri 9/18/09
21	Contractor Bidding	30 days	Mon 9/21/09	Fri 10/30/09
22	Bid Review, Selection, and Contract Execution	20 days	Mon 11/2/09	Fri 11/27/09
23	**GWBW Construction**	**220 days**	**Mon 11/30/09**	**Fri 10/1/10**
24	Mobilization and Site Preparation	20 days	Mon 11/30/09	Fri 12/25/09
25	Surface and Route Clearance	20 days	Mon 12/28/09	Fri 1/22/10
26	GWBW Construction	120 days	Mon 1/25/10	Fri 7/9/10
27	GWBW Cap Construction	20 days	Mon 7/12/10	Fri 8/6/10
28	GWBW Piezometer Construction	20 days	Mon 8/9/10	Fri 9/3/10
29	Demobilization	20 days	Mon 9/6/10	Fri 10/1/10
30				
31	**Groundwater Extraction & Treatment System**	**785 days**	**Mon 7/7/08**	**Fri 7/8/11**
32	**GWTS Permitting**	**85 days**	**Mon 7/7/08**	**Fri 10/31/08**
33	Application Preparation	50 days	Mon 7/7/08	Fri 9/12/08
34	ODEQ/EPA Review	49 edays	Fri 9/12/08	Fri 10/31/08
35	Permits Issued	0 days	Fri 10/31/08	Fri 10/31/08
36	**GWTS Pre-Design Investigation**	**105 days**	**Mon 7/7/08**	**Fri 11/28/08**
37	PDI Scoping	20 days	Mon 7/7/08	Fri 8/1/08
38	Surveyor and Driller Bidding and Contracting	10 days	Mon 8/4/08	Fri 8/15/08
39	Recovery Well Installation	10 days	Mon 9/1/08	Fri 9/12/08
40	Pumping Tests	10 days	Mon 9/15/08	Fri 9/26/08
41	Data Reduction and Evaluation	15 days	Mon 9/29/08	Fri 10/17/08
42	Confirmatory Ground Water Modeling	30 days	Mon 10/20/08	Fri 11/28/08
43	**GWTS Design**	**185 days**	**Mon 12/1/08**	**Fri 8/14/09**
44	Pre-Final Design Preparation and Submittal	120 days	Mon 12/1/08	Fri 5/15/09
45	ODEQ/EPA review and approval	49 edays	Fri 5/15/09	Fri 7/3/09
46	Final Design Preparation	30 days	Mon 7/6/09	Fri 8/14/09
47	**GWTS Equipment Procurement**	**210 days**	**Mon 8/17/09**	**Fri 6/4/10**
48	Bid Specifications Preparation	30 days	Mon 8/17/09	Fri 9/25/09
49	Vendor Bidding	20 days	Mon 9/28/09	Fri 10/23/09
50	Bid Evaluation, Selection, and PO Execution	20 days	Mon 10/26/09	Fri 11/20/09
51	Fabrication Drawing Preparation, Review, and Approval	40 days	Mon 11/23/09	Fri 1/15/10
52	Fabrication and Delivery	100 days	Mon 1/18/10	Fri 6/4/10
53	**GWTS Bidding and Contracting**	**90 days**	**Mon 8/17/09**	**Fri 12/18/09**
54	Bid Package Preparation	30 days	Mon 8/17/09	Fri 9/25/09
55	Bidding	30 days	Mon 9/28/09	Fri 11/6/09
56	Bid Review, Selection, and Contracting	30 days	Mon 11/9/09	Fri 12/18/09
57	**GWTS Construction**	**205 days**	**Mon 1/18/10**	**Fri 10/29/10**
58	Mobilization	20 days	Mon 1/18/10	Fri 2/12/10
59	Site Preparation	20 days	Mon 2/15/10	Fri 3/12/10
60	Treatment Equipment Building Construction	60 days	Mon 3/15/10	Fri 6/4/10
61	Utilities	40 days	Mon 6/7/10	Fri 7/30/10
62	Equipment Installation	40 days	Mon 6/7/10	Fri 7/30/10
63	Conveyance Piping/Conduit Trenching and Installation	60 days	Mon 6/7/10	Fri 8/27/10
64	Well Installation, Development, Pump Setting, and Wellhead Construction	60 days	Mon 8/9/10	Fri 10/29/10
65	**GWTS Operation & Maintenance**	**180 days**	**Mon 11/1/10**	**Fri 7/8/11**
66	Startup	180 days	Mon 11/1/10	Fri 7/8/11
67	Commence Routine O&M	0 days	Fri 7/8/11	Fri 7/8/11
68				
69	**Interim Remedial Measure Implementation Report**	**95 days**	**Mon 7/11/11**	**Fri 11/18/11**
70	Report Preparation and Submittal	60 days	Mon 7/11/11	Fri 9/30/11
71	ODEQ/EPA Review	49 edays	Fri 9/30/11	Fri 11/18/11



Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

Tables

DRAFT
Table 4-1
Preliminary Project ARARs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

ARAR and Citation	Description	Applicability
Federal		
Federal Water Pollution Control Act/Clean Water Act (CWA) [33 USC Sections 1313, 1314, 1341 and 1344; 40 CFR Parts 131, 230]	The CWA establishes the basic structure for regulation of discharges of pollutants into the water of the United States. Section 404 (33 USC §1344) regulates the discharge of dredged material or fill into navigable waters. Section 401(33 USC §1341) requires state certification that a discharge will not violate state water quality standards.	The implementing regulations of the CWA are applicable to potential toe-of-slope barrier wall construction.
Rivers and Harbors Appropriations Act [33 USC Section 403; 33 CFR Parts 230, 322]	The Rivers and Harbors Act prohibits unauthorized activities that obstruct or alter a navigable waterway. It controls the alteration of navigable waters (i.e., waters subject to ebb and flow of the tide shoreward to the mean high water mark). Activities controlled include construction of structures such as piers, berms, and installation of pilings. Section 10 may be applicable for any action that may obstruct or alter a navigable waterway.	The Rivers and Harbors Act regulations are applicable to potential remedial activities adjacent to the river, including potential barrier wall construction actions.
Resource Conservation and Recovery Act (RCRA) [42 USC Section 6921; 40 CFR Parts 260, 261]	RCRA provides standards for the identification and management of solid and hazardous waste.	These regulations are applicable because waste materials generated as a result of barrier wall construction and/or groundwater treatment actions (e.g., metal hydroxide sludge) that contain a listed or characteristic waste, if any, may be subject to RCRA requirements for storage, treatment, and disposal.
The Endangered Species Act (ESA) [16 USC Section 1536; 50 CFR Part 402]	The ESA requires an evaluation of a federal agency's action's impacts on listed (or proposed for listing) species of fish, wildlife, or plants.	The ESA regulations are unlikely to be applicable because barrier wall construction is not expected to impact listed species in and adjacent to the Willamette River.

ARAR and Citation	Description	Applicability
Floodplain Management and Wetlands Protection [40 CFR Part 6 App. A and Executive Order 11988 and 11990]	Floodplain Management and Wetlands Protection requires federal agencies to conduct their activities to avoid, if possible, adverse impacts associated with the destruction or modification of wetlands and occupation or modification of floodplains. Executive Order 11988 requires federal projects to avoid adverse effects associated with construction in floodplains.	This regulation may be applicable because barrier wall construction could at least in part be within a floodplain.
Magnuson-Stevens Fishery Conservation and Management Act [16 USC Section 1855(b); 50 CFR Part 600, subparts J-K]	Section 305(b) of the Magnuson-Stevens Act requires federal agencies to evaluate impacts to essential fish habitat (EFH) for activities that may adversely affect EFH.	This regulation is unlikely to be applicable because barrier wall construction is not expected to impact EFH in the Willamette River.
Marine Mammal Protection Act [16 USC Section 1372]	EPA must ensure that the actions do not involve the unauthorized taking of marine mammals.	This regulation is unlikely to be applicable because marine species do not inhabit the lower Willamette River.
Hazardous Materials Transportation Act [49 USC Section 15101 *et seq.*; 49 CFR Section 171-177]	Regulations provide for packaging, documentation, and transportation of hazardous waste (some RCRA requirements also apply).	This regulation is applicable if any material generated as a result of barrier wall construction and/or groundwater treatment actions is identified as hazardous waste and requires shipment for treatment or disposal.
National Historic Preservation Act (NHPA) [16 USC Sections 470h-2]	The NHPA requires EPA to consider the effects of remedial actions on historic properties.	This regulation is unlikely to be applicable because this site is not an historic property.
Archaeological and Historical Preservation Act (AHPA) [16 USC Sections 4699a-1]	In the event that significant scientific, prehistoric, or archaeological data are present on site, the AHPA requires EPA to approve the remedial activities so that such data are preserved.	This regulation is unlikely to be applicable because the site has not been shown to be an archaeological resource.
Native American Graves Protection and Repatriation Act (NAGPR) [25 USC Section 3001 *et seq.*]	The NAGPR act requires federal agencies and museums with possession or control over Native American human remains and	This regulation is only applicable if Native American remains or funerary objects are at the

ARAR and Citation	Description	Applicability
	associated funerary objects to compile an inventory of such items. It requires federal agencies and museums with possession or control over Native American non-associated funerary objects, sacred objects, or objects of cultural patrimony to provide a written summary of such objects. It prescribes when a federal agency or museum must return Native American cultural items.	site, which, based on current information, is considered very unlikely.
National Pretreatment Standards for Discharges to publicly owned treatment works (POTW) [40 CFR Part 403]	The National Pretreatment Program identifies discharge standards to POTWs.	This regulation is potentially applicable to any discharges to a City of Portland POTW.
Safe Drinking Water Act (SWDA) [42 USC 300f *et seq.*]	The SDWA establishes maximum contaminant level (MCL) standards for the protection of drinking water sources.	This regulation is not applicable because the site is not impacting a drinking water source; however, the MCL standards are to be considered (TBC) in evaluating treatment and discharge options for groundwater.
State and Local Requirements		
Oregon Water Quality Law (WQL) [ORS 468b.005 – 468b.095 (surface water) and ORS 468B.150-190 (groundwater); Oregon Water Quality Standards and Criteria, OAR Chapter 340, Divisions 40 and 41]	The WQL designates beneficial uses of water bodies and water quality standards and criteria necessary to protect those uses. In particular, OAR 340-041-0340 provides the beneficial water uses that shall be protected in the Willamette Basin. OAR 340-041-0442 through 340-041-0445 provide water quality standards for the State of Oregon. With respect to groundwater, OAR 340-0404-020 and 340-0404-0303(3)(b) define an "antidegradation policy to emphasize the prevention of groundwater pollution and to control waste discharges to groundwater so that the highest possible water quality is maintained."	This regulation is likely applicable to groundwater and the Willamette River. Water quality standards may apply to discharge of treated groundwater.

ARAR and Citation	Description	Applicability
Oregon Regulations Pertaining to NPDES and WPCF Permits[OAR Chapter 340, Division 45]	The Oregon NPDES regulations establish discharge limits and monitoring requirements for direct discharges to surface waters.	The requirements of this regulation are potentially applicable to any direct discharges of treated water to the Willamette River.
Oregon Underground Injection Control (UIC) Rules [OAR Chapter 340, Division 44]	The Oregon UIC rules establish requirements for underground injection activities, including the construction, modification, or maintenance of any injection system. Under the UIC rules, it is prohibited to conduct any injection activity that would allow the direct or indirect movement of fluids containing contaminants into groundwater that may cause a violation of any primary drinking water regulation under the federal Safe Drinking Water Act, or fails to comply with groundwater quality protection requirements specified in OAR 340-040.	This regulation is potentially applicable to any subsurface injections conducted as part of the remedy.
Oregon Solid Waste Management Act (SWMA) [ORS 459.005 *et* seq.; OAR 340-094-0040]	The SWMA provides standards for the management and handling of solid wastes in Oregon.	This regulation is potentially applicable because disposal of non-hazardous waste materials may occur at a Subtitle D landfill.
Hazardous Waste Regulations [ORS 466.005-466.225; OAR Chapter 340-101-0033]	Hazardous waste regulations provide standards for the identification and management of hazardous wastes in Oregon.	This regulation is applicable if any material generated during barrier wall construction and/or groundwater treatment actions is identified as hazardous waste and requires shipment for treatment or disposal in Oregon.
Cleanup Standards [OAR 340-122-0040(2)(a), (4) and (6]	The cleanup standards provide hazardous substance remedial action levels and requirements.	This regulation may be applicable to the establishment of cleanup levels and other requirements for treatment and discharge of groundwater.
Indian Graves and Protected Objects (IGPO) [ORS 97.740 *et seq.*]	The IGPO protects human remains, funerary objects, sacred objects, and objects of cultural patrimony.	This regulation is only applicable if Native American remains or

ARAR and Citation	Description	Applicability
		funerary objects are at the site, which, based on current information, is considered very unlikely.
Archaeological Objects Site [ORS 358.905 *et seq.*]	The archaeological objects laws protect archaeological objects and sites; requires notice upon discovery of artifacts.	This regulation is unlikely to be applicable because the site has not been shown to be an archaeological resource.
Visible Air Contaminant Limitations [OAR 340-208-0110]	The visible air contaminant limitations prohibit the emission of any air contaminant from a new source for a period or periods aggregating more than 3 minutes in any 1 hour that is equal to or greater than 20% opacity. These rules are for "special control areas" including Multnomah County.	This regulation is only applicable if barrier wall construction and groundwater treatment actions generate visible emissions of air contaminants, which is considered unlikely.
Fugitive Emission Requirements (FER) [OAR 340-208-0200, 0210]	The FER prohibits any handling, transporting, or storage of materials, or use of a road, or any equipment to be operated, without taking reasonable precautions to prevent particulate matter from becoming airborne. These rules are for "special control areas" including Multnomah County.	This regulation is potentially applicable only if material generated during barrier wall construction has very low water content and requires shipment, which is considered unlikely.
Lower Willamette River Management Plan (LWRMP) [ORS 273.045; OAR Chapter 141 Division 80]	The LWRMP provides policy direction and guidance to the Department of State Lands' (DSL) regulatory and proprietary interests of the lower 17.5 miles of the Willamette River.	This regulation would likely be applicable for toe-of-slope barrier wall construction and likely not applicable for other remedial actions considered in this FFS.

ARAR and Citation	Description	Applicability
Oregon Water Resources Department Willamette Basin Plan [OAR Chapter 690]	Oregon Water Resources Department (WRD) permit rules apply to any withdrawal of surface water from the Willamette River or groundwater from a well in the Willamette Basin. Production or recovery wells must also comply with WRD general standards for construction and maintenance of water wells (OAR Chapter 690, Division 200) and monitoring wells must comply with the appropriate standards for their construction and maintenance (OAR Chapter 690, Division 240).	This regulation is potentially applicable to the installation of groundwater extraction or monitoring wells as part of the remedial action.
Removal Fill Laws and Regulations (RFLR) [ORS 196.795 through 196.990; OAR Chapter 141, Division 85]	The RFLR define the requirements for dredging and filling activities and coordination of the permit requirements with federal regulations.	This regulation may be applicable if barrier wall construction includes dredging and/or filling in the Willamette River, which is considered unlikely.
City of Portland Industrial Wastewater Discharge Limits [Section 17.34 of the Portland Code]	The City of Portland Industrial Wastewater Discharge Limits establish discharge limits for industrial discharges to the City of Portland Sewer System. The City of Portland requires any "significant industrial user" to obtain a permit before discharging to the City of Portland Sewer System.	This regulation is potentially applicable to discharges from the site to the City of Portland Sewer System.
City of Portland Requirements for Greenway overlay zones [City of Portland Zoning Code Chapter 33.440]	The City of Portland has established Greenway overlay zones adjacent to the Willamette River to conserve natural, scenic, historical, economic, and recreational qualities and to promote public access, flood protection, and aesthetic factors. The regulations for Greenway overlays require that proposed development not be detrimental to the use and function of the river and abutting lands and must conserve, enhance, and maintain scenic qualities and natural habitat.	This regulation is potentially applicable to remedial activities at the site, as the site is located within a Greenway overlay.

General Response Action	Remediation Technology	Process Option	Description	Effectiveness	Implementability	Cost	Summary of Evaluation
Containment	Groundwater Barrier Wall	Conventional Excavated Soil Slurry Wall	Construct barrier wall and related facilities in stages. • Clear surface and subsurface obstructions. • Grade excavation and slurry mix pads. • Excavate trench to depth supported by mined clay slurry; usually 3 feet wide. • Mix excavation spoil, slurry, and, if necessary, imported fines and/or mined clay to make soil-slurry backfill. • Place soil-slurry backfill in slurry trench in stages that fill trench without voids. • Due to limited slurry backfill slump and excavation clearances, a 60-VF deep wall would require 400 to 600 LF of trench to be open during all but initial and final stages of excavation. • Stabilize upper part of backfill to support surface loads, if necessary. • Construct well-drained low-permeability cap over slurry wall. • Provide groundwater extraction facilities to maintain an adequate inward gradient and to control affected groundwater flow. • Install pairs of piezometers on exterior and interior sides of the wall to confirm effectiveness of the wall.	Good effectiveness for containment of affected groundwater. • Slurry backfill hydraulic conductivity usually less than 1 x 10E-07 cm/sec. • Can divert affected groundwater toward a permeable reactive barrier or capture zone. • Needs groundwater extraction to prevent increased groundwater levels on upgradient side of wall, flow through the wall due to high hydraulic gradient across the wall, or migration around the end of the wall if not completely surrounding affected groundwater.	Good potential for implementability in suitable locations: • Adequate site characterization and groundwater modeling to select final location and groundwater extraction rate needed. • Clearance of subsurface objects > 24-inch maximum dimension. • Adequate provision for permanent or temporary plugging of crossing pipes and site drainage during construction. • Clearance of structural surfacing. • Nearly level excavation pad approximately 20-feet wide. • Nearly level slurry mix pad with width approximately equal to trench depth. • Adequate quality slurry mix water supply. • Adequate native soil fines in excavation spoil or adequate quality and quantity of imported clay soil. • Adequate compatibility of slurry and slurry backfill with formation pore water and soil constituents, esp. TDS. • Limited, if any, affected excavation spoil and other affected waste. • Overall production rate expected to be roughly 50 LF per work day. • Proven technology used to control affected groundwater at many similar sites in US.	Average range total present value. • Average range mobilization and demobilization costs. • Average range site preparation cost. • Average range construction cost. • Average CQA cost. • Low range post-RA cost. • Average overall present value.	• Retain for further screening and evaluation in the FFS.

General Response Action	Remediation Technology	Process Option	Description	Effectiveness	Implementability	Cost	Summary of Evaluation
		Shielded Ladder Trench Excavated Soil Slurry Wall	Similar to Conventionally Excavated Soil Slurry Wall, except: • Shallow slurry reservoir trench needed to provide slurry reserve. • No slurry mix pad required. • Trench supported by slurry and steel plate shield. • Usually 1 to 2 feet wide. • Mix excavation spoil, slurry, and, if necessary, imported fines and/or mined clay with ladder excavator-mixer in trench to make slurry backfill. • Only a few feet of trench open at any time.	Good effectiveness, similar to Conventional Excavated Soil Slurry Wall, except: • Depth is limited to approximately 35 VF below work platform.	Poor potential for implementability at this site; otherwise similar to Conventional Excavated Soil Slurry Wall, except:: • Needs clearance of subsurface objects > 6-inch maximum dimension. • Not practical for depths greater than 35 VF below excavation work platform. • Excavation to 60 VF depth needed would require excavation of many thousands of CY of affected soil and, if not allowed to be used as backfill, on-site or off-site disposal. • Overall production rate expected to be roughly 300 to 600 LF per work day.	Low to average range overall present value. • High range mobilization and demobilization costs. • Average range site preparation cost. • Low to average range construction cost. • Low to average waste management cost. • Low to average CQA cost. • Low range post-RA cost.	• Omit from further consideration because of inadequate depth capability.
		Conventional Excavated Plastic Concrete Slurry Wall	Similar to Conventional Excavated Soil Slurry Wall, except: • No slurry mix pad needed. • Portland cement of other suitable S/S reagent is added to slurry. • All native soil excavation spoil is placed in on-site or off-site waste disposed cell or landfill. • Key into prior partially-set plastic concrete wall when restarting work from overnight or weekend work break. • Usually have 50 to 100 LF of slurry trench open at a time.	Good effectiveness, similar to Conventional Excavated Soil Slurry Wall, except: • Hydraulic conductivity is typically one or two orders of magnitude higher that a soil slurry wall in similar conditions.	Good potential for implementability in suitable locations, similar to Conventional Excavated Soil Slurry Wall, except:: • Would require much more slurry trench excavation soil waste management. • Would require a higher rate of groundwater extraction and treatment. • Overall production rate expected to be roughly 50 to 75 LF per work day.	Average to high overall present value. • Average range mobilization and demobilization costs. • Average range site preparation cost. • Average to high range construction cost. • High range waste management cost. • Average CQA cost. • Average range post-RA cost.	• Omit from further consideration because of much higher construction and waste management costs.
		Shielded Ladder Trench Excavated Plastic Concrete Slurry Wall	Similar to Shielded Ladder Trench Excavated Slurry Wall, except: • Portland cement or other suitable S/S reagent is added to slurry.	Good effectiveness, similar to Shielded Ladder Trench Excavated Soil Slurry Wall, except : • Hydraulic conductivity is typically two or three orders of magnitude higher for similar conditions.	Poor potential for implementability at this site; otherwise similar to Shielded Ladder Trench Soil Slurry Wall, except:: • Would require a higher rate of groundwater extraction and treatment. • Not practical for depths greater than 35 VF. • Overall production rate expected to be roughly 50 LF per work day. • Overall production rate expected to be roughly 300 to 500 LF per work day.	Average to high range overall present value. • High range mobilization and demobilization costs. • Average range site preparation cost. • Average to high range construction cost. • Low to average waste management cost. • Low to average CQA cost. • Average range post-RA cost.	• Omit from further consideration because of inadequate depth capability and higher construction and waste management costs.

General Response Action	Remediation Technology	Process Option	Description	Effectiveness	Implementability	Cost	Summary of Evaluation
		Vibrated Beam Plastic Concrete Slurry Wall	Construct barrier wall and related facilities in stages. • Clear surface and subsurface obstructions. • Grade excavation pads (no slurry mix pad is needed). • Excavate shallow slurry reservoir trench; approximately 50 to 75 LF open at a time. • Advance 4-inch wide x 3-LF excavation-slurry injection tool vertically from the surface to the target total depth by jetting cement slurry through nozzles in the base of the excavation tool. • Mix native soil and injected cement in panel as the excavation-injection tool is withdrawn. • Overlap excavation-injection panels to establish continuity of the wall. • Approximately 50 to 75 LF of panels open at a time; only one 3 LF panel worked at a time. • Panels gain strength usually adequate to support surface loads without further solidification. • Relatively small volume of expanded formation expelled from excavation could be placed in slurry trench, unless constituent concentrations require special management. • Construct well-drained low-permeability cap over slurry wall. • Provide groundwater extraction facilities to maintain an adequate inward gradient and to control affected groundwater flow. • Install pairs of piezometers on exterior and interior sides of the wall to confirm effectiveness of the wall.	Good effectiveness similar to a Conventional Excavated Soil Slurry Wall, except: • Hydraulic conductivity ranges between 10E-06 cm/sec and 10E-08 cm/sec. • The relatively thin wall produces much higher hydraulic gradients than conventional slurry walls, although permeability still multiple orders of magnitude less than the native formation.	Good potential for implementability in suitable locations, similar to Conventional Excavated Soil Slurry Wall, except: • Depth limited to approximately 80 VF. • Does not require exacavtion/removal of soil. • Clearance of subsurface objects > 4-inch maximum dimension. • Can generally be constructed in areas with less width available for excavation-injection equipment. • Would require a higher rate of groundwater extraction and treatment. • Overall production rate expected to be roughly 50 to 75 LF per work day.	Average range overall present value. • Average to high range mobilization and demobilization costs. • Average range site preparation cost. • Average range construction cost. • Low to average waste management cost. • Average range CQA cost. • Low to average range post-RA cost.	• Retain for further screening and evaluation in the FFS.

General Response Action	Remediation Technology	Process Option	Description	Effectiveness	Implementability	Cost	Summary of Evaluation
		HDPE Curtain Wall	Construct barrier wall and related facilities in stages similar to a Conventional Soil Slurry Wall, except: • Prior to placement of slurry backfill, deploy a HDPE membrane into the open trench using a crane supporting a deployment frame. • Seal panel joints using a suitable sealant resistant to groundwater constituents and the formation. • Slurry backfill is placed on both sides of the membrane after the membrane is deployed to total depth.	Poor to excellent effectiveness, depending on quality of the installation, and similar to Conventional Excavated Soil Slurry Wall, except: • HDPE barrier, if installed properly, can greatly reduce the effective hydraulic conductivity of the barrier wall.	Poor potential for implementability at this site; otherwise similar to Conventional Excavated Soil Slurry Wall, except: • The relatively thin HDPE membrane is difficult to place and is susceptible to damage during placement in the slurry trench. • Overall production rate expected to be roughly 50 to 300 LF per work day	High range overall present value. • High range to high range mobilization and demobilization costs. • Average range site preparation cost. • Average to high range construction cost. • Low to average range waste management cost. • Average to high range CQA cost. • Low to average range post-RA cost.	Omit from further consideration because of high implementability uncertainty and high construction and waste management costs.
		HDPE Panel Wall	Construct barrier wall and related facilities in stages similar to a HDPE Membrane Wall, except: • Push 4- to 8-foot wide vertical HDPE panels directly into low permeability layer at the base of the formation using a mandrel frame. • Seal panel joints using a suitable sealant resistant to groundwater and constituents affecting groundwater and the formation.	Poor to excellent effectiveness, similar to the HDPE Membrane Wall, except: • HDPE barrier panel joints may be marginally more transmissive than the membrane in the panels.	Low potential for implementability at this site; otherwise similar to HDPE Membrane Wall, except: • Depth limited by resistance of the formation to the placement mandrel and HDPE panel, probably limiting the placement depth to much less than the 60 VF depth needed. • Excavation to 60 VF depth needed would require excavation of many thousands of CY of affected soil and, if not allowed to be used as backfill, on-site or off-site disposal. • Overall production rate expected to be roughly 50 to 300 LF per work day	High range overall present value. • High range mobilization and demobilization costs. • Average range site preparation cost. • Average range to high range construction cost. • Low to average range waste management cost. • Average to high range CQA cost. • Low to average range post-RA cost.	Omit from further consideration because of high implementability uncertainty and high construction and waste management costs.
		Biofilm Barrier	Construct barrier wall and related facilities in stages: • Construct nutrient injection wells. • Inject nutrient solution to establish and maintain vigorous and persistent low permeability microflora and microfauna barrier wall. • Monitor effectiveness with piezometers and monitoring wells similar to facilities for other barrier wall technology options.	Poor to excellent effectiveness, depending on: • Compatibility of the biofilm organisms to constituents in groundwater and the formation. • May be poorly effective in zones affected by DNAPL. • Resulting effectiveness of groundwater control. • Existence of storm sewer controls.	Poor to excellent potential for implementation at this site, depending on: • Number of zones to be injected and well spacing needed to produce an effective biobarrier. • Nutrient injection type and rate needed to establish and maintain biobarrier. • Acceptability of release of excess nutrients on the river side of the biobarrier.	Low to high overall present value. • Low range mobilization and demobilization costs. • Low range site preparation cost. • Average range construction cost. • Low to average range waste management cost. • Low range CQA cost. • Average to high range post-RA cost. Average overall present value.	Omit from further consideration because of high implementability uncertainty and lack of applicability to all site constituents.

General Response Action	Remediation Technology	Process Option	Description	Effectiveness	Implementability	Cost	Summary of Evaluation
		Frozen Earth Barrier	Construct barrier wall and related facilities in stages: • Construct network of refrigerant conduits in parts of the formation needing control. • Construct and operate a refrigeration plant to freeze groundwater in the zones desired. • Construct effectiveness monitoring piezometers and wells similar to other barrier wall technology options.	Poor to good effectiveness, depending on: • Compatibility of the freezing process with groundwater, especially in areas affected by brine and elevated TDS. • May be poorly effective in zones affected by DNAPL. • Lack of storm sewer control needs to be added to surface water controls.	Poor potential for implementation at this site, depending on: • Number of refrigerant lines and plants needed to produce an effective barrier. • Ability to avoid subsurface obstructions. • Thermal conductivity of the formation and related refrigerant load. • Ability to establish and maintain an effective barrier at elevations adequate to control infiltration and exfiltration of affected groundwater during and following seasonal and storm-caused high river stage.	High range overall present value. • Average range mobilization and demobilization costs. • Average range site preparation cost. • High range construction cost. • Average range waste management cost. • Average to high range CQA cost. • High range post-RA cost.	Omit from further consideration because of high implementability uncertainty and high construction cost.
		Conventional Steel Sheet Pile Wall	Construct barrier wall and related facilities in stages: • Clear surface and subsurface obstructions. • Drive steel sheet piles from surface into a low permeability layer at the base of the formation using a conventional pile driver. • Connect sheets with structural sheet, but unsealed, joints. • Cut off sheet pile below surface and cap with a compacted clay layer to reduce surface infiltration. • Provide groundwater extraction facilities to maintain an adequate inward gradient and to control affected groundwater flow. • Install pairs of piezometers on exterior and interior sides of the wall to confirm effectiveness of the wall.	Moderate to good effectiveness depending on: • Ability to drive to the depth needed. • Quality of the installation. • Joint configuration. • Joint spacing. • Hydraulic gradient across the joint gap.	Good potential for implementability at this site in suitable locations, similar to other barrier walls, except: • Proven technology of somewhat limited use for control of affected groundwater. • Lengths in excess of 40 LF may require specialty supply and equipment; probably limited to max depth of 60 VF. • Any significant size durable subsurface obstructions can prevent placement. • Placement pad elevation and scope can vary more than for slurry walls. • No significant excavation required or excavation spoil generated. • Compatible with most soil constituents, but might be affected by contact with low pH and high TDS groundwater and soil. • Overall production rate expected to be roughly 25 to 50 LF per work day.	High range overall present value. • Average range mobilization and demobilization costs. • Average to high range site preparation cost. • High range construction cost. • Low range waste management cost. • Low to average range CQA cost. • Low to average range post-RA cost	Omit from further consideration because of high implementability uncertainty and high construction cost.

General Response Action	Remediation Technology	Process Option	Description	Effectiveness	Implementability	Cost	Summary of Evaluation
		Sealed-Joint Steel Sheet Pile Wall	Construct barrier wall and related facilities in stages similar to Conventional Steel Sheet Pile Wall, except: • Connect sheets with structural sheet seal and suitable sealant resistant to affected groundwater and formation.	Good effectiveness depending on uncertainties similar to Conventional Steel Sheet Pile Wall, plus: • the compatibility of the joint sealant with affected groundwater and formation.	Good potential for implementability depending on uncertainties similar to Conventional Steel Sheet Pile Wall, plus: • Better suited to groundwater control. • Long lengths may not be available. • Work platform excavation and backfill may be necessary to achieve target depth.	High range overall present value. • Average range mobilization and demobilization costs. • Average to high range site prep cost. • High range construction cost. • Low to average range waste management cost. • Average range CQA cost. • Low to average range post-RA cost.	Retain for further screening and evaluation in the FFS.
		Sealed-Joint PVC Sheet Pile Wall	Construct barrier wall and related facilities in stages similar to Sealed Steel Sheet Pile Wall, except: • Use PVC sheet pile in lieu of steel sheet pile. • Excavate a work platform to achieve a level compatible with the length limit of PVC sheet pile. • Apply and cure a suitable sealant to the full length of each joints that is resistant to groundwater and constituents affecting groundwater and the formation • Push PVC sheet pile from the work platform through the formation and into low permeability layer at the base of the formation using a mandrel frame.	Good to excellent effectiveness similar to Sealed Steel Sheet Pile Wall, plus: • Enhanced compatibility of the PVC sheet and sealant with affected groundwater and formation.	Poor potential for implementability depending on uncertainties similar to Sealed Steel Sheet Pile Wall, plus: • Not a structural wall. • Needs extensive work platform excavation due to sheet length limits and depths needed. • May need supplemental barrier to cut of infiltration and exfiltration of affected groundwater above the barrier during and flowing high river stage. • Compatible with most soil constituents, but might be affected by contact with organics, especially chlorinated solvents and related constituents.	Average to high range overall present value. • Average range mobilization and demobilization costs. • Average to high range site preparation cost. • Average to high range construction cost. • Low range waste management cost. • Average range CQA cost. • Low to average range post-RA.	Omit from further consideration because of high implementability uncertainty and high construction cost.
	Hydraulic Groundwater Barrier	Groundwater Extraction Using Conventional Vertical Wells	Create a hydraulic barrier to capture affected groundwater prior to migration off site: • Construct groundwater extraction wells, including nested wells if necessary. • Place well pumps to extract groundwater at rates that accomplish capture adequate to control migration of affected groundwater.	Moderate to excellent effectiveness depending on: • Ability to capture groundwater at necessary rates; • Compatibility of well, pumps, and related components with affected groundwater and soil; and • Long term resistance to well efficiency decline due to biofouling, chemical precipitation, or corrosion.	Good potential for implementability at this site in suitable locations: • Proven technology if site is suitable. • Additional wells or well pump capacity makes system flexible for meeting GWE needs. • If used as a perimeter control without a barrier wall, will need to be sized to remove off-site groundwater in addition to controlling migration of affected groundwater. • Some well excavation spoil and well development water generated. • Treatment and discharge of affected groundwater will be necessary.	Average to high range overall present value. • Low to average range mobilization and demobilization costs. • Low to average range site preparation cost. • Low to average range construction cost, excluding treatment. • Low range waste management cost. • Low to average range CQA cost. • Average to high range post-RA, excluding treatment.	Retain as a GWE component combined with an appropriate groundwater barrier wall.

Table 4-3

Ex Situ Groundwater Treatment Technologies and Associated Target Contaminants
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

Target Contaminant	Selected General Ex Situ Groundwater Treatment Technologies							
	Air Stripping	**Aerobic Biological Treatment**	**Anaerobic Biological Treatment**	**Chemical Oxidation**	**Chemical Precipitation**	**Chemical Reduction**	**Ion Exchange**	**Liquid-Phase Carbon Adsorption**
	Volatile organic compounds removed from groundwater via countercurrent flow of air through perforated trays or packing media	Compounds degraded by aerobic bacteria in packed bed reactor	Compounds degraded by anaerobic bacteria in fluidized or packed bed reactor	Compounds degraded using chemical oxidants (e.g., hydrogen peroxide, ozone)	Metals removed in insoluble form (e.g., hydroxide) via pH adjustment and settling	Compounds degraded using chemical reductants (e.g., zero-valent iron, sodium metabisulfite)	Ionic compounds adsorbed on polymeric resin and replaced by innocuous ions (e.g., chloride, sodium)	Compounds adsorbed on granular activated carbon
Pesticides								
DDT, DDD, DDE			X(1,2)	X(1,2)		X(1,2)		X
Volatile Organic Compounds (VOCs)								
Benzene	X	X		X				X
Carbon Tetrachloride	X		X	X(2)		X(1,2)		X
Chlorobenzene (mono/di)	X	X(1)	X(1)	X				X
Chloroethane	X	X(1)	X(1)	X(2)		X(1,2)		X
Chloroform	X	X(1)	X(1)	X(2)		X(1,2)		X
Chlorinated Ethenes (PCE, TCE)	X	X(1)	X	X		X(1,2)		X
Semivolatile Organic Compounds (SVOCs)								
Fluoranthene		X(1)	X(1,2)	X				X
Pyrene		X(1)	X(1,2)	X				X
Metals								
Arsenic		X(1)			X	X(1)	X(1)	X(1)
Chromium (includes hexavalent chromium)					X	X(3)	X(1)	X(1)
Other Inorganics								
Perchlorate			X			X(1,2)	X	

Notes:

X = Technology is expected to be effective for listed contaminant.

(1) = Potentially effective. Technology may require specific site conditions for effectiveness or may not be proven in the field for particular contaminant.

(2) = Partial treatment expected. Technology would be expected to result in incomplete treatment of contaminant.

(3) = Preliminary step before additional treatment.

Blank = Technology is not expected to be effective for listed contaminant.

PCE = Tetrachloroethene

TCE = Trichloroethene

DRAFT
Table 4-4

Screening of Ex Situ Groundwater Treatment Technologies
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

Remediation Technology	Effectiveness	Implementability	Cost	Summary of Evaluation
Air Stripping	Generally effective for volatile compounds, primarily VOCs.	Technically implementable. Potential equipment fouling from inorganic scaling and biological growth. Requires performance of periodic monitoring to ensure achievement of treatment goals.	Low capital. Low to moderate O&M.	Based on groundwater treatability studies, aeration is required for treatment of metals and air stripping is expected to provide little additional treatment for VOCs. This technology is removed from further consideration during the FFS.
Aerobic Biological Treatment	Generally effective for VOCs, and expected to provide limited treatment for SVOCs and possibly metals.	Technically implementable. Process requires fairly consistent characteristics and low concentrations of toxic compounds in influent, and can be prone to upset. Process will generate biosolids, requiring handling and disposal. Requires performance of periodic monitoring to ensure achievement of treatment goals.	High capital. High O&M.	Based on groundwater treatability studies, aerobic biological treatment is expected to provide little additional benefit for treatment for VOCs. This technology is removed from further consideration during the FFS.
Anaerobic Biological Treatment	Effective for perchlorate and chlorate, and expected to provide limited treatment for pesticides, VOCs (primarily chlorinated ethenes), and SVOCs.	Technically implementable. Process requires fairly consistent characteristics and low concentrations of toxic compounds in influent, and can be prone to upset. Process will generate biosolids, requiring handling and disposal. Requires performance of periodic monitoring to ensure achievement of treatment goals.	High capital. High O&M.	Based on groundwater treatability studies, this technology will be retained for further evaluation during the FFS.
Chemical Oxidation	Generally effective for VOCs and SVOCs, and expected to provide limited treatment for DDx.	Technically implementable. Effectiveness depends on selection of proper chemical oxidant, and other compounds present in influent may interfere with treatment and create high oxidant demand. Storage and handling of oxidant may present health & safety issues. Requires performance of periodic monitoring to ensure achievement of treatment goals.	Moderate capital. Moderate to high O&M.	Although potentially effective for treatment of DDx, VOCs, and SVOCs, technology is not a preferred treatment alternative relative to liquid-phase carbon adsorption. This technology is removed from further consideration during the FFS.
Chemical Precipitation	Generally effective for metals, assuming metals present in dissolved form and proper valence state.	Technically implementable. Effectiveness depends on form and valence state of metals in influent. Process will generate sludge, requiring handling and disposal. Additional filtering of treated effluent may be required to achieve discharge standards. Requires performance of periodic monitoring to ensure achievement of treatment goals.	High capital. High O&M.	Based on groundwater treatability studies, this technology will be retained for further evaluation during the FFS.
Chemical Reduction	Effective for hexavalent chromium and arsenic, and expected to provide limited treatment for DDx, VOCs (primarily chlorinated ethenes), and perchlorate. Also, considered as potential pretreatment step to reduce chlorate concentrations to improve efficiency of biological treatment of perchlorate.	Technically implementable. Effectiveness depends on selection of proper chemical reductant, and other compounds present in influent may interfere with treatment. Storage and handling of reductant may present health & safety issues. Requires performance of periodic monitoring to ensure achievement of treatment goals.	Moderate capital. Moderate to high O&M.	Based on groundwater treatability studies, chemical reduction is not considered necessary/effective for pretreatment of chlorate and perchlorate. This technology is removed from further consideration during the FFS.
Ion Exchange	Generally effective for perchlorate, chlorate, and metals, assuming metals present in ionized form (either dissolved (e.g., trivalent chromium) or complexed (e.g., chromate)).	Technically implementable. Perchlorate and chlorate removed using anion exchange resin. Effectiveness for metals depends on form and valence state of metals in influent. Resin regeneration process will generate concentrated contaminant stream, requiring handling and disposal. Requires performance of periodic monitoring to ensure achievement of treatment goals.	High capital. High O&M.	Based on groundwater treatability studies, ion exchange is not expected to be required for treatment of perchlorate, chlorate, or metals. This technology is removed from further consideration during the FFS.
Liquid-Phase Carbon Adsorption	Generally effective for organic compounds, including DDx, VOCs, and SVOCs, and may also provide limited treatment for metals depending on form.	Technically implementable. Proven technology for removal of organic compounds. Potential equipment fouling from solids. Periodic replacement of carbon beds required. Requires performance of periodic monitoring to ensure achievement of treatment goals.	Moderate capital. Moderate to high O&M.	This technology will be retained for further evaluation during the FFS.

Notes:
DDx = DDT, DDE, DDD
VOCs = Volatile organic compounds
SVOCs = Semivolatile organic compounds
O&M = Operation and maintenance
COPCs - Constituents of Potential Concern

DRAFT

Table 4-5

Treated Groundwater Discharge Options

Groundwater Source Control IRM

Arkema Inc. - Portland, Oregon

Discharge Option[1]	General Description	Technical Considerations	Regulatory Considerations
Discharge to Willamette River	Treated groundwater would be discharged directly to the Willamette River via existing storm water Outfall #4 and an in-river diffuser.	Confirm design of existing outfall adequate for anticipated discharge rate of treated groundwater.	Discharge limits under this scenario set by NPDES permit, and would require application for process water discharge under existing NPDES permit.
Reinjection to Shallow Groundwater	Treated groundwater would be injected into a series of shallow injection wells, trenches, or infiltration basin/gallery.	Infiltration/injection testing would be needed to assess ability of formation to accept groundwater. Could perform testing as part of pumping tests and discharge pumped groundwater into existing and/or new wells. Fouling by solids and/or biological growth is a concern, and use of a biocide and/or periodic redevelopment of wells may be required. Option allows for substrate addition to reinjected water to facilitate in situ remediation of COIs.	Discharge option contingent upon receipt of UIC permit from ODEQ. The preliminary discharge criteria for shallow reinjection are anticipated to be MCLs. Final discharge limits will be based on the applicable State water quality permit.
Discharge to POTW	Treated groundwater would be discharged to the municipal POTW sewer system.	Issues to consider include proximity of nearest tie-in location and available capacity of the sewer line and down-pipe pumping stations.	Discharge option contingent upon municipality acceptance of the discharge. POTW pretreatment requirements will dictate the extent to which this water must be treated.
Reinjection to Deep Groundwater	Treated groundwater would be injected into a series of deep injection wells.	Presence and depth of saline aquifer beneath site would need to be confirmed. Injection testing would be needed to assess ability of formation to accept groundwater. Well depth and installation may present technical difficulties. Fouling by solids and/or biological growth is a concern, and use of a biocide and/or periodic redevelopment of wells may be required.	Discharge option contingent upon receipt of UIC permit from ODEQ. The preliminary discharge criteria for deep reinjection are anticipated to be MCLs. Final discharge limits will be based on the applicable State water quality permit.

Notes:

(1) - One or combination of discharge options may be used for treated groundwater.

ODEQ = Oregon Department of Environmental Quality

POTW = Publicly owned treatment works

UIC = Underground injection control

DRAFT

Table 4-6

Barrier Wall Construction Details
Groundwater Source Control IRM
Arkema Inc. – Portland, Oregon

Vibrated Beam Slurry Wall
• Clear surface and subsurface obstructions. • Grade excavation pad. • Excavate shallow slurry reservoir trench. • Advance excavation-slurry injection tool vertically from the surface to the target depth by jetting cement slurry through nozzles in the base of the tool. • Mix native soil and injected slurry mix in panel as the excavation-injection tool is withdrawn. • Overlap excavation-injection panels to establish continuity of the wall. • Panel strength usually adequate to support surface loads without further solidification. • Construct well-drained low-permeability cap over wall. • Provide groundwater extraction facilities to control affected groundwater flow. • Install pairs of piezometers on exterior and interior sides of the wall to monitor wall performance.
Slurry Trench Slurry Wall
• Clear surface and subsurface obstructions. • Grade excavation and slurry backfill mix pads. • Excavate trench to depth supported by clay slurry. • Mix excavation spoil, slurry, and, if necessary, imported fines to make soil-slurry backfill. • Place mixed soil-slurry backfill in slurry trench in stages that fill trench from top to bottom along sloped surface of prior slurry backfill without voids. • Stabilize upper part of backfill to support surface loads, if necessary. • Construct well-drained low-permeability cap over slurry wall. • Provide groundwater extraction facilities to control affected groundwater flow. • Install pairs of piezometers on exterior and interior sides of the wall to monitor wall performance.
Sealed Steel Sheet Pile Barrier Wall
• Clear surface and subsurface obstructions. • Drive steel sheet piles from surface into a low permeability layer at the base of the formation using a conventional pile driver. • Connect sheets with structural sheet seal and suitable sealant that will not be negatively affected by subsurface conditions. • Cut off sheet pile below surface and construct a low-permeability cap to reduce surface infiltration. • Provide groundwater extraction facilities to control affected groundwater flow. • Install pairs of piezometers on exterior and interior sides of the wall to monitor wall performance.

DRAFT

Table 4-7

List of Components of Groundwater Barrier Wall Alternatives

Groundwater Source Control IRM

Arkema Inc. - Portland, Oregon

Barrier Wall Location	Barrier Wall Technology	Barrier Wall Depth
River Side High Bank	Vibrated Beam Slurry Wall	T.D. at Basalt
	Slurry Trench Slurry Wall	
	Sealed Steel Sheet Pile	
Full Enclosure	Vibrated Beam Slurry Wall	T.D. at Basalt
	Slurry Trench Slurry Wall	
	Sealed Steel Sheet Pile	

Notes:
T.D. = Total Depth

Table 4-8

Treated Groundwater Discharge Criteria Summary
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

Constituent[m]	Units	Direct Discharge to Willamette River [a]		Shallow Reinjection [b]		Discharge to POTW [g]		Deep Reinjection [b] (Basalt Aquifer)	
		Value	Note	Value	Note	Value	Note	Value	Note
Pesticides									
4,4'-DDD	µg/L	TBD	a	NA	b	1	h	NA	b
4,4'-DDE	µg/L	TBD	a	NA	b	1	h	NA	b
4,4'-DDT	µg/L	TBD	a	NA	b	1	h	NA	b
alpha-BHC	µg/L	TBD	a	NA	b	1	h	NA	b
alpha-Chlordane	µg/L	TBD	a	2	c,d	30	d,i	2	c,d
Endrin	µg/L	TBD	a	2	c,d	1	h	2	c,d
gamma-BHC [Lindane]	µg/L	TBD	a	0.2	c,e	1	h	0.2	c,e
Heptachlor epoxide	µg/L	TBD	a	NA	b	1	h	NA	b
Volatile Organic Compounds									
1,2-Dichloroethane	µg/L	TBD	a	5	c	500	i	5	c
Acetone	µg/L	TBD	a	NA	b	NA	j	NA	b
Benzene	µg/L	TBD	a	5	c	140	k	5	c
Bromodichloromethane	µg/L	TBD	a	NA	b	10	h	NA	b
Carbon disulfide	µg/L	TBD	a	NA	b	NA	j	NA	b
Carbon tetrachloride	µg/L	TBD	a	5	c	30	k	5	c
Chlorobenzene	µg/L	TBD	a	100	c	200	i	100	c
Chloroethane	µg/L	TBD	a	NA	b	430	k	NA	b

Constituent[m]	Units	Direct Discharge to Willamette River [a]		Shallow Reinjection [b]		Discharge to POTW [g]		Deep Reinjection [b] (Basalt Aquifer)	
		Value	Note	Value	Note	Value	Note	Value	Note
Chloroform	µg/L	TBD	a	NA	b	200	i	NA	b
Chloromethane	µg/L	TBD	a	NA	b	10	h	NA	b
cis-1,2-Dichloroethene	µg/L	TBD	a	NA	b	NA	j	NA	b
Methylene chloride	µg/L	TBD	a	NA	b	2,100	k	NA	b
Tetrachloroethene	µg/L	TBD	a	5	c	300	k	5	c
Toluene	µg/L	TBD	a	1,000	c	1,400	k	1,000	c
Trichloroethene	µg/L	TBD	a	5	c	200	i	5	c
Semivolatile Organic Compounds									
2-Chlorophenol	µg/L	TBD	a	NA	b	NA	j	NA	b
Acenaphthene	µg/L	TBD	a	0.2	c	NA	j	0.2	c
Benzo[a]anthracene	µg/L	TBD	a	0.2	c	NA	j	0.2	c
Benzo[a]pyrene	µg/L	TBD	a	0.2	c	10,000	k	0.2	c
Benzo[b]fluoranthene	µg/L	TBD	a	0.2	c	NA	j	0.2	c
Benzo[k]fluoranthene	µg/L	TBD	a	0.2	c	NA	j	0.2	c
Chrysene	µg/L	TBD	a	0.2	c	4,700	k	0.2	c
Fluoranthene	µg/L	TBD	a	0.2	c	NA	j	0.2	c
Fluorene	µg/L	TBD	a	0.2	c	NA	j	0.2	c
Hexachloroethane	µg/L	TBD	a	NA	b	100	k	NA	b

Constituent[m]	Units	Direct Discharge to Willamette River [a]		Shallow Reinjection [b]		Discharge to POTW [g]		Deep Reinjection [b] (Basalt Aquifer)	
		Value	Note	Value	Note	Value	Note	Value	Note
Indeno[1,2,3-cd] pyrene	µg/L	TBD	a	0.2	c	NA	j	0.2	c
Naphthalene	µg/L	TBD	a	0.2	c	2,700	k	0.2	c
Phenanthrene	µg/L	TBD	a	0.2	c	NA	j	0.2	c
Pyrene	µg/L	TBD	a	0.2	c	NA	j	0.2	c
Metals (Criteria Based on Total Metals, Unless Otherwise Specified)									
Arsenic	µg/L	TBD	a	10	c	200	i	10	c
Cadmium	µg/L	TBD	a	5	c,f	700	i	5	c,f
Chromium	µg/L	TBD	a	100	c	5,000	i	100	c
Copper	µg/L	TBD	a	1,300	c,f	3,700	i	1,300	c,f
Lead	µg/L	TBD	a	15	c,f	700	i	15	c,f
Nickel	µg/L	TBD	a	NA	b	2,800	i	NA	b
Selenium	µg/L	TBD	a	50	c	600	i	50	c
Silver	µg/L	TBD	a	NA	b	400	i	NA	b
Zinc	µg/L	TBD	a	NA	b	3,700	i	NA	b
Conventional Parameters and Miscellaneous Compounds									
Total Chloride	µg/L	TBD	a	NA	b	n	j	NA	b
Total Dissolved Solids	varies	TBD	a	NA	b	1,721	l,m	NA	b
Perchlorate	µg/L	TBD	a	NA	b	NA	j	NA	b

Table 4-8

Treated Groundwater Discharge Criteria Summary
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

Constituent[m]	Units	Direct Discharge to Willamette River [a]		Shallow Reinjection [b]		Discharge to POTW [g]		Deep Reinjection [b] (Basalt Aquifer)	
		Value	Note	Value	Note	Value	Note	Value	Note
pH	SU	TBD	a	NA	b	5.0 - 11.5	i	NA	b

Screening Notes
a - Values to be determined based on NPDES permitting process.
b - Values provided are based on USEPA Primary MCL when available.
c - Drinking water; USEPA Primary MCL
d - Value for chlordane (cis- and trans-) used
e - Value for HCH (gamma) lindane used
f - Value specified for dissolved fraction assuming a hardness of 25 mg/L as $CaCO_3$
g - Local limits, screening values, and prohibited discharges provided for preliminary use by Miguel Santana, Env. Manager, City of Portland Bureau of Environmental Services. Actual discharge limits would be specified in the discharge permit.
h - City of Portland Prohibited Discharge. Values provided are minimum required detection limits.
i - City of Portland POTW Local Limits. ENB-4.03 Industrial Wastewater Discharges Administrative Rules.
j - No local limit, screening value, or prohibited discharge detection requirement available. Per 1-17-07 email communication from Miguel Santana, City of Portland Bureau of Environmental Services, discharge values for this constituent would be established through an evaluation of "treatability, worker health, LEL, process inhibitions, TCLP, and OAR 340-41."
k - City of Portland POTW Screening Value provided by Miguel Santana, City of Portland. Based on conversations with Mr. Santana, permits are rarely, if ever, issued allowing discharges above screening values.
l - City of Portland Discharge Permit Limit. Specified in other IU permits per Miguel Santana.
m - Total Dissolved Solids in lbs/day.
n - No permit limit currently identified. However, there is a total dissolved solids limit of 1,721 lbs/day per site.

IU = Industrial user
MCL = Maximum contaminant level
mg/L = milligrams per liter
NA = Not available
NPDES = National Pollutant Discharge Elimination System
POTW - Publicly owned treatment works
TBD = To be determined
ug/L = micrograms per liter
USEPA = United States Environmental Protection Agency

Barrier Wall Configuration	Barrier Wall Technology	Barrier Wall Depth	Effectiveness	Score	Long-Term Reliability	Score	Implementability	Score	Implementation Risk	Score	Reasonableness of Cost	Score	Summary of Evaluation	Average Score
River Side High Bank Route	Vibrated Beam Slurry Wall	T.D. at Basalt	• Reduces risk posed by affected media left in place. • Some potentially affected residuals left on the river side of the barrier wall. • Small amount of RA construction affected residuals. • Hydraulic conductivity of cured clay-cement plastic concrete sample was greater than for soil-slurry backfill, but adequately low to accomplish control of affected groundwater. • Effective immediately after completion of RA construction.	3	• Permanent control. • Few long-term uncertainties. • Compatible with site soils. • Hydraulic conductivity of clay-cement shown to be stable for control of affected ground water based on pore volume of each affected groundwater sample used as permeants. • Little apparent additional seismic risk compared to current condition. • Compatible with reasonable range of future in water actions (i.e. river bank regrading, capping, sediment dredging, sediment capping).	3.5	• Practical at this location. • No important technical difficulties. • No known legal difficulties. • Proven technology with few unknowns; the single major contractor in the US is a well-established diversified company with well-maintained commercially manufactured equipment. • Can be monitored with piezometers. • Consistent with federal, state and local requirements. • No special authorization required. • Services, materials, equipment, and specialists are commercially available. • Clearance of subsurface objects > 4-inch maximum dimension.	3.5	• No significant impacts on community. • Little potential for adverse impact on workers. • Worker PPE and work procedures address worker risks. • Low potential for adverse impact on environment, such as release of residuals to the river. • Simple and reliable controls address potential adverse risk on environment. • Vibration expected to be insignificant off site; may need more study. • Effective immediately on completion of RA construction and start-up of GWE and treatment components of RA.	3	• Low-range capital cost. • No O&M cost. • No special periodic review needed. • NPV = $9,500,000	3	• Good effectiveness. • Very good reliability. • Very good implementability. • Moderate implementation risk. • Lowest NPV.	3.2

Barrier Wall Configuration	Barrier Wall Technology	Barrier Wall Depth	Effectiveness	Score	Long-Term Reliability	Score	Implementability	Score	Implementation Risk	Score	Reasonableness of Cost	Score	Summary of Evaluation	Average Score
River Side High Bank Route	Slurry Trench Slurry Wall	T.D. to Basalt	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative, except: • Hydraulic conductivity of soil-slurry backfill was slightly less than for clay-cement plastic concrete sample and adequately low to accomplish control of affected groundwater. • Slightly greater volume of potentially affected RA construction residuals.	2.5	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative. • Hydraulic conductivity of soil-slurry backfill was shown to be stable for control of affected ground water based on pore volume of each affected groundwater sample used as permeants, including for sample prepared using DNAPL-affected soil.	3.5	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative except: • More uncertainty related to potential for chloride-affected formation and ground water to affected stability of slurry during slurry trench excavation. • Clearance of subsurface objects > 24-inch maximum dimension.	3.5	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative except: • More potential for exposure of workers and the environment to COCs excavated from the trench and during slurry backfill mixing. • No significant vibration.	2.5	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative except: • Higher low-range capital cost. • NPV = $9,800,000	2	• Reasonable effectiveness. • Very good reliability. • Very good implementability. • Some implementation risk. • Low-range NPV.	2.8
River Side High Bank Route	Sealed Steel Sheet Pile	T.D. to Basalt	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative, except: • Hydraulic conductivity of sheet pile is zero at sheets and is anticipated to be insignificant at joints sealed with compatible sealant; adequately low to accomplish control of affected groundwater. • Lower volume of potentially affected RA construction residuals.	3.5	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative.	3.5	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative except: • Smaller debris can obstruct installation. • Subject to corrosion, but not expected to affect useful life of barrier wall.	3	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative except: • Less potential for exposure of workers and the environments to COCs excavated from the trench and during slurry backfill mixing. • Vibration may be significant off site; needs more study if sheet pile barrier wall is chosen.	3.5	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative except: • High median-range capital cost. • NPV = $15,200,000	1.5	• Very good effectiveness. • Very good reliability. • Good implementability. • Very low implementation risk. • High median-range NPV.	3

Barrier Wall Configuration	Barrier Wall Technology	Barrier Wall Depth	Effectiveness	Score	Long-Term Reliability	Score	Implementability	Score	Implementation Risk	Score	Reasonableness of Cost	Score	Summary of Evaluation	Average Score
Full Enclosure Route	Vibrated Beam Slurry Wall	T.D. to Basalt	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative, except: • Larger amount of RA construction affected residuals.	2.5	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative.	3.5	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative, except: • Greater length presents greater uncertainty.	3	Essentially the same comments as for the River Side High Bank Vibrated Beam alternative, except: • Slightly more impacts on community. • Slightly more potential for adverse impact on workers. • Slightly more potential for adverse impact on environment.	2.5	• High-range capital cost. • No O&M cost. • No special periodic review needed. • NPV = $17,200,000	2.5	• Moderate effectiveness. • Very good reliability. • Good implementability. • Some implementation risk. • High-range NPV.	2.8
Full Enclosure Route	Slurry Trench Slurry Wall	T.D. to Basalt	Essentially the same comments as for the Full Enclosure Vibrated Beam alternative, except: • Slightly greater volume of potentially affected RA construction residuals.	2	Essentially the same comments as for the Full Enclosure Vibrated Beam alternative.	3.5	Essentially the same comments as for the Full Enclosure Vibrated Beam alternative except: • More uncertainty related to potential for chloride-affected formation and ground water to affect stability of slurry during slurry trench excavation. • Clearance of subsurface objects > 24-inch maximum dimension.	2.5	Essentially the same comments as for Full Enclosure Vibrated Beam alternative except: • More potential for exposure of workers and the environments to COCs excavated from the trench and during slurry backfill mixing.	2	Essentially the same comments as for Full Enclosure Vibrated Beam alternative except: • Higher high-range capital cost. • NPV = $18,100,000	2	• Poor effectiveness. • Very good reliability. • Moderate implementability. • High implementation risk. • High-range NPV.	2.4

Barrier Wall Configuration	Barrier Wall Technology	Barrier Wall Depth	Effectiveness	Score	Long-Term Reliability	Score	Implementability	Score	Implementation Risk	Score	Reasonableness of Cost	Score	Summary of Evaluation	Average Score
Full Enclosure Route	Sealed Steel Sheet Pile	T.D. to Basalt	Essentially the same comments as for the Full Enclosure Vibrated Beam alternative, except: • Lower volume of potentially affected RA construction residuals.	3	Essentially the same comments as for the Full Enclosure Vibrated Beam alternative.	3.5	Essentially the same comments as for the Full Enclosure Vibrated Beam alternative except: • Smaller debris can obstruct installation. • Subject to corrosion, but not expected to affect useful life of barrier wall.	2	Essentially the same comments as for the Full Enclosure Vibrated Beam alternative except: • Less potential for exposure of workers and the environments to COCs excavated from the trench and during slurry backfill mixing.	3	Essentially the same comments as for the Full Enclosure Vibrated Beam Deep Zone Key alternative except: • Much higher high-range capital cost. • NPV = $29,800,000	1.5	• Good effectiveness. • Very good reliability. • Poor implementability. • Low implementation risk. • High-range NPV.	2.6

Notes:

1. Each alternative was scored against each criterion on a scale of 1 to 4 (1 = not anticipated to meet evaluation factor, 4 = anticipated to meet evaluation factor)
2. Budgetary costs (+50% to -30%) for each alternative were developed for the Focused Feasibility Study, and are intended for comparison purposes only.

COCs = Constituents of Concern
PPE = Personal Protective Equipment
RA = Remedial Action
T.D. = Total Depth
GWE = Groundwater Extractions
NPV = Net Present Value
O&M = Operation and Maintenance

Table 5-2

Evaluation Summary for Ex Situ Groundwater Treatment Alternatives

Groundwater Source Control IRM

Arkema Inc. - Portland, Oregon

Treatment Alternative	Effectiveness	Score	Long-Term Reliability	Score	Implementability	Score	Implementation Risk	Score	Reasonableness of Cost	Score	Summary of Evaluation	Average Score
Hydroxide Precipitation with Anaerobic Biological Treatment	• In combination with groundwater barrier wall and extraction system, will effectively reduce discharge of COPCs in groundwater to Willamette River and associated exposure risks. • As part of an interim remedial measure, is not intended as source area treatment but will slowly reduce concentrations of COPCs in groundwater and associated exposure risks during operation. • Treatment residuals generated as byproducts of groundwater treatment (e.g., metal hydroxide sludge, biosolids) will be properly managed and disposed per applicable waste regulations.	3.5	• Overall, alternative is expected to be effective for treatment of extracted groundwater and reducing COPC concentrations to meet discharge criteria shown on Table 4-8. • Based on groundwater treatability studies, chemical precipitation using sodium hydroxide and aeration is expected to be effective for removal of iron (other metals not present at elevated concentrations). • Based on expected solids loading in effluent from precipitation reactor, use of a clarifier with an associated sludge handling system is required. • Treatment system will require long-term management (i.e. operation, maintenance, and monitoring) to ensure proper and dependable treatment of groundwater.	3.5	• The treatment technologies that comprise this treatment alternative are readily available from a variety of manufacturers. • While the bioreactors may be less readily available, custom designed and constructed units are available from manufacturers. • Effectiveness of the groundwater treatment system can be monitored by analytical testing of influent and effluent samples. • Groundwater treatment system will comply with federal, state, and local requirements. • Infrastructure and services required to support groundwater treatment system are available at site.	4	• Potential impacts on the community, site workers, and the environment, associated with the groundwater extraction and treatment system are expected to be low. • Design and construction of the groundwater extraction and treatment system is expected to require approximately 1.5 years. • For purposes of FFS, assumed operating life of ex situ treatment alternatives is 30 years.	3.5	• Reasonable capital and O&M costs. • Costs driven by potential requirements for recovery well and piping cleaning, chemical usage, and waste disposal. • Depending on media replacement frequency required for EHC®/sand reactor, may be cost-effective alternative to FBR or PBR. • NPV = $13,110,000	3	• Based on evaluation, this treatment process is a viable treatment alternative.	3.5

Notes:
Each alternative was scored against each criterion on a scale of 1 to 4 (1 = not anticipated to meet evaluation factor, 4 = anticipated to meet evaluation factor)
Budgetary costs (+50% to -30%) for each alternative were developed for the Focused Feasibility Study, and are intended for comparison purposes only.

Table 5-3

Evaluation Summary for Treated Groundwater Discharge Alternatives

Groundwater Source Control IRM

Arkema Inc. - Portland, Oregon

Discharge Alternative	Effectiveness	Score	Long-Term Reliability	Score	Implementability	Score	Implementation Risk	Score	Reasonableness of Cost	Score	Summary of Evaluation	Average Score
Discharge to Willamette River	• Straightforward design and construction. • Low risk of discharge system failure.	2.5	• No major O&M required. • Regular monitoring would ensure discharge criteria are being met.	4	• Minimal infrastructure required. • Confirmation of adequate hydraulic capacity in outfall required. • Revised facility NPDES permit required for industrial discharge.	2	• Short construction schedule. • Low risk to community, employees, and environment during discharge implementation. • Estimated 6 to 12 month permit process.	3	• Low capital and O&M costs. • Not sensitive to discharge rate (assuming adequate capacity available). • 30-year NPV = $800,000	4	• Long-term reliability of this option is the simplest and most straightforward. • Revised facility NPDES permit required for industrial discharge.	3
Reinjection to Shallow Groundwater	• Injection modeling shows adequate reinjection capacity in shallow aquifer (Lot 2). • Potentially increased benefits via addition of remedial amendment to shallow well injections.	3.5	• Regular O&M and monitoring required. • Potential for biofouling/clogging in wells. • Long-term aquifer response to reinjection unknown. • Storm water infiltration basin is a low maintenance and low energy alternative relative to wells.	2.5	• Could potentially utilize storm water infiltration basin. • Dependent on subsurface acceptance of treated water, but modeling has shown aquifer can accept anticipated flow rates.	3	• UIC permit approval required. • Injection well installation presents low risk to community, employees, and environment during discharge implementation.	3	• Reasonable capital and O&M costs. • Well design will limit range of discharge flow rate. • 30-year NPV = $1,340,000	3	• Shallow wells would require regular O&M but the implementation and long term reliability could be simplified by utilizing storm water infiltration basin. • Storm water infiltration basin is a low maintenance and low energy alternative relative to wells.	3
Discharge to POTW	• Straightforward design and construction. • Low risk of discharge system failure. • POTW treatment provides increased protectiveness to potential receptors.	4	• No major O&M required. • Regular monitoring would ensure discharge criteria are being met. • Subject to annual permit renewal (potential criteria/cost revisions) and POTW capacity.	3.5	• Minimal infrastructure, accessible tie-in location. • Dependent on POTW acceptance of treated water (hydraulic and constituent loading.) • Likely difficulty meeting total dissolved solids (TDS) limit.	2	• Short construction schedule. • Low risk to community, employees, and environment during discharge implementation. • Estimated 6 month to 3 year permit process.	3	• Net present value extremely high due to unit-based discharge fees at POTW. • Cost may be prohibitive. • 30-year NPV = $9,540,000	1	• Design and construction is low risk and easy to implement. • Unit-based discharge costs to the POTW cause the annual cost to be an order of magnitude higher than the alternatives. • Likely difficulty meeting total dissolved solids (TDS) limit. • Estimated 6 month to 3 year permit process.	2.5

Table 5-3

Evaluation Summary for Treated Groundwater Discharge Alternatives

Groundwater Source Control IRM

Arkema Inc. - Portland, Oregon

Discharge Alternative	Effectiveness	Score	Long-Term Reliability	Score	Implementability	Score	Implementation Risk	Score	Reasonableness of Cost	Score	Summary of Evaluation	Average Score
Reinjection to Deep Groundwater	• No beneficial use of saline aquifer. • Dependent on determination of lack of hydraulic connection between deep aquifer and basalt.	3	• Regular O&M and monitoring required. • Potential for biofouling/clogging in wells. • Long-term aquifer response to reinjection unknown. • Operational challenges of deep injections.	2	• Currently prohibited by Oregon UIC rules – OAR 340-044 (could possibly be waived). • Dependent on subsurface acceptance of treated water. • Aquifer response unknown.	1	• Regulatory approval for deep UIC permit potentially time consuming (estimated 5 year approval process). • Deep wells may be difficult to install.	2	• Reasonable capital and O&M costs. • Well design will limit range of discharge flow rate. • 30-year NPV = $1,800,000	2.5	• Deep well injections create a challenge from both a technical and permitting perspective. • The well design would require additional tests and analysis. • Regulations currently prohibit this option, and the time required for permit approval could be prohibitive.	2

Notes:
Each alternative is scored against each criterion on a scale of 1 to 4 (1 = not anticipated to meet evaluation factor, 4 = anticipated to meet evaluation factor)
Budgetary costs (+50% to -30%) for each alternative were developed for the Focused Feasibility Study, and are intended for comparison purposes only.
NPV = Net Present Value

Appendix A
Groundwater Modeling Report

APPENDIX A

Legacy Site Services, LLC

Groundwater Modeling Report
Arkema Chemicals Facility, Portland, Oregon

March 2008

ERM-West, Inc.
915 118th Avenue Southeast, Suite 130
Bellevue, Washington 98005
T: 425-462-8591
F: 425-455-3573

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 MODEL DESIGN AND CALIBRATION 2

2.1 MODEL CODES 2

2.1.1 Groundwater Flow 2

2.1.2 Groundwater Flow Paths 2

2.2 MODEL DOMAIN 3

2.3 MODEL GRID LAYERS 3

3.0 GROUNDWATER BARRIER WALL ALTERNATIVES SIMULATIONS 4

3.1 SIMULATION OF GROUNDWATER BARRIER WALLS AND UPGRADIENT WITHDRAWAL WELLS 4

3.1.1 Groundwater Barrier Walls 4

3.1.2 Withdrawal Wells 5

3.2 EVALUATION OF GROUNDWATER CONTAINMENT BY BARRIER WALL ALTERNATIVES 5

3.2.1 Impact of Barrier Wall Thickness on Groundwater Containment by Barrier Walls 6

3.2.2 River Side Groundwater Barrier Wall 7

3.2.2.1 Groundwater Barrier Wall Installed to Top of Basalt 7

3.2.2.2 Groundwater Barrier Wall Installed into Deep Zone 7

3.2.3 Full Enclosure Groundwater Barrier Wall 7

3.2.3.1 Groundwater Barrier Wall Installed to Top of Basalt 7

3.2.3.2 Groundwater Barrier Wall Installed into Deep Zone 8

3.2.4 Impact of Reinjection of Treated Water on Groundwater Containment by Barrier Walls 8

3.2.4.1 Reinjection in Lot 2 9

3.2.4.1 Reinjection in Lots 2, 3, and 4 9

4.0 UNCERTAINTY IN MODEL SIMULATIONS 10

5.0 CONCLUSIONS 11

6.0 REFERENCES 12

LIST OF FIGURES (Figures immediately follow text)

FIGURE A 2-1	*Finite-Difference Model Grid*
FIGURE A 2-2	*Hydrostratigraphic Units*
FIGURE A 2-3	*Model Grid Layers*
FIGURE A 3-1	*Flow Boundary Conditions; River Side High Bank Groundwater Barrier Wall Simulations; Shallow Zone (Layer 1)*
FIGURE A 3-2	*Flow Boundary Conditions; Full Enclosure Groundwater Barrier Wall Simulations; Shallow Zone (Layer 1)*
FIGURE A 3-3	*Comparison of Groundwater Mounding in Shallow Zone (Layer 1); 4-Inch and 3-Foot Wall Thickness; River Side High Bank Groundwater Barrier Wall Installed to Top of Basalt*
FIGURE A 3-4	*Comparison of Groundwater Mounding in Shallow Zone (Layer 1); 4-Inch and 3-Foot Wall Thickness; River Side High Bank Groundwater Barrier Wall Installed into Deep Zone*
FIGURE A 3-5	*Comparison of Groundwater Mounding in Shallow Zone (Layer 1); 4-Inch and 3-Foot Wall Thickness; Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt*
FIGURE A 3-6	*Comparison of Groundwater Mounding in Shallow Zone (Layer 1); 4-Inch and 3-Foot Wall Thickness; Full Enclosure Groundwater Barrier Wall Installed into Deep Zone*
FIGURE A 3-7	*River Side High Bank Groundwater Barrier Wall Installed to Top of Basalt (Layer 5); Withdrawal Wells in Shallow Zone (Layer 1)*
FIGURE A 3-8	*River Side High Bank Groundwater Barrier Wall Installed to Top of Basalt (Layer 5); Withdrawal Wells in Intermediate Zone (Layer 3)*
FIGURE A 3-9	*River Side High Bank Groundwater Barrier Wall Installed to Top of Basalt (Layer 5); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3)*
FIGURE A 3-10	*River Side High Bank Groundwater Barrier Wall Installed into Deep Zone (Layer 4); Withdrawal Wells in Shallow Zone (Layer 1)*
FIGURE A 3-11	*River Side High Bank Groundwater Barrier Wall Installed into Deep Zone (Layer 4); Withdrawal Wells in Intermediate Zone (Layer 3)*
FIGURE A 3-12	*River Side High Bank Groundwater Barrier Wall Installed into Deep Zone (Layer 4); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3)*

FIGURE A 3-13 *Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt (Layer 5); Withdrawal Wells in Shallow Zone (Layer 1)*

FIGURE A 3-14 *Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt (Layer 5); Withdrawal Wells in Intermediate Zone (Layer 3)*

FIGURE A 3-15 *Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt (Layer 5); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3)*

FIGURE A 3-16 *Full Enclosure Groundwater Barrier Wall Installed into Deep Zone (Layer 4); Withdrawal Wells in Shallow Zone (Layer 1)*

FIGURE A 3-17 *Full Enclosure Groundwater Barrier Wall Installed into Deep Zone (Layer 4); Withdrawal Wells in Intermediate Zone (Layer 3)*

FIGURE A 3-18 *Full Enclosure Groundwater Barrier Wall Installed into Deep Zone (Layer 4); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3)*

FIGURE A 3-19 *River Side High Bank Groundwater Barrier Wall Installed to Top of Basalt (Layer 5); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3); Reinjection in Lot 2*

FIGURE A 3-20 *River Side High Bank Groundwater Barrier Wall Installed into Deep Zone (Layer 4); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3); Reinjection in Lot 2*

FIGURE A 3-21 *Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt (Layer 5); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3); Reinjection in Lot 2*

FIGURE A 3-22 *Full Enclosure Groundwater Barrier Wall Installed into Deep Zone (Layer 4); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3); Reinjection in Lot 2*

FIGURE A 3-23 *River Side High Bank Groundwater Barrier Wall Installed to Top of Basalt (Layer 5); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3); Reinjection in Lots 2, 3 and 4*

FIGURE A 3-24 *River Side High Bank Groundwater Barrier Wall Installed into Deep Zone (Layer 4); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3); Reinjection in Lots 2, 3 and 4*

FIGURE A 3-25 *Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt (Layer 5); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3); Reinjection in Lots 2, 3 and 4*

FIGURE A 3-26 *Full Enclosure Groundwater Barrier Wall Installed into Deep Zone (Layer 4); Withdrawal Wells in Shallow and Intermediate Zone (Layers 1 and 3); Reinjection in Lots 2, 3 and 4*

LIST OF TABLES (Tables immediately follow Figures)

TABLE A 3-1 *Results of Groundwater Barrier Wall AlternativesSimulations*

TABLE A 3-2 *Results of Treated Water Reinjection Alternatives Simulations*

LIST OF APPENDICES

APPENDIX A *Three-dimensional visualizations of the results of the river side GWBW simulations and interactive viewer for the visualizations on CD*

1.0 INTRODUCTION

A three-dimensional, numerical groundwater flow model for the Arkema Inc. (Arkema) site ("Arkema site") in Portland, Oregon, was developed to support the Groundwater Source Control Interim Remedial Measure Focused Feasibility Study for upland groundwater. The extent of the model (the "model domain") includes portions of upgradient and adjacent properties of the Arkema site.

THIS PAGE INTENTIONALLY LEFT BLANK

2.0 MODEL DESIGN AND CALIBRATION

The Arkema site groundwater model was designed and calibrated in accordance with the American Society for Testing and Materials (ASTM) guidelines for groundwater modeling (ASTM 1996), U.S. Environmental Protection Agency (USEPA) Region 10 guidelines for hydrogeologic modeling (USEPA 1994), and generally accepted industry practice (Anderson and Woessner 1992). The ASTM guidelines were developed as part of a cooperative agreement between the USEPA, the U.S. Geological Survey (USGS), and the U.S. Navy. The design of the groundwater model and the methods that were used to calibrate the model to observed groundwater conditions at the facility are described in the *Draft Groundwater Modeling Report, Arkema Inc., Facility, Portland, Oregon* (Environmental Resources Management [ERM] 2007).

2.1 MODEL CODES

2.1.1 Groundwater Flow

The model code that was used to develop the Arkema site groundwater flow model is MODFLOW (McDonald and Harbaugh 1988), a three-dimensional, finite-difference, groundwater flow model developed by the USGS. MODFLOW was selected for development of the Arkema site flow model because it is well documented (McDonald and Harbaugh 1988; Harbaugh 2005), and has been verified for a wide range of field problems (USEPA, 1993). MODFLOW has also been widely accepted by state and federal regulatory agencies, and numerous models based on this code have been published in technical journals (Anderson and Woessner 1992).

2.1.2 Groundwater Flow Paths

Groundwater flow paths were simulated with the model code PATH3D. PATH3D is a three-dimensional, numerical, particle tracking code for calculating groundwater flow paths and travel times from the head solution output by MODFLOW. This model code was developed at the University of Wisconsin - Madison, and the Wisconsin Geological and Natural History Survey (Zheng et al. 1992; Zheng 2001). PATH3D is well documented and has been verified for a range of field problems.

2.2 *MODEL DOMAIN*

The model domain is centered on the Arkema site, located at 6400 N.W. Front Avenue in Portland, Oregon, along the west bank of the Willamette River, at approximately river mile 7.5 (Figure 2-1). The model domain covers an area of approximately 260 acres and is bounded on the west by the West Hills (across Highway 30) and on the east by the Willamette River. The model extends between approximately 500 and 700 feet (ft) into the Willamette River. The model area slopes gently eastwards toward the Willamette River with topographic elevations between 66 and 28 ft relative to the North American Vertical Datum of 1988 (NAVD88).

2.3 *MODEL GRID LAYERS*

The groundwater flow systems at the Arkema site are simulated in the model by seven layers:

- Layer 1 – Shallow Zone;
- Layer 2 – Shallow-Intermediate Silt Zone;
- Layer 3 – Intermediate Zone;
- Layer 4 – Deep Zone;
- Layer 5 – Gravel Zone
- Layer 6 – Fractured Basalt; and
- Layer 7 – Slightly Weathered Basalt.

The model grid layers represent the seven major hydrostratigraphic units identified during the development of the conceptual hydrogeologic model for the Arkema site (Figure 2-2). A southwest to northeast cross-section along column 120 of the model grid is shown in Figure 2-3.

3.0 GROUNDWATER BARRIER WALL ALTERNATIVES SIMULATIONS

The groundwater flow model developed for the Arkema site was used to evaluate the following alternative conceptual groundwater barrier wall (GWBW) designs;

1. River Side High Bank GWBW installed to the top of the basalt;
2. River Side High Bank GWBW wall installed into the upper part of the Deep Zone;
3. Full enclosure GWBW installed to the top of the basalt; and
4. Full enclosure GWBW wall installed into the upper part of the Deep Zone.

In all four alternative conceptual GWBW designs, upgradient withdrawal wells would be installed to prevent groundwater from flowing underneath the GWBWs or around the ends of the river side GWBWs.

The Arkema site model was used to evaluate the effectiveness of groundwater containment by the alternative conceptual GWBW designs, and to determine the number and flow rate of the upgradient withdrawal wells needed for each alternative design. In addition, the model was used to evaluate: 1) the relative effectiveness of a 4-inch thick GWBW installed using a vibrating beam method and a 3-ft thick GWBW installed using conventional excavation methods; and 2) the impact of reinjection of treated water on groundwater containment by the alternative conceptual GWBW designs.

3.1 SIMULATION OF GROUNDWATER BARRIER WALLS AND UPGRADIENT WITHDRAWAL WELLS

3.1.1 Groundwater Barrier Walls

The GWBWs were represented in the groundwater flow model as MODFLOW horizontal-flow-barrier boundaries (Hsieh and Freckelton 1993). For the simulations of a GWBW installed to the top of the basalt, horizontal-flow-barrier boundaries were added to the groundwater flow model in layers 1 to 5 (Shallow Zone to top of basalt). The location of the horizontal-flow-barrier boundaries representing the river side and full enclosure GWBWs in the model are shown in Figures 3-1 and 3-2.

To simulate a GWBW installed into the upper part of the Deep Zone, the model layer representing the Deep Zone in the model (layer 4) was subdivided into two layers. The bottom elevation of the uppermost sublayer was set to 10 ft below the bottom of layer 3 (Intermediate Zone)

to represent a GWBW installed 10 ft into the Deep Zone. In areas where the Deep Zone was less than 10 ft thick, the bottom elevation of the uppermost sublayer was set to 2 ft above the top of layer 5 (top of basalt) to represent a GWBW installed into the Deep Zone 2 ft above the top of the basalt. Horizontal-flow-barrier boundaries were then added to the flow model in layers 1 to 3 (Shallow Zone to Intermediate Zone) and to the uppermost sublayer of Layer 4 representing the upper part of the Deep Zone.

The hydraulic characteristic (MODFLOW input parameter HYDCHR) of the horizontal-flow-barrier boundaries representing the GWBWs was calculated using a uniform hydraulic conductivity of 2.83×10^{-3} ft/day (1.0×10^{-6} centimeter/second) according to the methods outlined in (Hsieh and Freckelton 1993). A uniform wall thickness of 4 inches was used for the simulations of a GWBW installed using a vibrating beam method and a uniform wall thickness of 3 ft was used for the simulations of a GWBW installed using conventional excavation methods (Section 3.2).

3.1.2 Withdrawal Wells

The upgradient withdrawal wells were simulated in the groundwater flow model as MODFLOW well nodes (point sinks). Three groundwater withdrawal alternatives were evaluated for each conceptual GWBW design: groundwater withdrawal from Shallow Zone; groundwater withdrawal from the Intermediate Zone; and groundwater withdrawal from the Shallow and Intermediate Zone.

For the simulations of the three groundwater withdrawal alternatives, well nodes were added to the model in layer 1 (Shallow Zone), layer 3 (Intermediate Zone), and layers 1 and 3 (Shallow Zone and Intermediate Zone). The number, location, and flow rates of the well nodes were then varied in successive simulations until no groundwater flow under the GWBWs or around the ends of the river side GWBWs occurred.

3.2 EVALUATION OF GROUNDWATER CONTAINMENT BY BARRIER WALL ALTERNATIVES

The effectiveness of groundwater containment by the alternative conceptual GWBW designs was evaluated by calculating groundwater flow paths for the head solutions from the barrier wall simulations using the particle tracking model code PATH3D (Section 2.1.2). Groundwater containment by the GWBWs and upgradient withdrawal wells was evaluated by placing particles in every grid node along a line approximately 400 ft upgradient of the horizontal-flow-barrier boundary

representing the GWBW. For the simulations of the GWBWs installed to the top of the basalt, the particles were placed in layer 5 (Gravel Zone). For the simulations of the GWBWs installed into the Deep Zone, the particles were placed in layer 4 (Deep Zone). A rigorous groundwater capture criteria (PATH3D particle capture option IOPSS=3) was used so that only those particles within the dividing streamlines of the well nodes representing the upgradient withdrawal wells were captured in the particle tracking simulations. Groundwater flow paths were calculated for steady-state flow conditions to fully delineate the ultimate flow paths of the particles within the model grid.

3.2.1 Impact of Barrier Wall Thickness on Groundwater Containment by Barrier Walls

The impact of wall thickness on groundwater containment by the GWBWs was evaluated by adding horizontal-flow-barrier boundaries to the groundwater flow model to represent the four alternative conceptual GWBW designs and solving the model for steady-state flow conditions. A uniform wall thickness of 4 inches was used for the simulations of a GWBW installed using a vibrating beam method and a uniform wall thickness of 3 ft was used for the simulations of a GWBW installed using conventional excavation methods (Section 3.1.1). The groundwater mounding produced by the alternative conceptual GWBW designs was then determined by subtracting the head solution for layer 1 (Shallow Zone) from the steady-state calibrated flow model (without GWBWs) from the head solutions for layer 1 (Shallow Zone) from the GWBW simulations.

Figures 3-3 and 3-4 show the results of the river side GWBW simulations with a 4-inch and 3-ft wall thickness. The extent and magnitude of the groundwater mounding produced by the 4-inch and 3-ft thick GWBW in the model simulations are approximately the same indicating that the 4-inch thick wall would be as effective as a 3-ft thick wall in containing groundwater.

Figures 3-5 and 3-6 show the results of the full enclosure GWBW simulations with a 4-inch and 3-ft wall thickness. As in the river side GWBW simulations, the extent and magnitude of the groundwater mounding produced by the 4-inch and 3-ft thick GWBWs are approximately the same indicating that the 4-inch thick wall would be as effective as a 3-ft thick wall in containing groundwater.

Based on the results of these simulations, groundwater containment by the alternative conceptual GWBW designs was evaluated using only a 4-inch wall thickness.

3.2.2 *River Side Groundwater Barrier Wall*

3.2.2.1 *Groundwater Barrier Wall Installed to Top of Basalt*

The results of the simulations of a river side GWBW installed to the top of the basalt are shown in Figures 3-7, 3-8, and 3-9. These figures show the locations of the GWBW and upgradient withdrawal wells, the steady-state head solution, and the calculated groundwater flow paths to the barrier wall and withdrawal wells. Complete groundwater containment by the barrier wall could be obtained with all three groundwater withdrawal alternatives. The number of withdrawal wells and well flow rates for each simulation are summarized in Table 3-1. Three-dimensional visualizations of the results of the river side GWBW simulations and an interactive viewer for the visualizations are included on a CD in Appendix A.

3.2.2.2 *Groundwater Barrier Wall Installed into Deep Zone*

Figures 3-10, 3-11, and 3-12 show the results of the simulations of a river side GWBW installed into the upper part of the Deep Zone. These figures show the locations of the GWBW and upgradient withdrawal wells, the steady-state head solution, and the calculated groundwater flow paths to the barrier wall and withdrawal wells. Complete groundwater containment by the barrier wall could be obtained with all three groundwater withdrawal alternatives. The number of withdrawal wells and well flow rates for each simulation are summarized in Table 3-1.

3.2.3 *Full Enclosure Groundwater Barrier Wall*

3.2.3.1 *Groundwater Barrier Wall Installed to Top of Basalt*

The results of the simulations of a full enclosure GWBW installed to the top of the basalt are shown in Figures 3-13, 3-14, and 3-15. These figures show the locations of the GWBW and upgradient withdrawal wells, the steady-state head solution, and the calculated groundwater flow paths to the barrier wall adjacent to the Willamette River and the withdrawal wells. Complete groundwater containment by the barrier wall could be obtained with all three groundwater withdrawal alternatives. The number of withdrawal wells and well flow rates for each simulation are summarized in Table 3-1.

3.2.3.2 *Groundwater Barrier Wall Installed into Deep Zone*

Figures 3-16, 3-17, and 3-18 show the results of the simulations of a full enclosure GWBW installed into the upper part of the Deep Zone. These figures show the locations of the GWBW and upgradient withdrawal wells, the steady-state head solution, and the calculated groundwater flow paths to the barrier wall adjacent to the Willamette River and the withdrawal wells. Complete groundwater containment by the barrier wall could be obtained with all three groundwater withdrawal alternatives. The number of withdrawal wells and well flow rates for each simulation are summarized in Table 3-1.

3.2.4 *Impact of Reinjection of Treated Water on Groundwater Containment by Barrier Walls*

The impact of reinjection of treated water on groundwater containment by the conceptual GWBW designs was evaluated for the following two reinjection alternatives:

1. Reinjection of treated water in a shallow reinfiltration trench and injection wells in the Intermediate Zone in Lot 2; and
2. Reinjection of treated water in shallow reinfiltration trenches in Lots 2, 3 and 4, and injection wells in the Intermediate Zone in Lot 2.

For the reinjection simulations, well nodes were added to the model in layer 1 (Shallow Zone) to represent the reinfiltration trenches. Well nodes were also added to layer 3 (Intermediate Zone) to represent five injection wells in the Intermediate Zone. A well spacing of 100 ft was use to minimize the mounding due to the reinjection of the treated water.

Reinjection of the treated water was apportioned between the well nodes representing the reinfiltration trenches and wells so that excessive groundwater mounding above the ground surface elevation did not occur. In the simulations of reinjection of treated water in Lot 2, 25 percent of the treated water was allotted to the reinfiltration trench and 75 percent to the reinjection wells. In the simulations of reinjection of treated water in Lots 2, 3 and 4, 30 percent of the treated water was allotted to the reinfiltration trench in Lot 2, 20 percent to the reinfiltration trenches in Lots 3 and 4, and 50 percent to the reinjection wells in Lot 2. The injection rates for the reinfiltration trenches and wells for each simulation are summarized in Table 3-2.

The reinjection of treated water was evaluated for only one groundwater withdrawal alternative – withdrawal wells in the Shallow Zone and Intermediate Zone (Section 3.1.2).

3.2.4.1 *Reinjection in Lot 2*

The results of the model simulations of reinjection in Lot 2 are shown in Figures 3-19 and 3-20 for the river side GWBW, and for the full enclosure GWBW in Figures 3-21 and 3-22. These figures show the locations of the GWBW, upgradient withdrawal wells, reinfiltration trench and reinjection wells, the steady-state head solution, and the calculated groundwater flow paths to the barrier wall adjacent to the Willamette River and the withdrawal wells. The results of these model simulations indicate that reinjection of treated water at Lot 2 would not significantly impact groundwater containment by the river side or full enclosure GWBWs. The injection rates for the reinfiltration trench and wells for each simulation are summarized in Table 3-2.

3.2.4.1 *Reinjection in Lots 2, 3, and 4*

The results of the model simulations of reinjection in Lots 2, 3 and 4 are shown in Figures 3-23 and 3-24 for the river side GWBW, and for the full enclosure GWBW in Figures 3-25 and 3-26. These figures show the locations of the GWBW, upgradient withdrawal wells, reinfiltration trenches and reinjection wells, the steady-state head solution, and the calculated groundwater flow paths to the barrier wall adjacent to the Willamette River and the withdrawal wells. The results of these model simulations indicate that reinjection of treated water at Lots 3 and 4 could significantly impact groundwater containment by the river side GWBW. Groundwater containment by the river side GWBW was incomplete with reinjection of only 5 percent of the treated water into the trenches in Lots 3 and 4 (Figures 3-23 and 3-24). Groundwater containment by the full enclosure GWBW was not significantly impacted by reinjection of treated water into Lots 2, 3 and 4 (Figures 3-25 and 3-26). The injection rates for the reinfiltration trenches and wells for each simulation are summarized in Table 3-2.

4.0 UNCERTAINTY IN MODEL SIMULATIONS

There are uncertainties in the groundwater flow field simulated by a numerical model. These uncertainties are due to the simplifications and assumptions in the design of the model, uncertainty in the boundary conditions and input parameters, and the limited data that is available to calibrate the model to the observed groundwater flow systems at a site. The uncertainties in the Arkema site groundwater model are discussed in more detail in the *Draft Groundwater Modeling Report, Arkema Inc., Facility, Portland, Oregon* (Environmental Resources Management [ERM] 2007).

Only a limited number of aquifer tests have been performed at the Arkema site and on the adjacent properties to measure the hydraulic conductivity of the groundwater zones. Therefore, there is a moderate uncertainty in the hydraulic conductivities used in the groundwater flow model. Because of this uncertainty, there is also an uncertainty in the number and flow rates of upgradient withdrawal wells needed for the alternative conceptual GWBW designs.

THIS PAGE INTENTIONALLY LEFT BLANK

5.0 CONCLUSIONS

The groundwater model evaluation of the conceptual GWBW designs indicates that all four alternative designs would be effective in containing groundwater. The number and total flow rates of the withdrawal wells in the river side GWBW simulations was somewhat greater than the full enclosure GWBW simulations, but not significantly so.

Reinjection of treated water in Lot 2 did not significantly impact containment by the alternative conceptual GWBW designs. Reinjection of treated water in Lots 3 and 4 did impact groundwater containment by the river side and full enclosure GWBW designs. The impact was greatest for the river side conceptual GWBW designs, where reinjection of only 5 percent of the treated water in Lots 3 and 4 resulted in incomplete groundwater capture by the GWBW.

THIS PAGE INTENTIONALLY LEFT BLANK

6.0 REFERENCES

Anderson, Mary P. and W.W. Woessner 1992. *Applied Groundwater Modeling.* Academic Press, Inc., San Diego, CA, 381 pp.

Harbaugh, A.W. 2005. *MODFLOW 2005, The U.S. Geological Survey Modular Ground-Water Model – the Ground-Water Flow Process*. U.S. Geological Survey Techniques and Methods 6-A16.

Hsieh, P.A. and J.R. Freckleton 1993. *Documentation of a Computer Program to Simulate Horizontal-Flow Barriers Using the U.S. Geological Survey's Modular Three-Dimensional Finite-Difference Ground-Water Flow Model*. U.S. Geological Survey Open-File Report 92-477, 32 pp.

McDonald, M.G. and A.W. Harbaugh 1988. *A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model.* Techniques of Water-Resources Investigations of the United States Geological Survey, Book 6, Chapter A1, 576 pp.

U.S. Environmental Protection Agency (USEPA) 1993. *A Manual of Instructional Problems for the U.S.G.S. MODFLOW Model*. EPA/600/R93/010.

USEPA 1994. *Guidelines for Hydrogeologic Modeling*. United States Environmental Protection Agency Region 10, Environmental Services Division, Seattle, WA. March 1994.

Zheng, C., K.R. Bradbury, and M.P. Anderson 1992. A Computer model for Calculation of Groundwater Paths and Travel Times in Transient Three-Dimensional Flows. Wisconsin Geological and Natural History Survey Information Circular 70, 22 pp.

Zheng, C. 2001. *PATH3D. A Ground-Water Path and Travel-Time Simulator, Version 4.6*. S.S. Papadopulos and Associates, Inc., Bethesda, MD. September 2001.

THIS PAGE INTENTIONALLY LEFT BLANK

Figures

Project No. 0057055

Date: 02/06/08

Drawn By: T. Cota

GIS File:

Aerial Photography - July, 2005

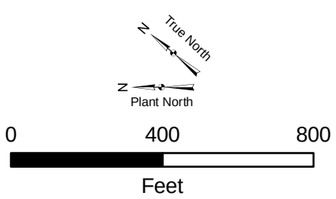


Figure A.2-1

Finite-Difference Model Grid

Arkema, Inc.

Portland, Oregon

ERM 02/08

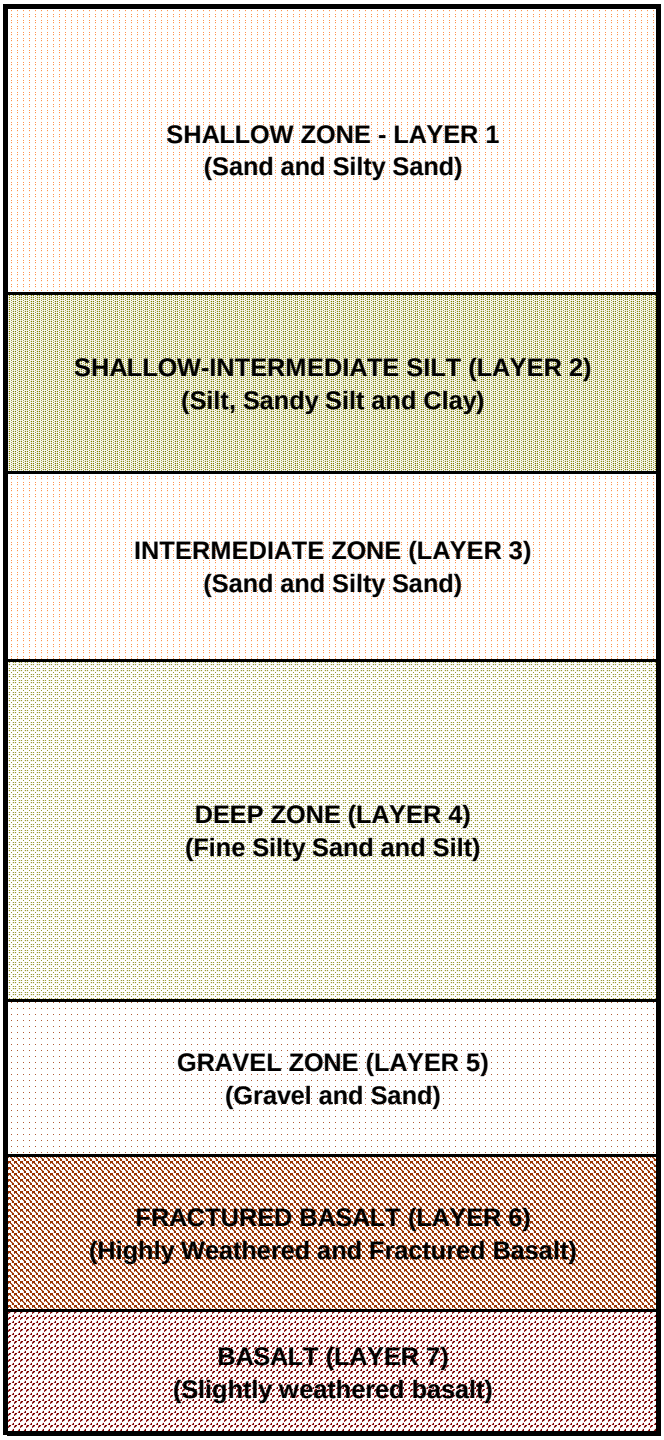
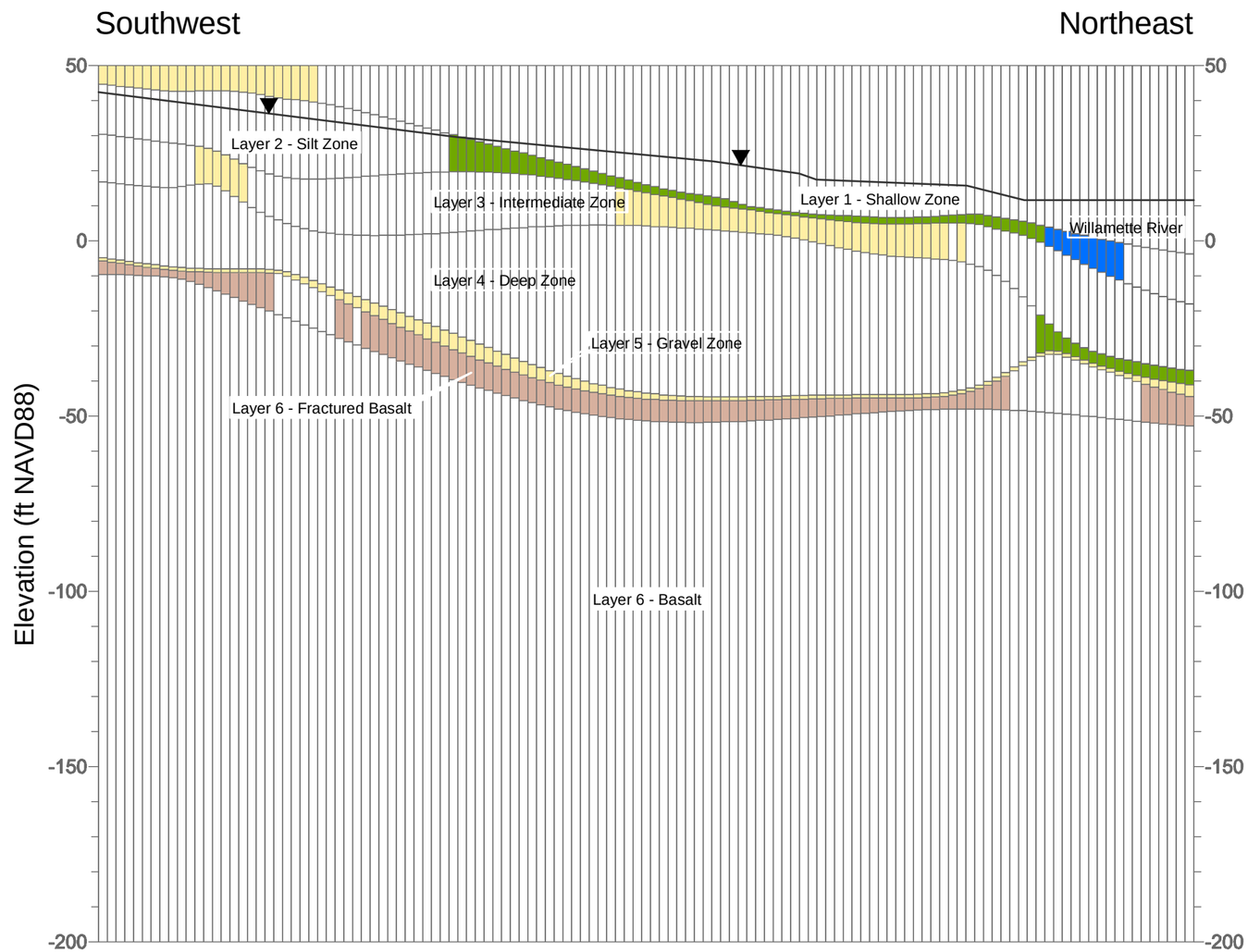


Figure A.2-2
Hydrostratigraphic Units
Arkema, Inc.
Portland, Oregon
ERM *10/07*

Project No. 0057055
Date: 02/06/08
Drawn By: T. Cota
GIS File:



Location of Cross-Section

0 400 800
Feet

Figure A.2-3
Model Grid Layers
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0057055

Aerial Photography - July, 2005

LEGEND

- Horizontal Flow Barrier
- Constant-Head (Willamette River)
- Constant-Head (Model Grid Margins)
- River (Head-Dependent Flow)

True North

Plant North

0 400 800

Feet

Figure A.3-1

Flow Boundary Conditions

River Side High Bank Groundwater Barrier Wall Simulations

Shallow Zone (Layer 1)

Arkema, Inc.

Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0057055

Aerial Photography - July, 2005

LEGEND

- Horizontal Flow Barrier
- Constant-Head (Willamette River)
- Constant-Head (Model Grid Margins)
- River (Head-Dependent Flow)

True North

Plant North

0 400 800

Feet

Figure A.3-2

Flow Boundary Conditions

Full Enclosure Groundwater Barrier Wall Simulations

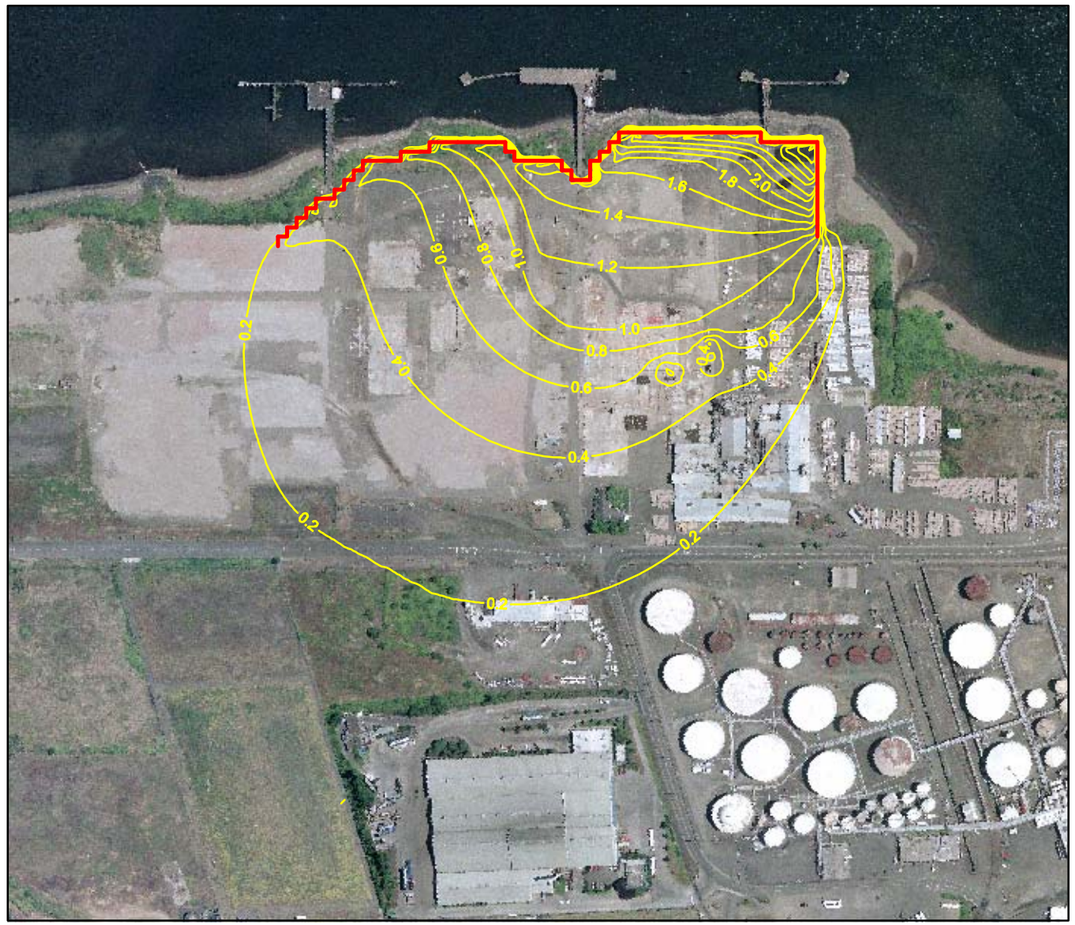
Shallow Zone (Layer 1)

Arkema, Inc.

Portland, Oregon

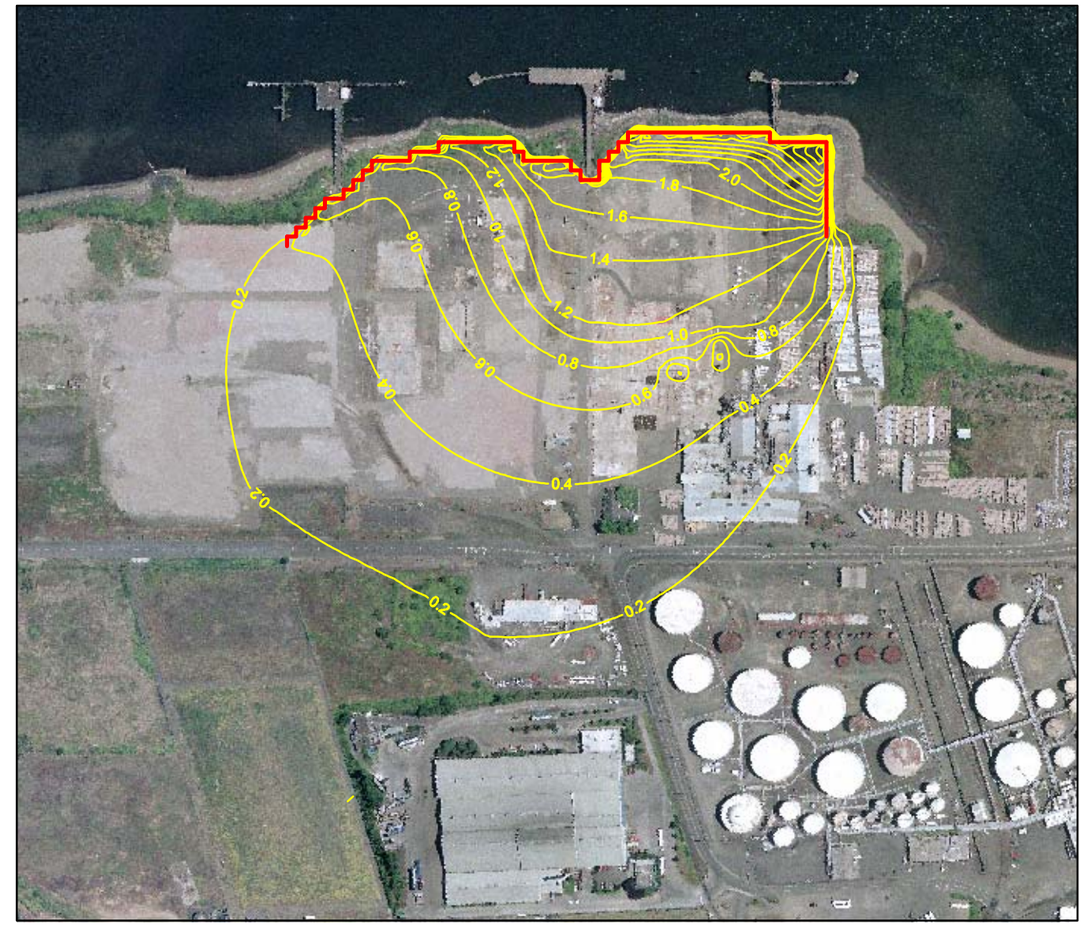
ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0057055



Aerial Photography - July, 2005

4-Inch Thick Barrier Wall Installed to Top of Basalt



Aerial Photography - July, 2005

3-Foot Thick Barrier Wall Installed to Top of Basalt

LEGEND

Groundwater Mounding (ft)

Groundwater Barrier Wall

True North

Plant North

0 400 800

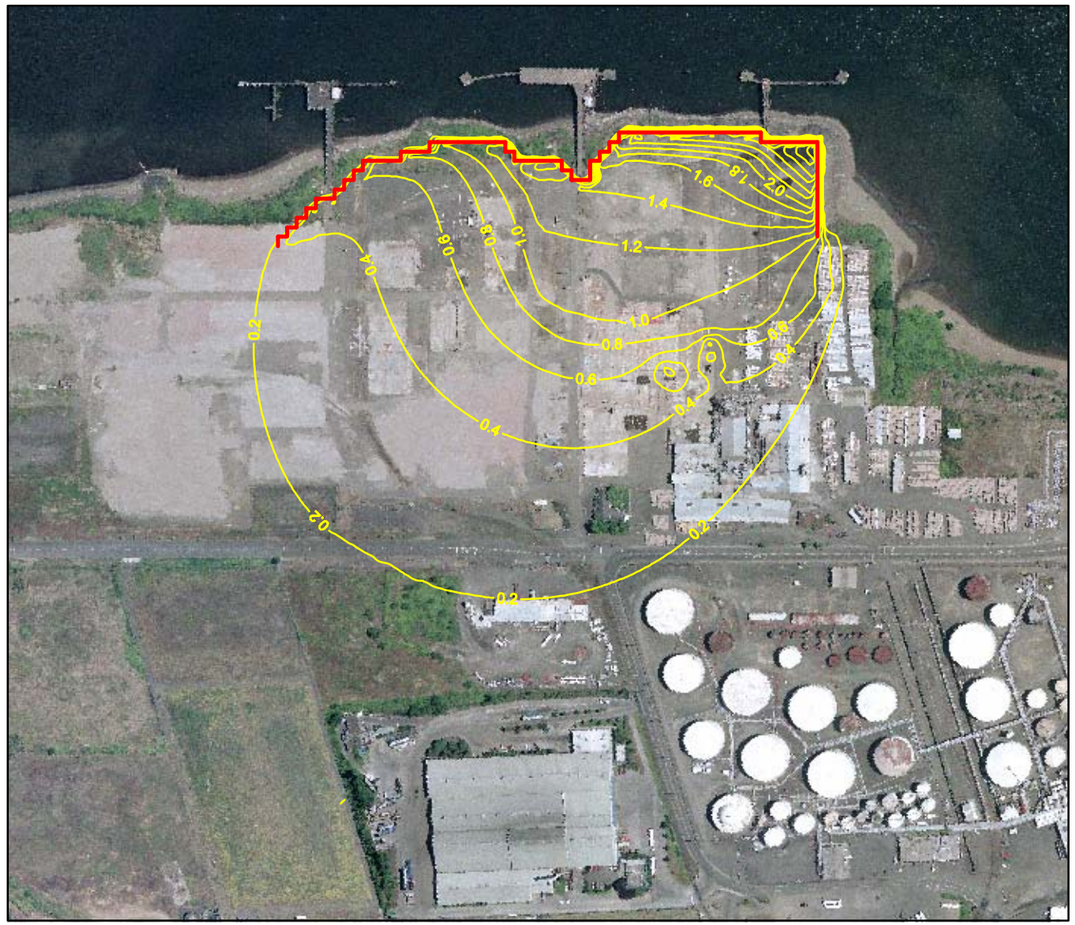
Feet

Figure A.3-3

Comparison of Groundwater Mounding in Shallow Zone (Layer 1)
4-Inch and 3-Foot Wall Thickness
River Side Groundwater Barrier Wall Installed to Top of Basalt
Arkema, Inc.
Portland, Oregon

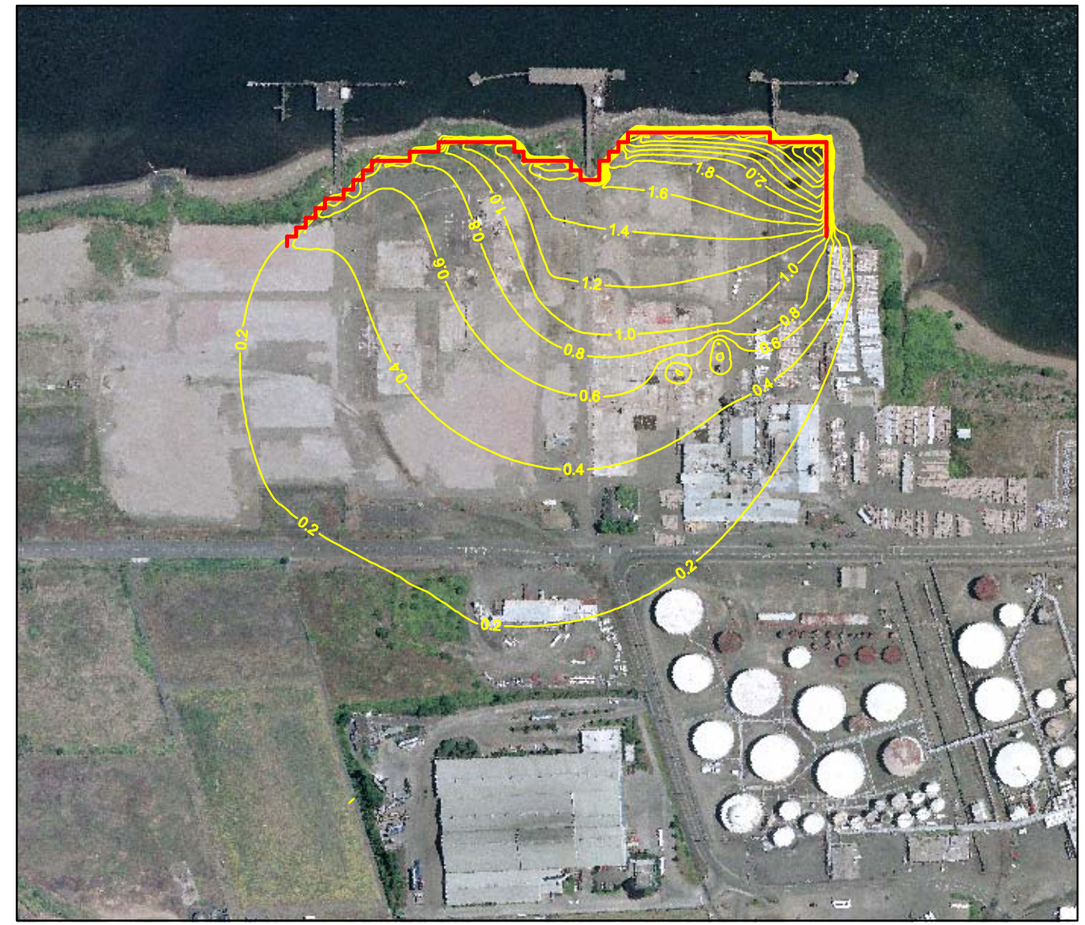
ERM *02/08*

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0057055



Aerial Photography - July, 2005

4-Inch Thick Barrier Wall Installed into Deep Zone



Aerial Photography - July, 2005

3-Foot Thick Barrier Wall Installed into Deep Zone

LEGEND

Groundwater Mounding (ft)

Groundwater Barrier Wall

True North

Plant North

0 400 800

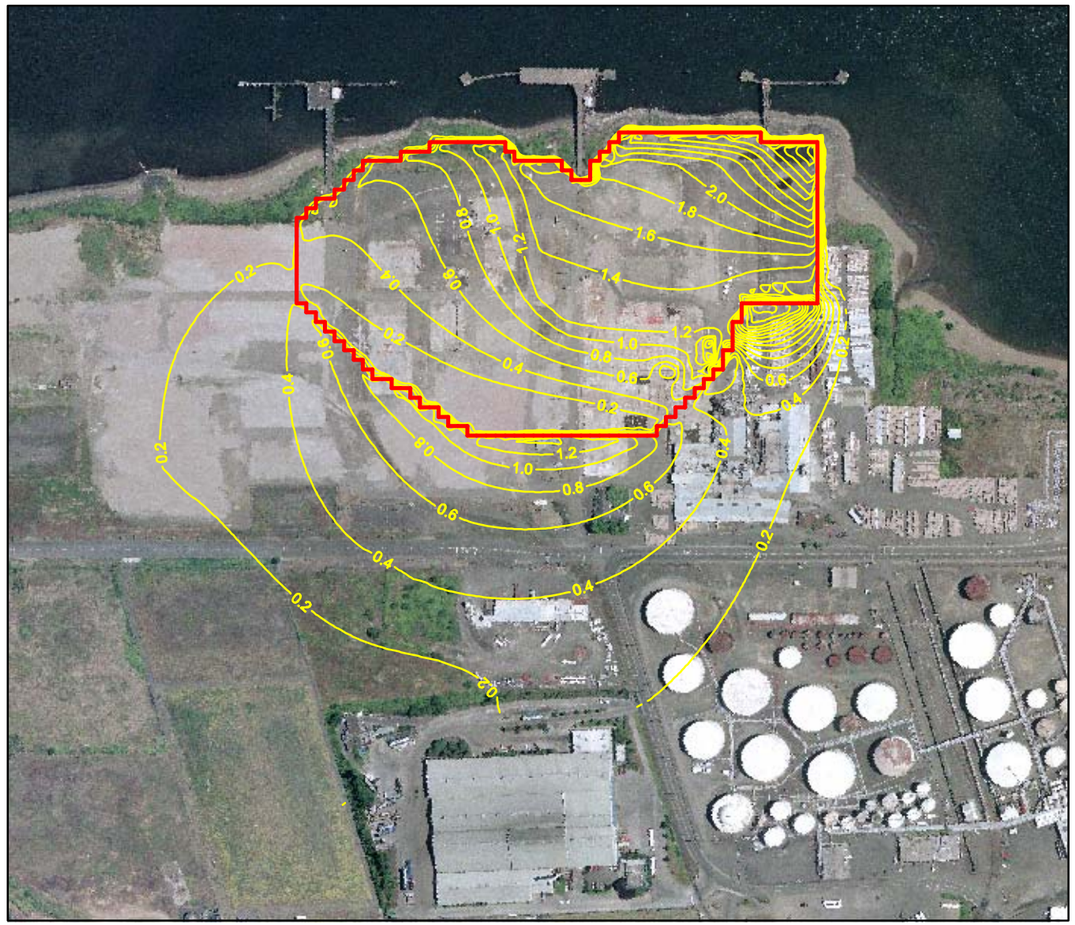
Feet

Figure A.3-4

Comparison of Groundwater Mounding in Shallow Zone (Layer 1)
4-Inch and 3-Foot Wall Thickness
River Side Groundwater Barrier Wall Installed into Deep Zone
Arkema, Inc.
Portland, Oregon

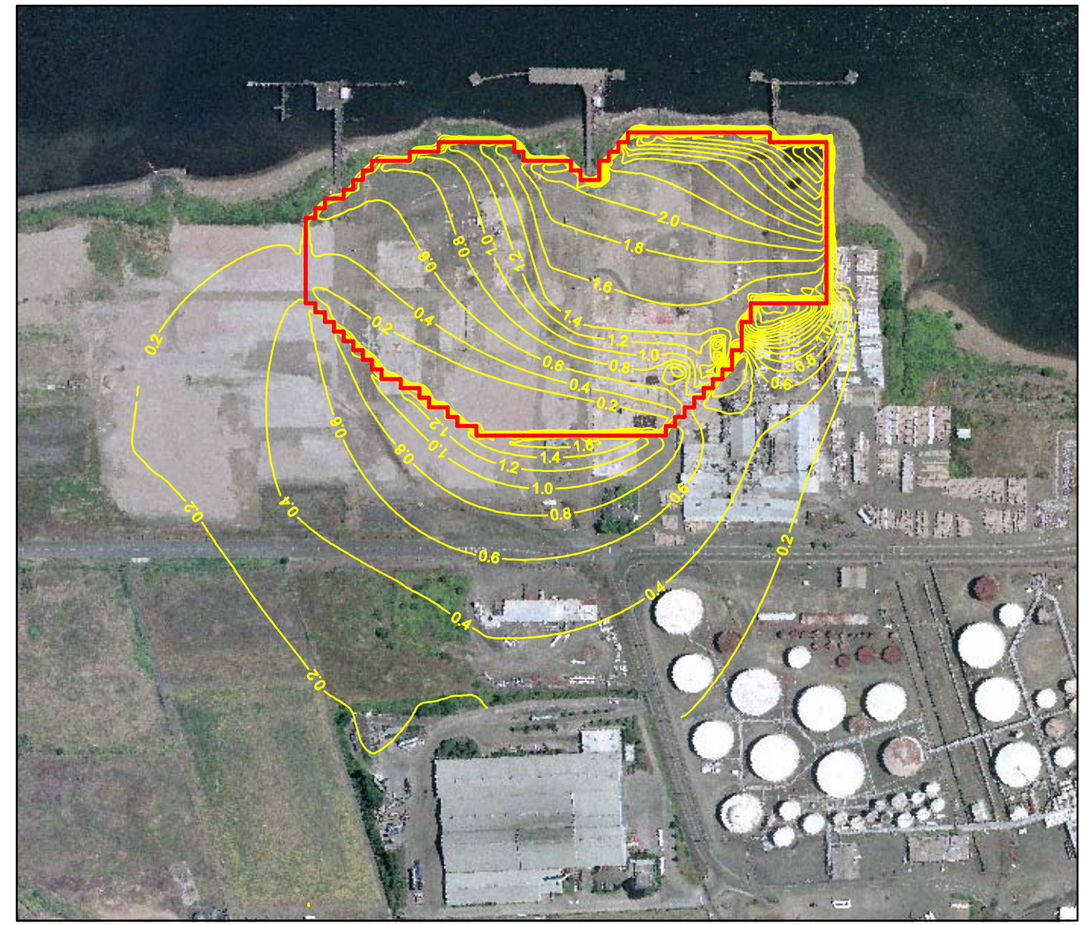
ERM *02/08*

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0057055



Aerial Photography - July, 2005

4-Inch Thick Barrier Wall Installed to Top of Basalt



Aerial Photography - July, 2005

3-Foot Thick Barrier Wall Installed to Top of Basalt

LEGEND

Groundwater Mounding (ft)

Groundwater Barrier Wall

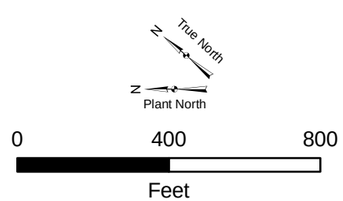


Figure A.3-5

Comparison of Groundwater Mounding in Shallow Zone (Layer 1)
4-Inch and 3-Foot Wall Thickness
Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt
Arkema, Inc.
Portland, Oregon

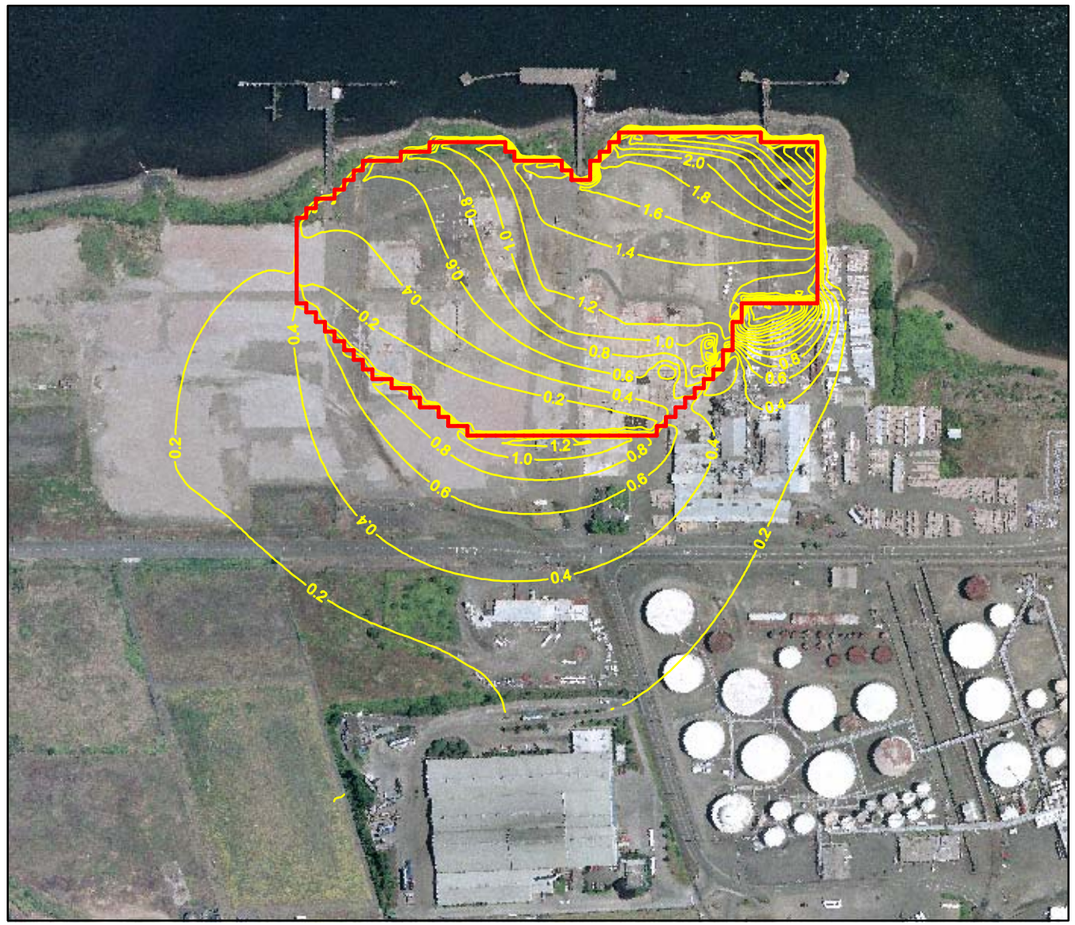
ERM *02/08*

GIS File:

Drawn By: T. Cota

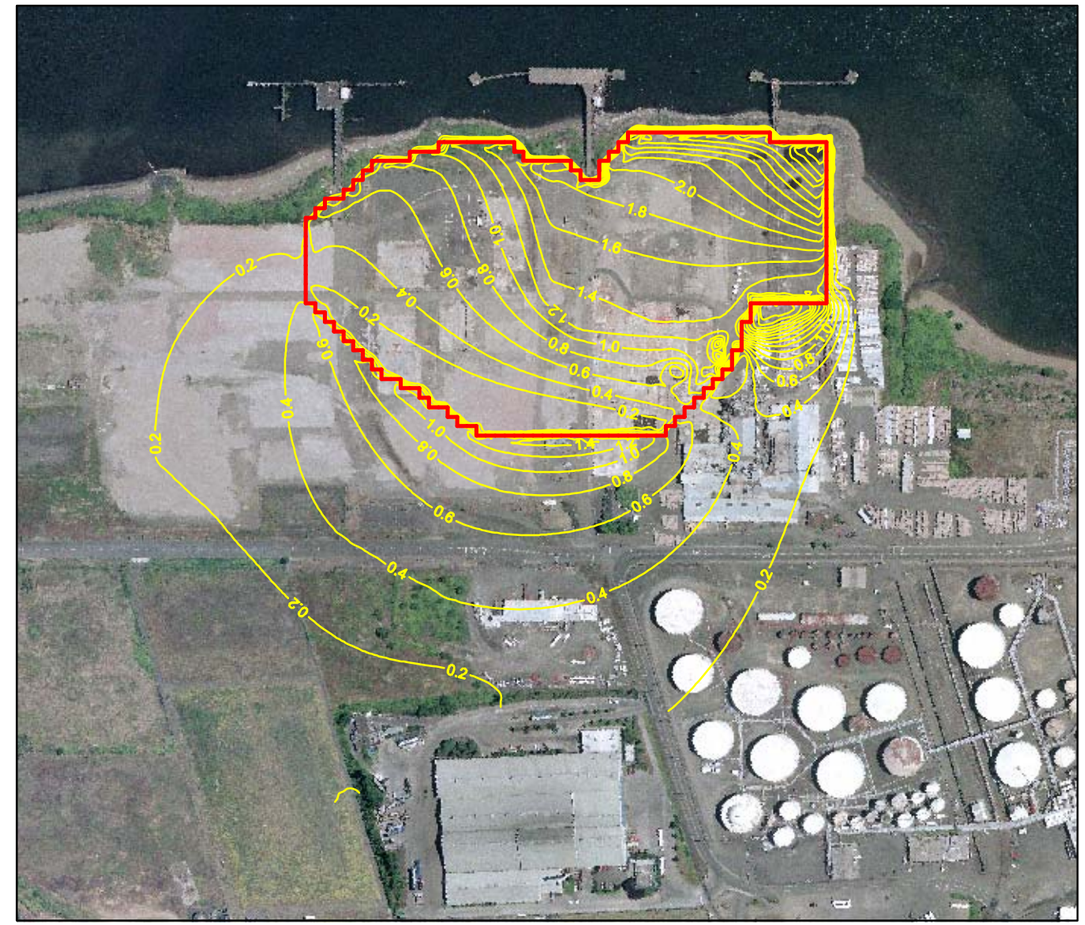
Date: 02/06/08

Project No. 0057055



Aerial Photography - July, 2005

4-Inch Thick Barrier Wall Installed into Deep Zone



Aerial Photography - July, 2005

3-Foot Thick Barrier Wall Installed into Deep Zone

LEGEND

Groundwater Mounding (ft)

Groundwater Barrier Wall

True North

Plant North

0 400 800

Feet

Figure A.3-6

Comparison of Groundwater Mounding in Shallow Zone (Layer 1)

4-Inch and 3-Foot Wall Thickness

Full Enclosure Groundwater Barrier Wall Installed into Deep Zone

Arkema, Inc.

Portland, Oregon

ERM *02/08*

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572

Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Shallow Zone Withdrawal Well
- Groundwater Barrier Wall

N True North

N Plant North

0 250 500

Feet

Figure A.3-7

River Side High Bank Groundwater Barrier Wall Installed to Top of Basalt (Layer 5)
Withdrawal Wells in Shallow Zone (Layer 1)
Arkema, Inc.
Portland, Oregon

ERM *02/08*

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572

Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Intermediate Zone Head Solution (ft NAVD88)
- Intermediate Zone Withdrawal Well
- Groundwater Barrier Wall

True North

Plant North

0 250 500

Feet

Figure A.3-8

River Side High Bank Groundwater Barrier Wall Install to Top of Basalt (Layer 5)
Withdrawal Wells in Intermediate Zone (Layer 3)
Arkema, Inc.
Portland, Oregon

ERM *02/08*

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572

Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Groundwater Barrier Wall

True North

Plant North

0 250 500

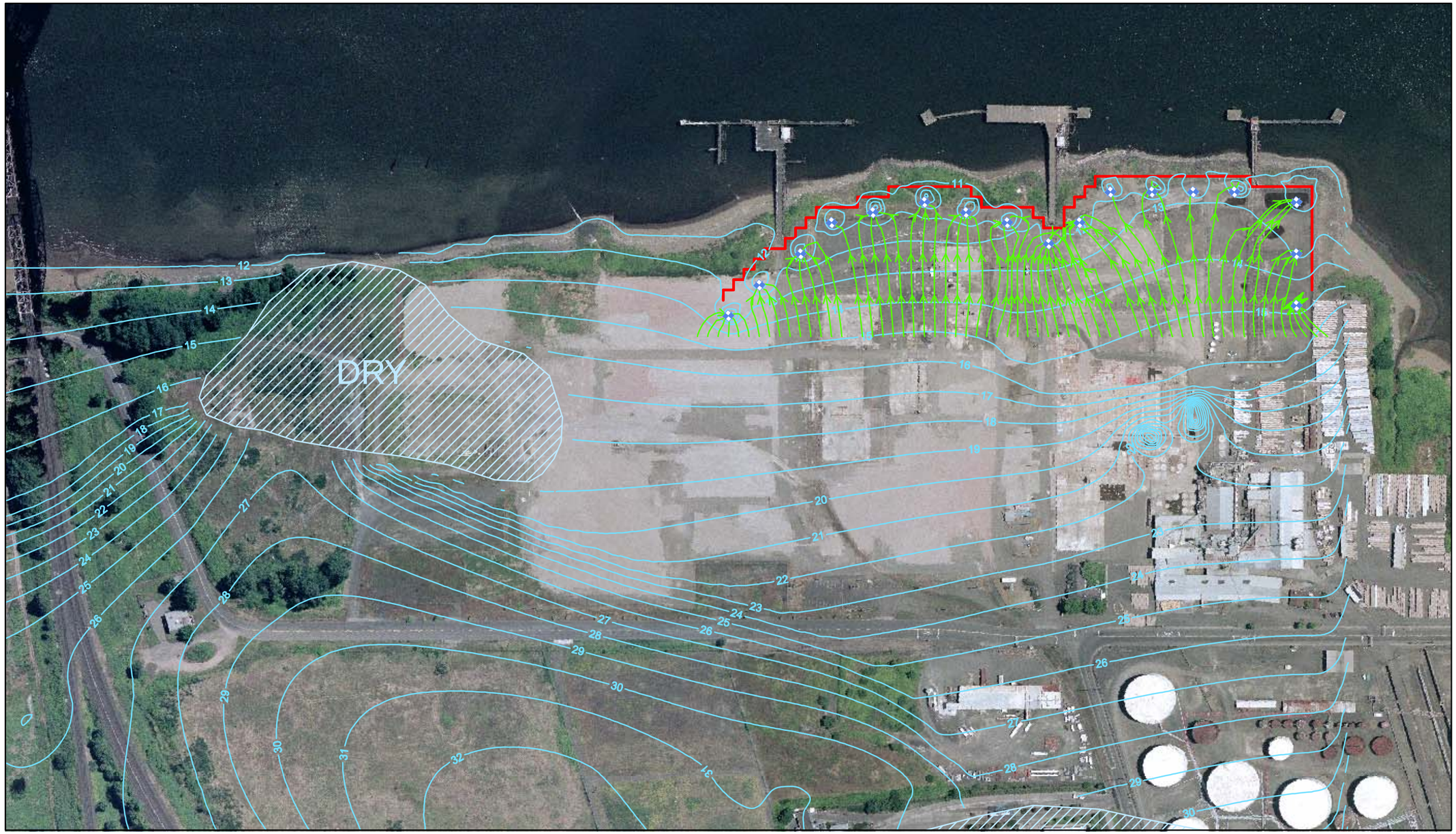
Feet

Figure A.3-9

River Side High Bank Groundwater Barrier Wall Installed to Top of Basalt (Layer 5)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Shallow Zone Withdrawal Well
- Groundwater Barrier Wall

True North

Plant North

0 250 500

Feet

Figure A.3-10

River Side High Bank Groundwater Barrier Wall Installed into Deep Zone (Layer 4)
Withdrawal Wells in Shallow Zone (Layer 1)
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572

Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Intermediate Zone Head Solution (ft NAVD88)
- Intermediate Zone Withdrawal Well
- Groundwater Barrier Wall

True North

Plant North

0 250 500

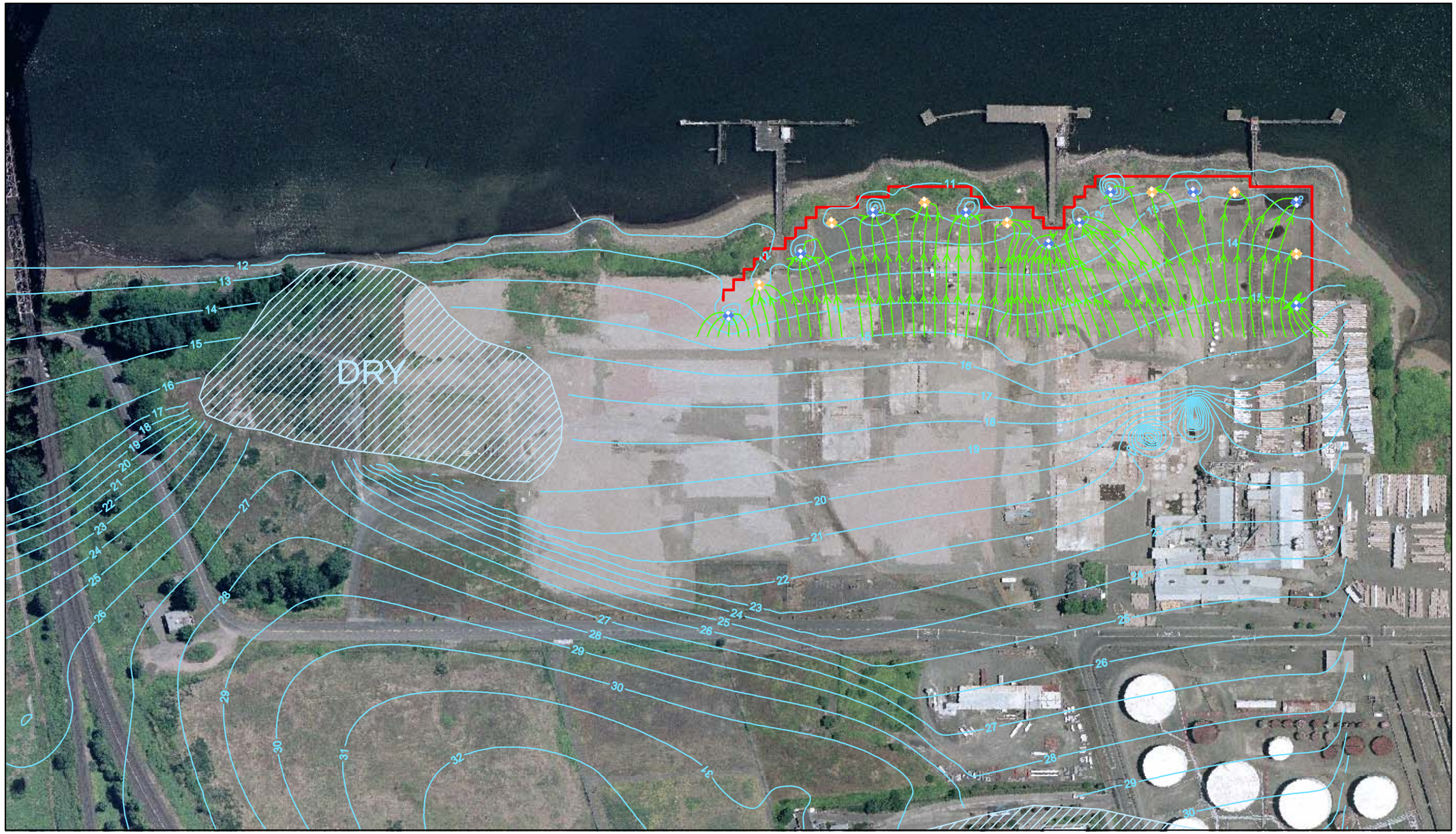
Feet

Figure A.3-11

River Side High Bank Groundwater Barrier Wall Installed into Deep Zone (Layer 4)
Withdrawal Wells in Intermediate Zone (Layer 3)
Arkema, Inc.
Portland, Oregon

ERM *02/08*

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Groundwater Barrier Wall

True North

Plant North

0 250 500

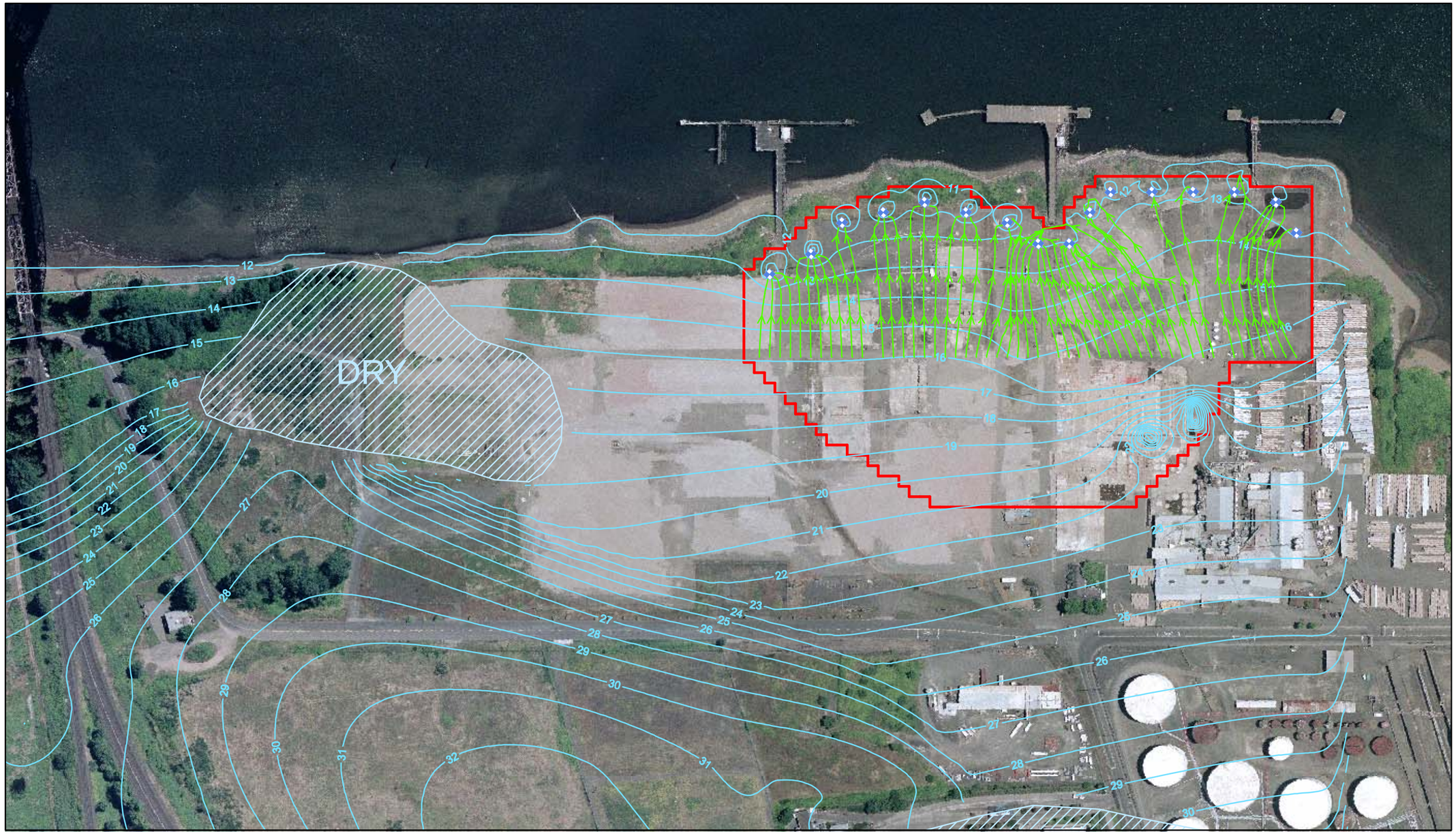
Feet

Figure A.3-12

River Side High Bank Groundwater Barrier Wall Installed into Deep Zone (Layer 4)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Arkema, Inc.
Portland, Oregon

ERM *02/08*

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Shallow Zone Withdrawal Well
- Groundwater Barrier Wall

True North

Plant North

0 250 500

Feet

Figure A.3-13

Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt (Layer 5)
Withdrawal Wells in Shallow Zone (Layers 1)
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572

Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Intermediate Zone Head Solution (ft NAVD88)
- Intermediate Zone Withdrawal Well
- Groundwater Barrier Wall

True North

Plant North

0 250 500

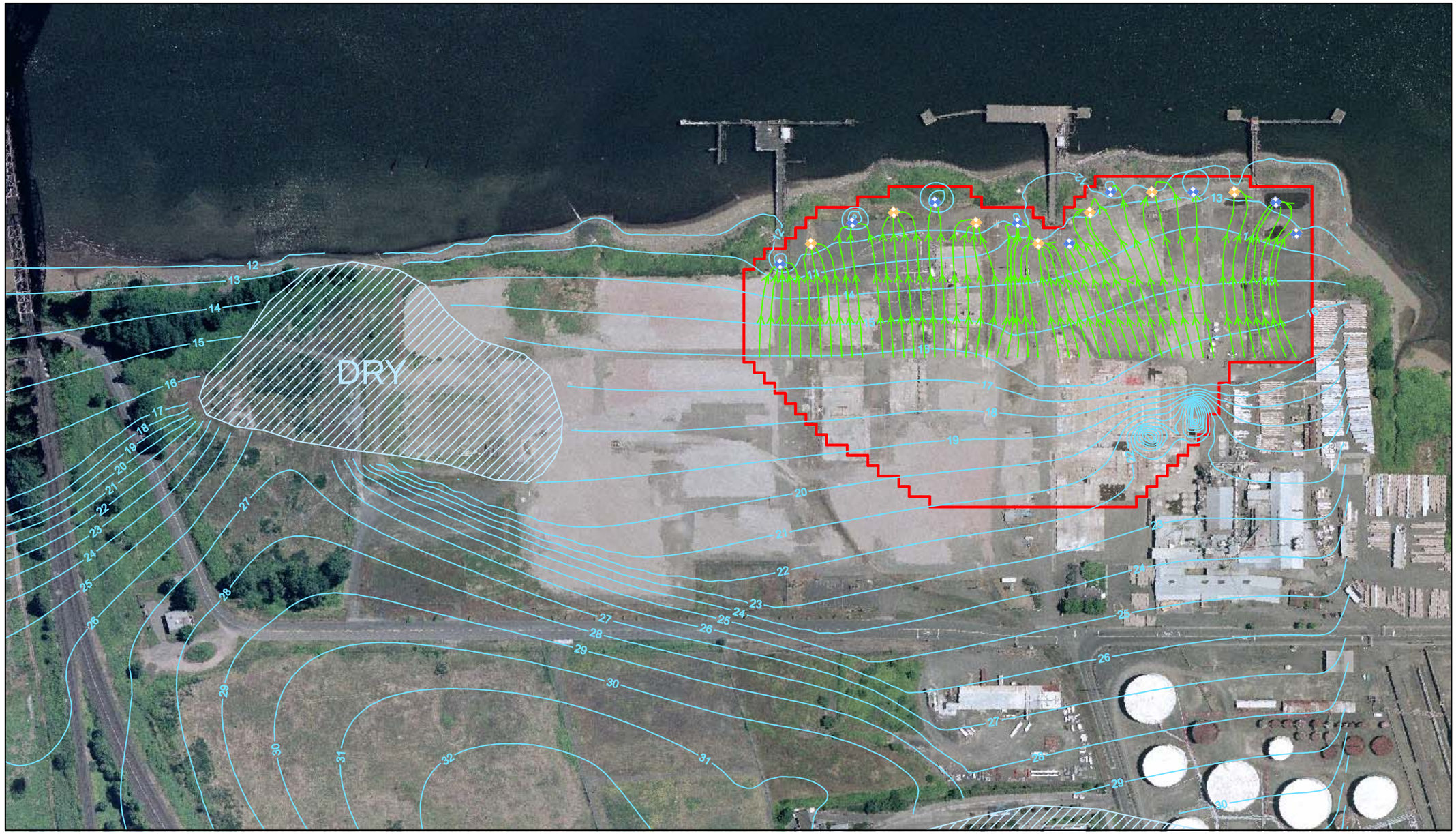
Feet

Figure A.3-14

Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt (Layer 5)
Withdrawal Wells in Intermediate Zone (Layer 3)
Arkema, Inc.
Portland, Oregon

ERM *02/08*

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Groundwater Barrier Wall

True North

Plant North

0 250 500

Feet

Figure A.3-15

Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt (Layer 5)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Arkema, Inc.
Portland, Oregon

ERM *02/08*

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572

Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Shallow Zone Withdrawal Well
- Groundwater Barrier Wall

True North

Plant North

0 250 500

Feet

Figure A.3-16

Full Enclosure Groundwater Barrier Wall Installed into Deep Zone (Layer 4)
Withdrawal Wells in Shallow Zone (Layer 1)
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572

Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Intermediate Zone Head Solution (ft NAVD88)
- Intermediate Zone Withdrawal Well
- Groundwater Barrier Wall

True North

Plant North

0 250 500

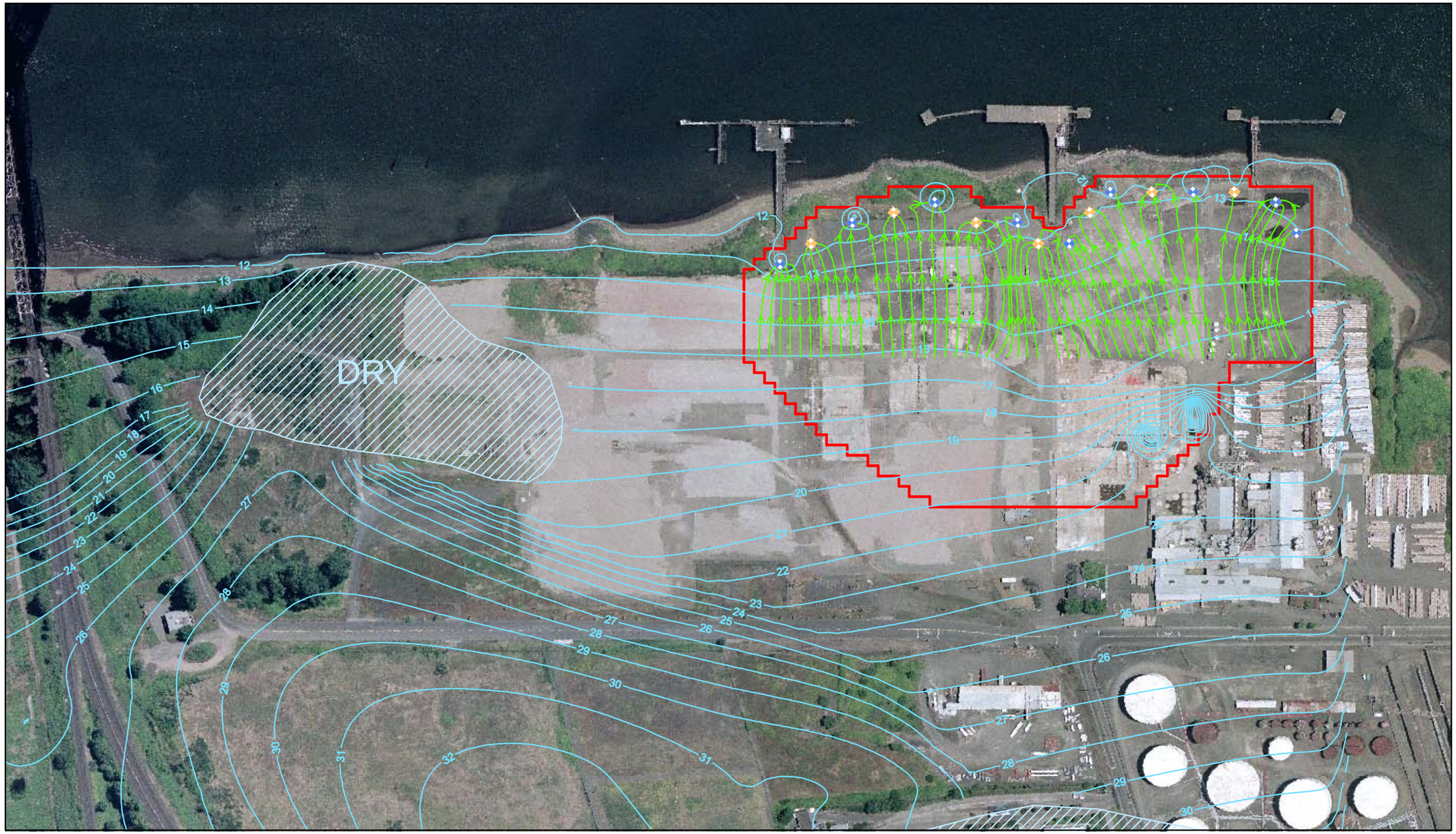
Feet

Figure A.3-17

Full Enclosure Groundwater Barrier Wall Installed into Deep Zone (Layer 4)
Withdrawal Wells in Intermediate Zone (Layer 3)
Arkema, Inc.
Portland, Oregon

ERM 12/07

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Groundwater Barrier Wall

N True North

N Plant North

0 250 500

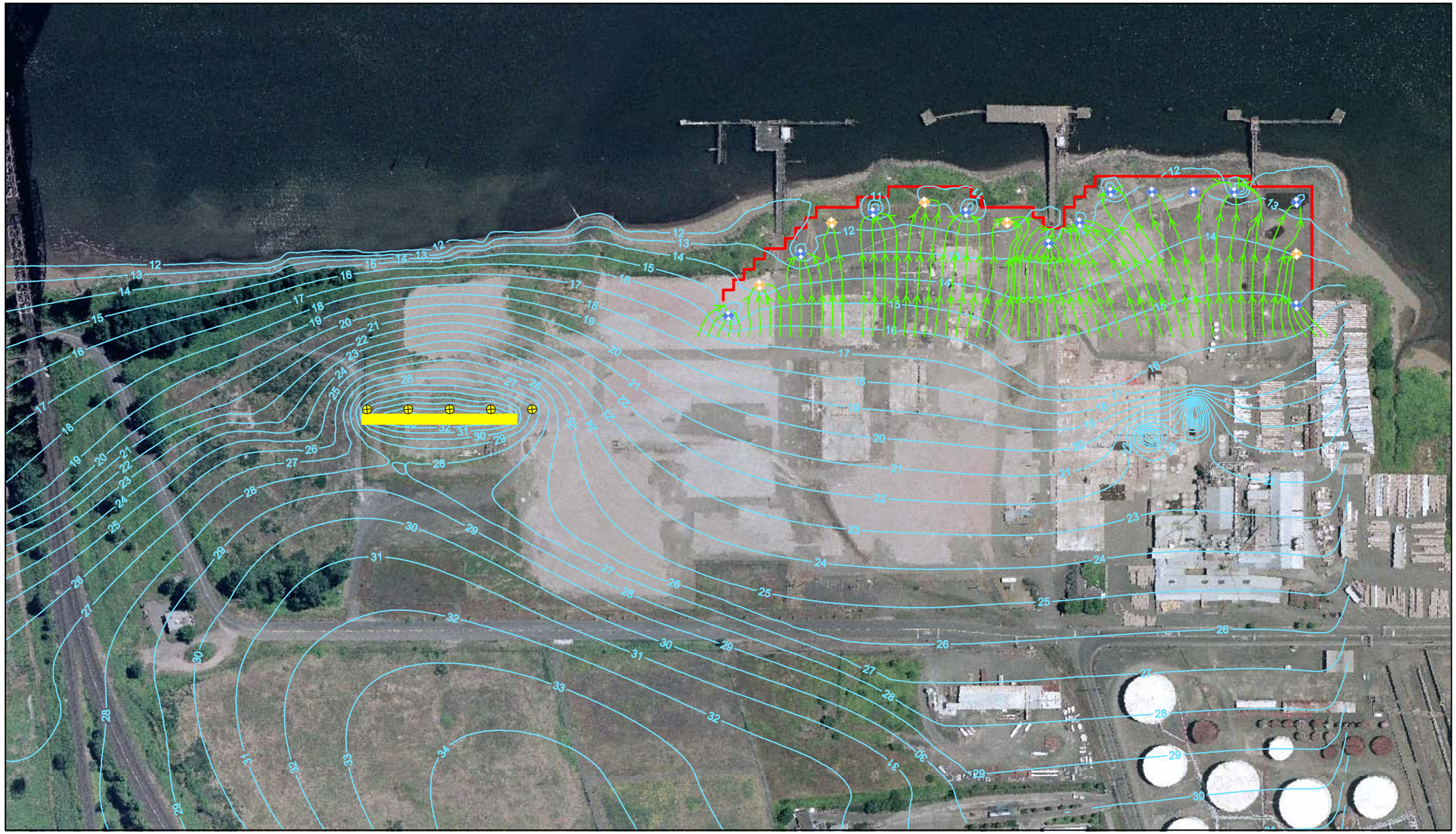
Feet

Figure A.3-18

Full Enclosure Groundwater Barrier Wall Installed into Deep Zone (Layer 4)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Arkema, Inc.
Portland, Oregon

ERM *02/08*

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Shallow Zone Reinfiltration Trench
- Intermediate Zone Reinjection Well
- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Groundwater Barrier Wall

True North

Plant North

0 250 500

Feet

Figure A.3-19

River Side High Bank Groundwater Barrier Wall Installed to Top of Basalt (Layer 5)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Reinjection in Lot 2
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572

Aerial Photography - July, 2005

LEGEND

- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Shallow Zone Reinfiltration Trench
- Intermediate Zone Reinjection Well
- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Groundwater Barrier Wall

True North

Plant North

0 250 500

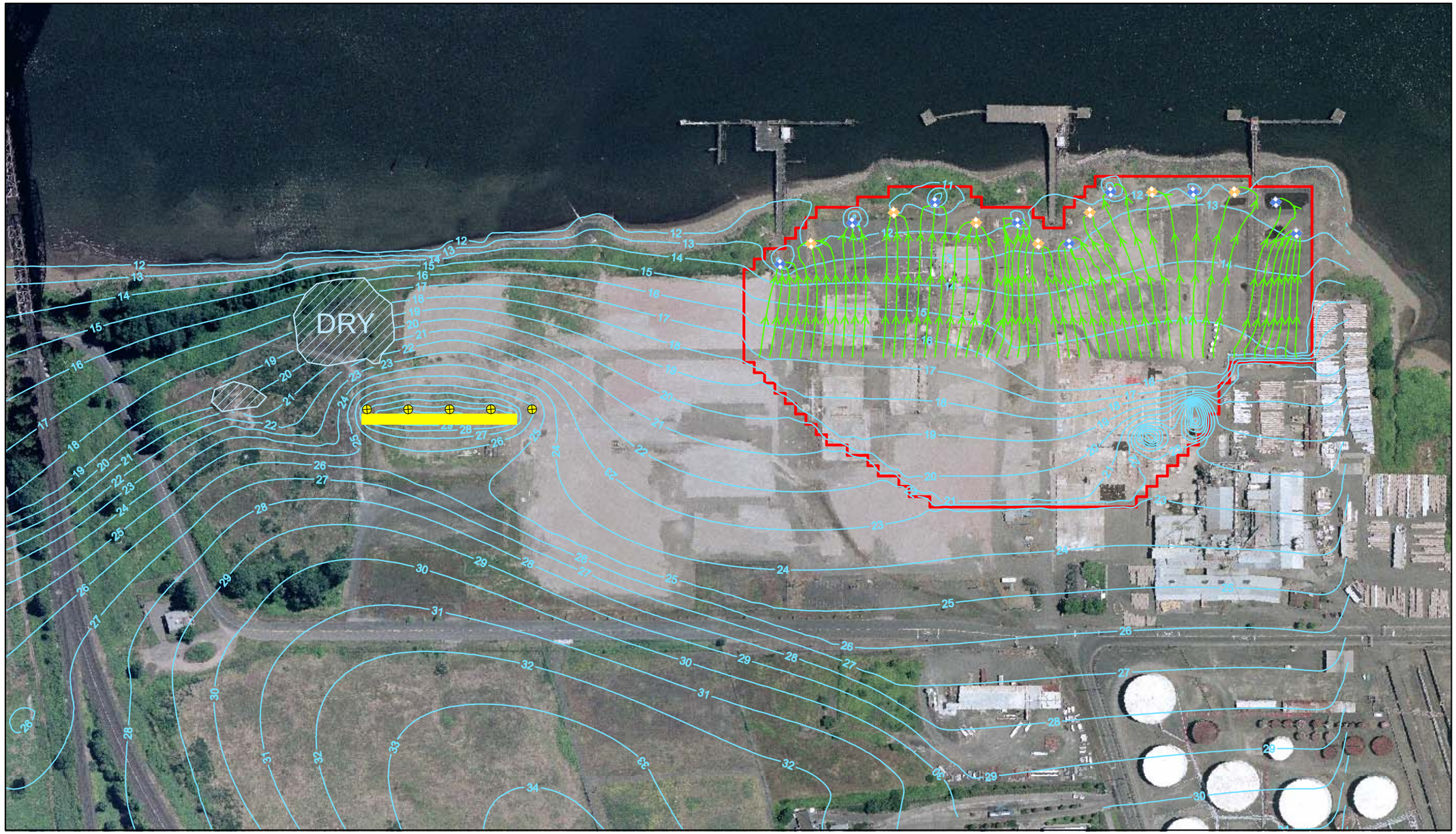
Feet

Figure A.3-20

River Side High Bank Groundwater Barrier Wall Installed into Deep Zone (Layer 4)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Reinjection in Lot 2
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Shallow Zone Reinfiltration Trench
- Intermediate Zone Reinjection Well
- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Groundwater Barrier Wall

True North

Plant North

0 250 500

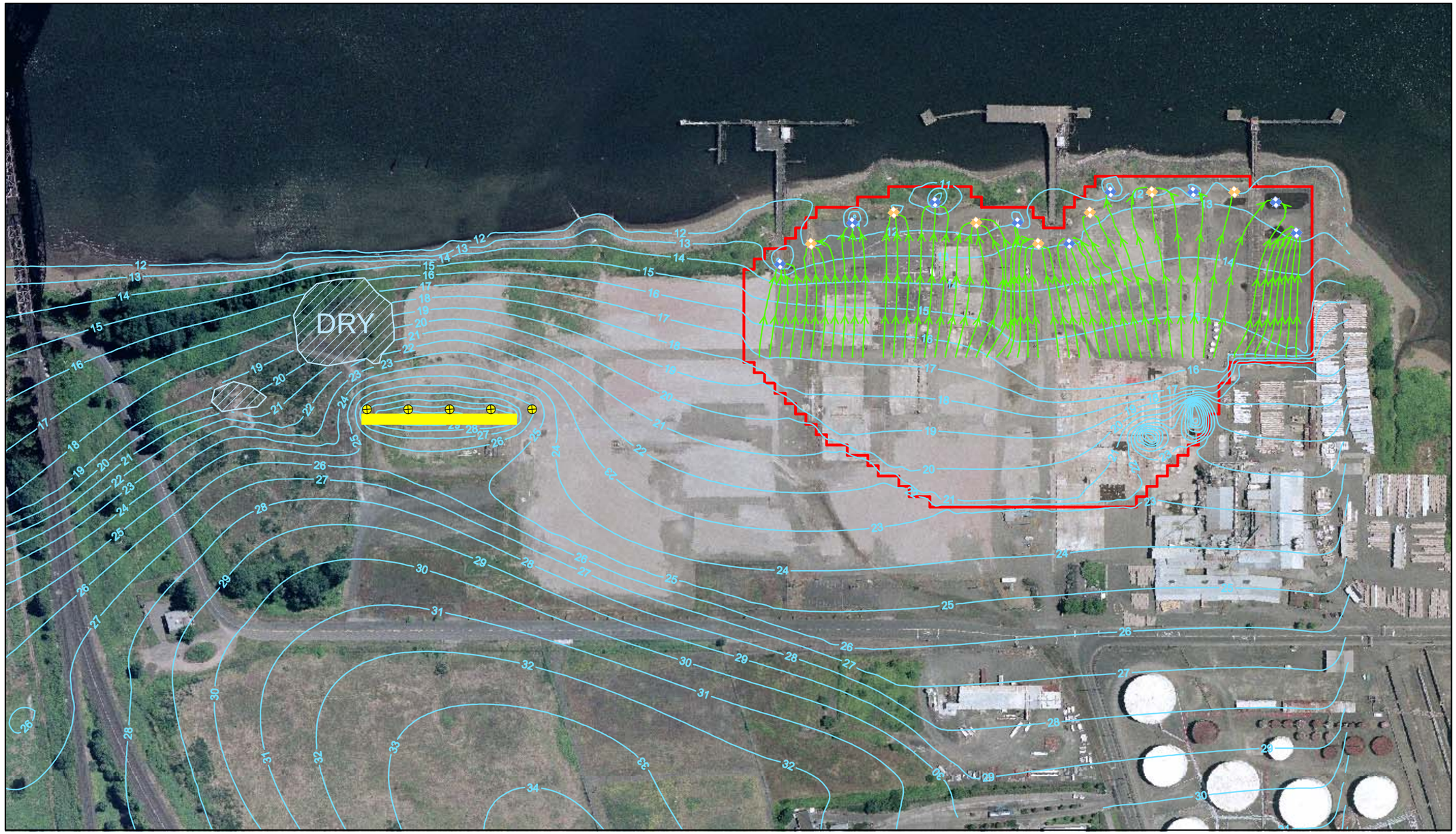
Feet

Figure A.3-21

Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt (Layer 5)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Reinjection in Lot 2
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Shallow Zone Reinfiltration Trench
- Intermediate Zone Reinjection Well
- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Groundwater Barrier Wall

True North

Plant North

0 250 500

Feet

Figure A.3-22

Full Enclosure Groundwater Barrier Wall Installed into Deep Zone (Layer 4)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Reinjection in Lot 2
Arkema, Inc.
Portland, Oregon

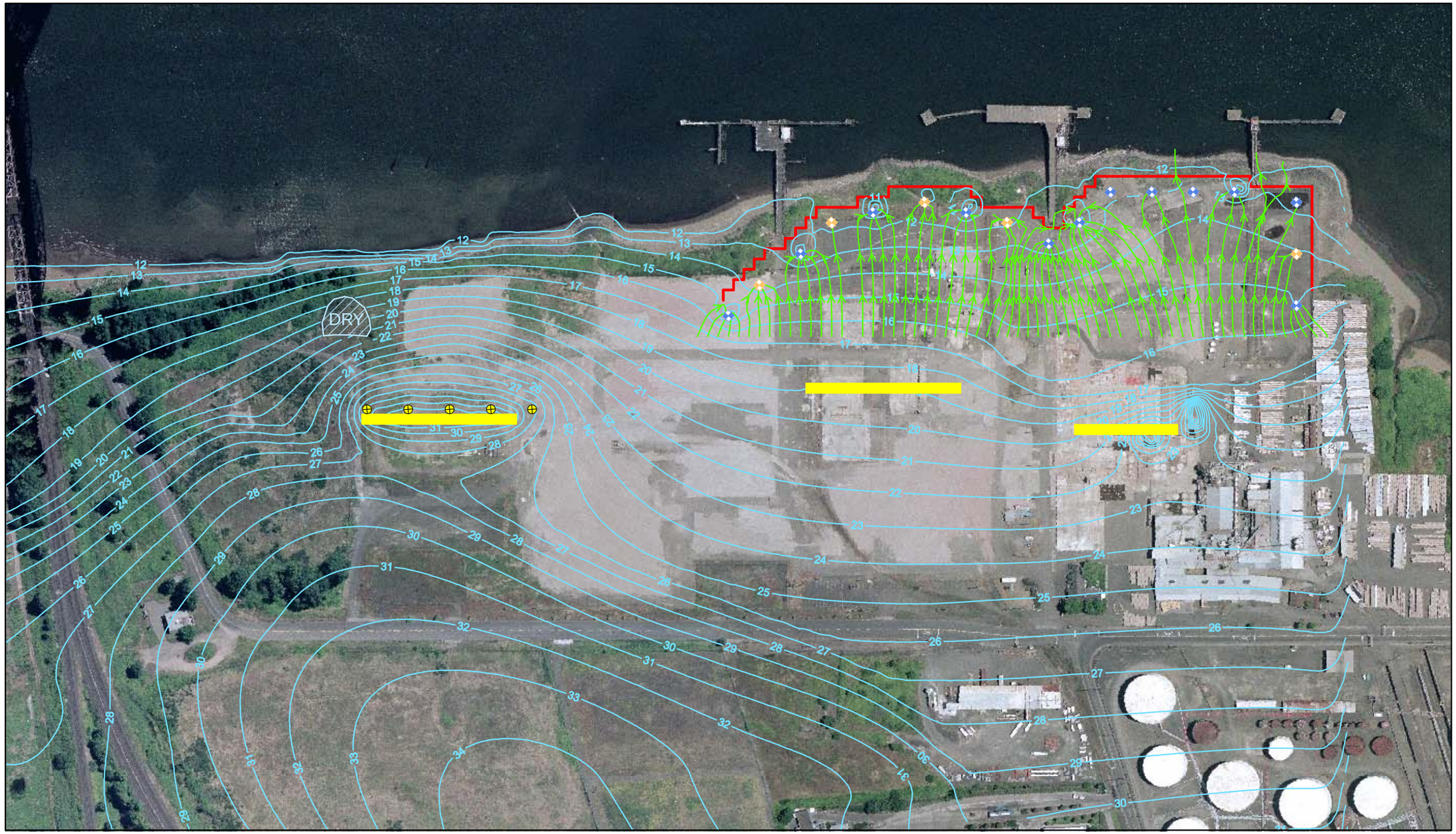
ERM *02/08*

Project No. 0065572

Date: 02/06/08

Drawn By: T. Cota

GIS File:



Aerial Photography - July, 2005

LEGEND

- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Shallow Zone Reinfiltration Trench
- Intermediate Zone Reinjection Well
- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Groundwater Barrier Wall

True North

Plant North

0 250 500

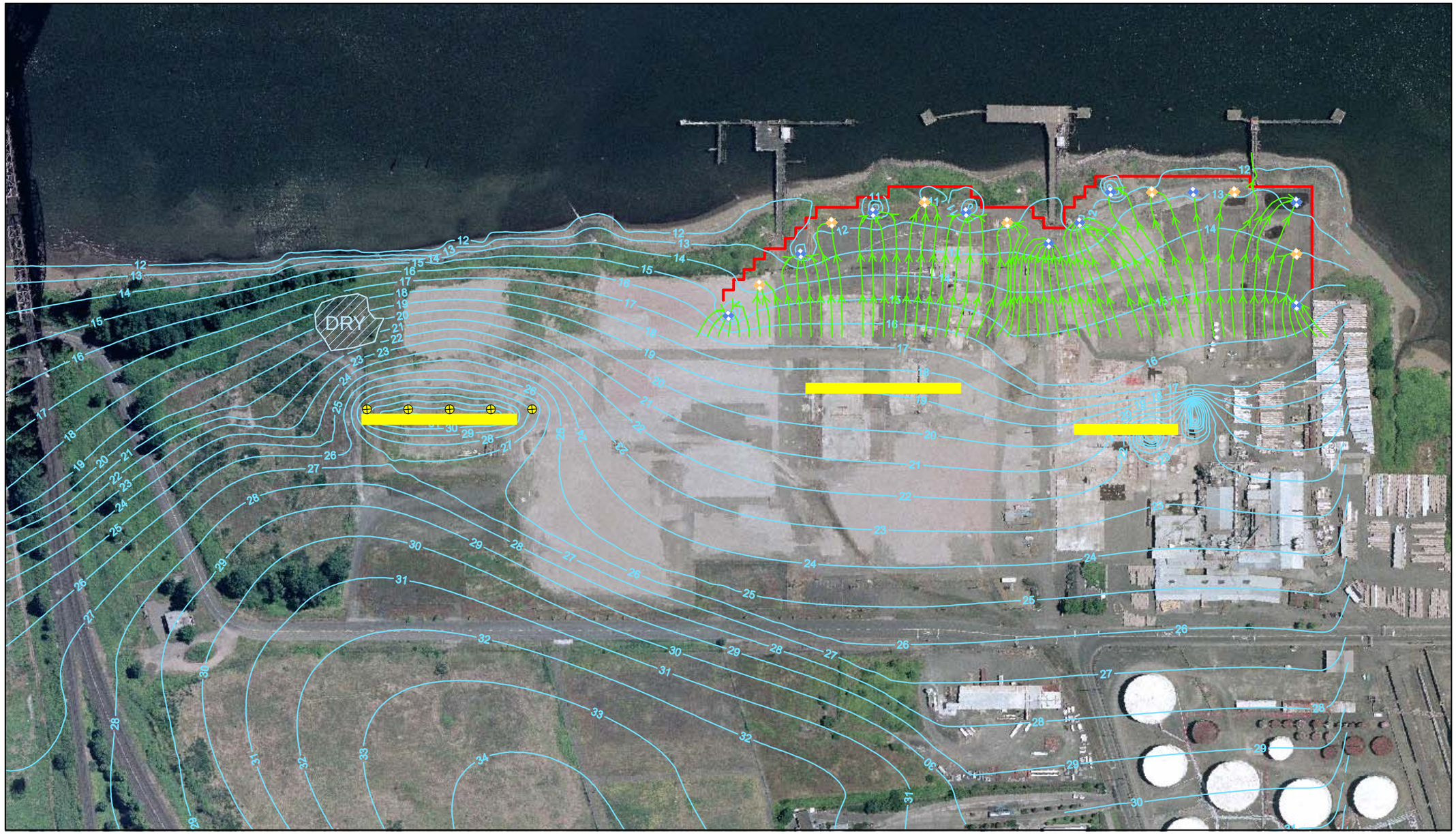
Feet

Figure A.3-23

River Side High Bank Groundwater Barrier Wall Installed to Top of Basalt (Layer 5)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Reinjection in Lots 2, 3, and 4
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Shallow Zone Reinfiltration Trench
- Intermediate Zone Reinjection Well
- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Groundwater Barrier Wall

True North

Plant North

0 250 500

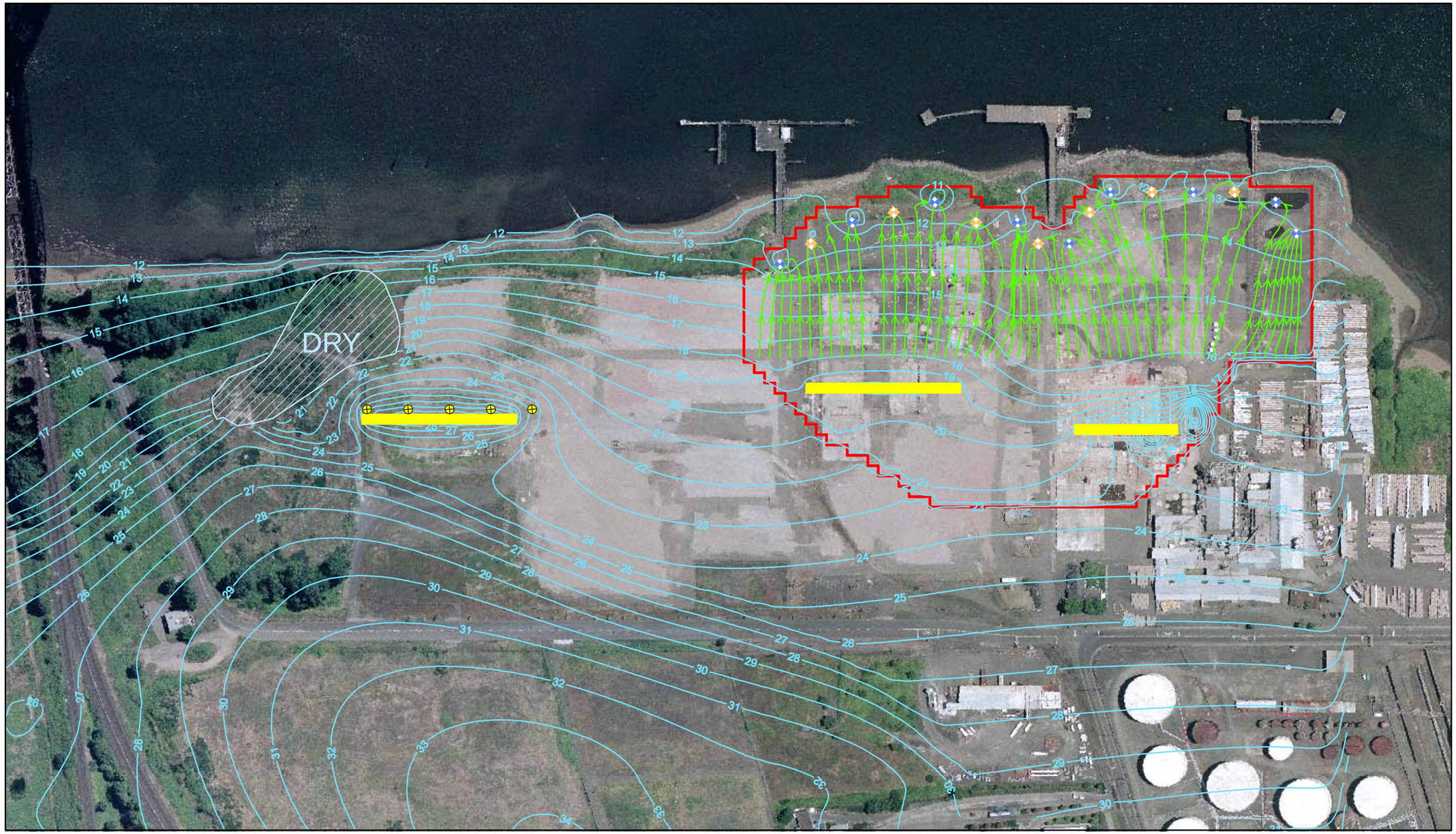
Feet

Figure A.3-24

River Side High Bank Groundwater Barrier Wall Installed into Deep Zone (Layer 4)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Reinjection in Lots 2, 3, and 4
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Intermediate Zone Reinjection Well
- Shallow Zone Reinfiltration Trench
- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Groundwater Barrier Wall

True North

Plant North

0 250 500

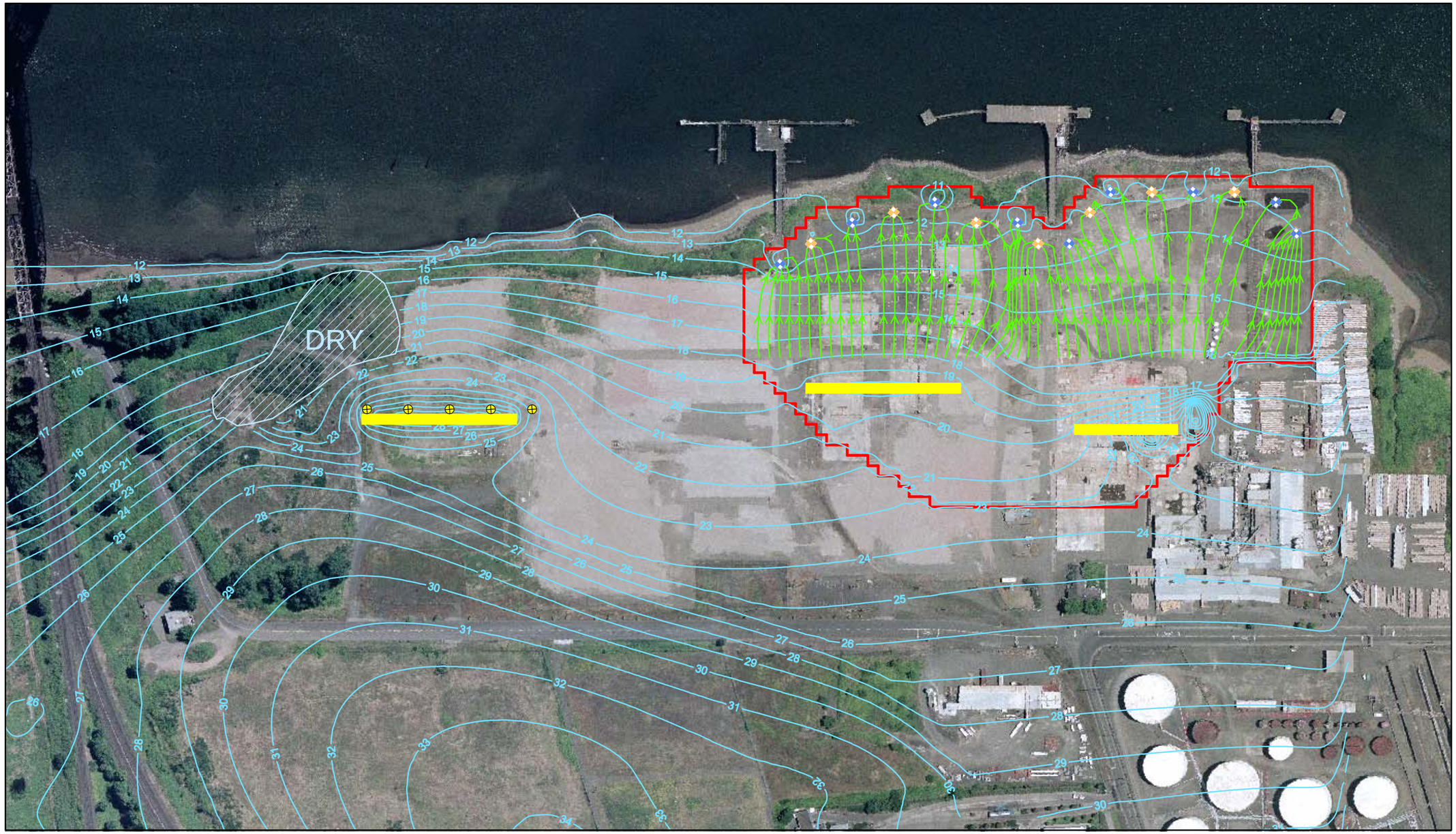
Feet

Figure A.3-25

Full Enclosure Groundwater Barrier Wall Installed to Top of Basalt (Layer 5)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Reinjection in Lots 2, 3, and 4
Arkema, Inc.
Portland, Oregon

ERM 02/08

GIS File:	Drawn By: T. Cota	Date: 02/06/08	Project No. 0065572



Aerial Photography - July, 2005

LEGEND

- Shallow Zone Withdrawal Well
- Intermediate Zone Withdrawal Well
- Shallow Zone Reinfiltration Trench
- Intermediate Zone Reinjection Well
- Groundwater Flow Path
- Shallow Zone Head Solution (ft NAVD88)
- Groundwater Barrier Wall

True North

Plant North

0 250 500

Feet

Figure A.3-26

Full Enclosure Groundwater Barrier Wall Installed into Deep Zone (Layer 4)
Withdrawal Wells in Shallow and Intermediate Zones (Layers 1 and 3)
Reinjection in Lots 2, 3, and 4
Arkema, Inc.
Portland, Oregon

ERM 02/08

Tables

Table A.3-1
Results of Groundwater Barrier Wall Alternatives Simulations
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

Downgradient Barrier Wall Installed to Top of Basalt

Simulation	Wells Layer	Wells No.	Total Flow Rate (gpm)	Flow Rate Range (gpm)
1. Shallow Zone Wells	1	17	133	2 - 20
2. Intermediate Zone Wells	3	20	124	5 - 10
3. Shallow and Intermediate Zone Wells	1	12	97	4 - 15
	3	8	40	5

Downgradient Barrier Wall Installed into Deep Zone

Simulation	Wells Layer	Wells No.	Total Flow Rate (gpm)	Flow Rate Range (gpm)
1. Shallow Zone Wells	1	17	135	3 - 20
2. Intermediate Zone Wells	3	20	124	5 - 10
3. Shallow and Intermediate Zone Wells	1	10	87	2 - 15
	3	8	41	5

Fully Enclosed Barrier Wall Installed to Top of Basalt

Simulation	Wells Layer	Wells No.	Total Flow Rate (gpm)	Flow Rate Range (gpm)
1. Shallow Zone Wells	1	16	112	5 - 15
2. Intermediate Zone Wells	3	16	92	5 - 7
3. Shallow and Intermediate Zone Wells	1	9	45	3 - 8
	3	9	54	5 - 8

Fully Enclosed Barrier Wall Installed into Deep Zone

Simulation	Wells Layer	Wells No.	Total Flow Rate (gpm)	Flow Rate Range (gpm)
1. Shallow Zone Wells	1	16	112	5 -15
2. Intermediate Zone Wells	3	16	92	5 - 7
3. Shallow and Intermediate Zone Wells	1	9	45	3 - 8
	3	9	54	5 - 8

Table A.3-2
Results of Treated Water Reinjection Alternatives Simulations
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

Downgradient Barrier Wall Installed to Top of Basalt

	Injection Rate			
	Shallow Zone Trench		Intermediate Zone Wells	
Simulation	Lot 2 (gpm)	Lots 3 and 4 (gpm)	Lot 2 (gpm)	Total (gpm)
1. Reinjection in Lot 2	34	--	103	137
2. Reinjection in Lots 2, 3, and 4	27	103	7	137

Downgradient Barrier Wall Installed into Deep Zone

	Injection Rate			
	Shallow Zone Trench		Intermediate Zone Wells	
Simulation	Lot 2 (gpm)	Lots 3 and 4 (gpm)	Lot 2 (gpm)	Total (gpm)
1. Reinjection in Lot 2	32	--	96	128
2. Reinjection in Lots 2, 3, and 4	26	96	6	128

Fully Enclosed Barrier Wall Installed to Top of Basalt

	Injection Rate			
	Shallow Zone Trench		Intermediate Zone Wells	
Simulation	Lot 2 (gpm)	Lots 3 and 4 (gpm)	Lot 2 (gpm)	Total (gpm)
1. Reinjection in Lot 2	25	--	74	99
2. Reinjection in Lots 2, 3, and 4	30	49	20	99

Fully Enclosed Barrier Wall Installed into Deep Zone

	Injection Rate			
	Shallow Zone Trench		Intermediate Zone Wells	
Simulation	Lot 2 (gpm)	Lots 3 and 4 (gpm)	Lot 2 (gpm)	Total (gpm)
1. Reinjection in Lot 2	25	--	74	99
2. Reinjection in Lots 2, 3, and 4	30	49	20	99

Appendix A

Three-dimensional visualizations of the results of the riverside GWBW simulations and interactive viewer for the visualizations on CD

Appendix B
Geotechnical Evaluation Report

APPENDIX B – GROUNDWATER BARRIER WALL GEOTECHNICAL ENGINEERING ANALYSIS

Introduction

The groundwater barrier wall (GWBW) conceptual design was subjected to a geotechnical engineering analysis to identify the minimum practical offset of the GWBW from the existing top of bank (TOB) of the Willamette River high stage bank and to confirm adequate bank stability during and following completion of construction of the GWBW. Criteria used for an acceptable offset included: (1) adequate short-term stability during clearance trench excavation and backfill; (2) adequate short-term stability during GWBW construction; and (3) adequate long-term bank stability, including rapid drawdown conditions in the river.

Investigations

The GWBW geotechnical engineering analysis was based on data obtained during prior site investigations and data obtained during preparation of the Groundwater Source Control IRM FFS. Prior data used included monitoring well and soil boring logs and groundwater level data. Data obtained during preparation of the FFS included four cone penetrometer test (CPT) logs, and logs for two soil borings completed along the part of the candidate GWBW route adjacent to the river bank TOB.

The CPT data provided information about the soil type, stratigraphy, and in-situ strength characteristics at the locations tested. The soil borings provided Standard Penetration Test data and both disturbed and, in fine soils, undisturbed soil samples for field characterization and subsequent laboratory testing. Confirmatory soil sampling and testing should be conducted on similar samples during the final design investigation.

The geotechnical engineering analysis for this site is based upon previously obtained data, research, and existing knowledge of similar soils and site scenarios. The subsurface exploration program was comprised of two deep borings, enumerated B-120 and B-121, with advance depths of 50.5 and 87 feet below ground surface (BGS), respectively. The testing performed on the samples of site soils consisted of particle-size distribution, Atterberg limits, soil classification, and moisture content. Boring logs and laboratory results are available in Appendix C of the FFS.

Based upon the soil borings, cone penetrometer testing, and other subsurface data derived previously, a nominal cross section of the subsurface conditions anticipated along the alignment was generated. This cross-section consisted of three broad zones of material, including the following:

1. An upper layer of sandy material, consisting of fill materials to an approximate depth of 25 feet BGS and native soils beneath to a depth of approximately 40 feet BGS (designated Soil Zone 1, comparable to the zone designated as the Shallow Zone in the FFS);

2. An intermediate zone of sandy silt materials extending from a depth of 40 feet BGS to a depth of 80 feet BGS (designated Soil Zone 2, comparable to the zone designated as the Intermediate Zone in the FFS); and,

3. A lower zone of silty material below a depth of 80 feet BGS until the top of the basaltic bedrock is encountered (designated Soil Zone 3, comparable to the zone designated as the Deep Zone in the FFS).

Each of these zones of subsurface materials was assigned index properties with respect to density, moisture content, and strength based on the geotechnical data generated and experience with similar materials. Since the strength properties of the materials are critical to the overall performance, a range of properties were selected to define the spectrum of anticipated performance. Site-specific data should be collected and analyzed for each of the materials to verify the performance anticipated before installation of any of the barrier walls. The index properties incorporated in the analyses are presented in the table below.

Depth (feet)	**Soil Zone No.**	**Expected Soil Type**	**Wet Unit Weight (lbs/cubic ft.)**	**Saturated Unit Weight (lbs/cubic ft.)**	**Cohesion**	**Φ (degrees)**
0 to 40	1	Sand	114.7	118.5	180	29
40 to 80	2	Sandy Silt	118.5	118.5	416	22
80 +	3	Silt	123.1	123.1	478.4	28

Analyses

Three scenarios were selected for wall installation:

1. A clearance trench excavated through the fill materials and, where present, natural materials, to a depth of approximately 25 feet BGS;

2. A GWBW that extends to the base of a key excavated approximately 10 vertical feet (VF) into Soil Zone 3, to a depth of approximately 60 feet BGS, which would reduce the potential for water to migrate into the site from the river and be captured by the proposed groundwater extraction system, or from the site to the river (i.e., as loss of control of migration of potentially affected groundwater); and,

3. A GWBW that extends to the top of the underlying basaltic bedrock, a depth of approximately 90 feet BGS.

For each scenario, the minimum distance between the GWBW and the river bank T.O.B. that produced adequate stability was analyzed, including for both short-term and rapid-drawdown conditions. ERM used the slope stability program STABL2.2, which considers both rotational and sliding block failures, to configure and perform multiple stability analyses for each scenario based on soil parameters and the corresponding geometry. The results of the various scenarios, which are presented graphically (attached), create an envelope of adequate soil stability. Multiple analyses were conducted to identify the minimum factor of safety acceptable while allowing the closest approach of the GWBW to the river bank T.O.B. The minimum factor of safety deemed acceptable was 1.5, an established industry standard. The index properties that were used in wall analyses and yielded the minimum factor of safety were chosen to define the spectrum of anticipated performance.

The soil properties and expected soil types have been assumed given the information and testing results available for the site soils. Also, slurry mixture properties have been assumed for any GWBW alternative using slurry. The typical slurry mixture was assumed to have a unit weight of 65 to 75 pounds per cubic foot (pcf), and a specific gravity of 1.03.

Upon determining the actual construction technique and depth of construction for the GWBW, other recommendations may be necessary to address conditions critical to the long-term stability of the GWBW and related improvements.

Results

The geotechnical engineering analysis results may be summarized as follows:

- A clearance trench to find and, if necessary, remove oversize objects that would otherwise be obstructions to construction of the GWBW in the former fill zone excavated to a depth of 25 feet BGS can be constructed using two (2) horizontal to 1 vertical (2H:1V) side slopes and located at a distance of closest approach of approximately 10 feet from the land side of the existing river high stage T.O.B. Therefore, the GWBW, constructed at the deep center of the clearance trench, would be approximately 60 feet on the land side of the river bank T.O.B. If a closer approach were required, excavation utilizing trench boxes, or temporary shoring or sheet piling would be required.

- A GWBW constructed using conventional slurry trench techniques from the ground surface to a depth that would be a maximum of 60 feet BGS can be located approximately 8 feet on the land side of the river bank T.O.B., while a similar wall constructed to a maximum depth of 90 feet BGS can be located approximately 10 feet on the land side of the river bank T.O.B. Those GWBW route recommendations assume that obstructions in the surficial fill deposits can be removed or circumvented with the trench excavation.

- The use of vibrated beam technology would permit the installation equipment to be placed landward of the GWBW in lieu of along the alignment. It would, however, also introduce a dynamic load into the subsurface that may create localized wave propagation that could result in localized liquefaction of fine-grained sand in lenses. This propagation would result in densification of these sands and some potential surface subsidence, but would not have any impact at great distances from the alignment that would adversely affect neighboring structures. Additional soil properties and liquefaction analyses can be conducted to address these concerns if warranted. Regardless, the offset of the GWBW route from the river bank T.O.B. could be constructed with the setback adopted for the conventional slurry wall construction noted above.

- Driven sheet piling is a displacement technique that will not create stability concerns except for river bank stability. By adopting the same setbacks as previously stated for conventional slurry wall construction, stability will be achieved. As with the vibrated beam technology, loading will be reduced by utilizing equipment which is landward of the alignment rather than across. The dynamic nature of the sheet pile

driving can induce localized densification of fine-grained sand lenses, creating some surface subsidence, but not extending to great distances outside of the construction zone.

This geotechnical engineering analysis is supported by the data obtained during preparation of the FFS, as well as research and knowledge of existing site conditions. The STABL2.2 program results and experience with similar soils and site scenarios are the foundation of recommendations made for acceptable GWBW offset distances and conclusions for the alternative techniques.

THIS PAGE INTENTIONALLY LEFT BLANK

Attachment 1
Existing River Bank (No GWBW) With Static Loads, Rapid Drawdown Condition (Baseline Condition)

** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION ARKEMA RD

BOUNDARY COORDINATES

5 Top Boundaries
7 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	75.00	10.00	75.00	3
2	10.00	75.00	14.00	79.00	1
3	14.00	79.00	19.00	84.00	1
4	19.00	84.00	25.00	90.00	1
5	25.00	90.00	100.00	90.00	1
6	0.00	50.00	100.00	50.00	2
7	0.00	10.00	100.00	10.00	3

1

ISOTROPIC SOIL PARAMETERS

3 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	114.7	118.5	175.0	29.0	0.00	0.0	1
2	118.5	118.5	416.0	22.0	0.00	0.0	1
3	123.1	123.1	478.4	28.0	0.00	0.0	1

1

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	75.00
2	10.00	75.00
3	15.00	80.00
4	100.00	80.00

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

250 Trial Surfaces Have Been Generated.

50 Surfaces Initiate From Each Of 5 Points Equally Spaced Along The Ground Surface Between X = 4.00 ft.
and X = 10.00 ft.

Each Surface Terminates Between X = 32.00 ft.
and X = 44.00 ft.

4.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -25.0 And 0.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)

1	10.00	75.00
2	14.00	74.94
3	17.95	75.58
4	21.72	76.91
5	25.20	78.88
6	28.28	81.43
7	30.87	84.48
8	32.87	87.95
9	33.62	90.00

Circle Center At X = 12.3 ; Y = 97.5 and Radius, 22.7

*** 1.508 ***

Individual data on the 12 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.0	954.7	0.0	380.1	0.0	0.0	0.0	0.0	0.0
2	1.0	526.6	0.0	212.4	0.0	0.0	0.0	0.0	0.0
3	2.9	2125.8	0.0	868.2	0.0	0.0	0.0	0.0	0.0
4	1.1	946.9	0.0	294.6	0.0	0.0	0.0	0.0	0.0
5	2.7	2824.6	0.0	642.6	0.0	0.0	0.0	0.0	0.0
6	3.3	3984.6	0.0	508.6	0.0	0.0	0.0	0.0	0.0
7	0.2	260.7	0.0	17.1	0.0	0.0	0.0	0.0	0.0
8	1.4	1642.0	0.0	61.5	0.0	0.0	0.0	0.0	0.0
9	1.7	1839.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	2.6	2086.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	2.0	871.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.7	88.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.59
3	16.46	74.95
4	20.30	76.07
5	23.86	77.90
6	27.00	80.38
7	29.60	83.42
8	31.58	86.90
9	32.61	90.00

Circle Center At X = 12.6 ; Y = 95.4 and Radius, 20.8

*** 1.577 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.58
3	16.46	74.92
4	20.31	76.02
5	23.88	77.83
6	27.04	80.28
7	29.67	83.29
8	31.68	86.75
9	32.82	90.00

Circle Center At X = 12.7 ; Y = 95.5 and Radius, 20.9

*** 1.582 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.50	74.95
3	16.45	75.55
4	20.26	76.79
5	23.81	78.62
6	27.02	81.01
7	29.80	83.88
8	32.08	87.17
9	33.42	90.00

Circle Center At X = 10.8 ; Y = 99.5 and Radius, 24.6

*** 1.587 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.43	74.24
3	16.43	74.35
4	20.31	75.32
5	23.89	77.10
6	27.00	79.61
7	29.50	82.74
8	31.26	86.33

9	32.15	90.00

Circle Center At X = 13.9 ; Y = 92.6 and Radius, 18.4

*** 1.599 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.45	74.39
3	16.45	74.58
4	20.33	75.55
5	23.94	77.27
6	27.14	79.67
7	29.81	82.65
8	31.84	86.10
9	33.14	89.88
10	33.16	90.00

Circle Center At X = 13.5 ; Y = 94.5 and Radius, 20.2

*** 1.602 ***

1

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.91
3	17.97	75.41
4	21.81	76.51
5	25.45	78.17
6	28.80	80.35
7	31.79	83.01
8	34.34	86.09
9	36.41	89.52
10	36.61	90.00

Circle Center At X = 12.6 ; Y = 101.4 and Radius, 26.6

*** 1.603 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.46	74.43
3	16.45	74.61
4	20.34	75.55
5	23.99	77.20
6	27.25	79.51
7	30.02	82.40
8	32.19	85.76
9	33.68	89.47
10	33.79	90.00

Circle Center At X = 13.5 ; Y = 95.4 and Radius, 21.0

*** 1.613 ***

1

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.39	74.06
3	16.39	74.00
4	20.30	74.85
5	23.92	76.54
6	27.07	79.00
7	29.60	82.10
8	31.37	85.69
9	32.29	89.58
10	32.29	90.00

Circle Center At X = 14.6 ; Y = 91.7 and Radius, 17.7

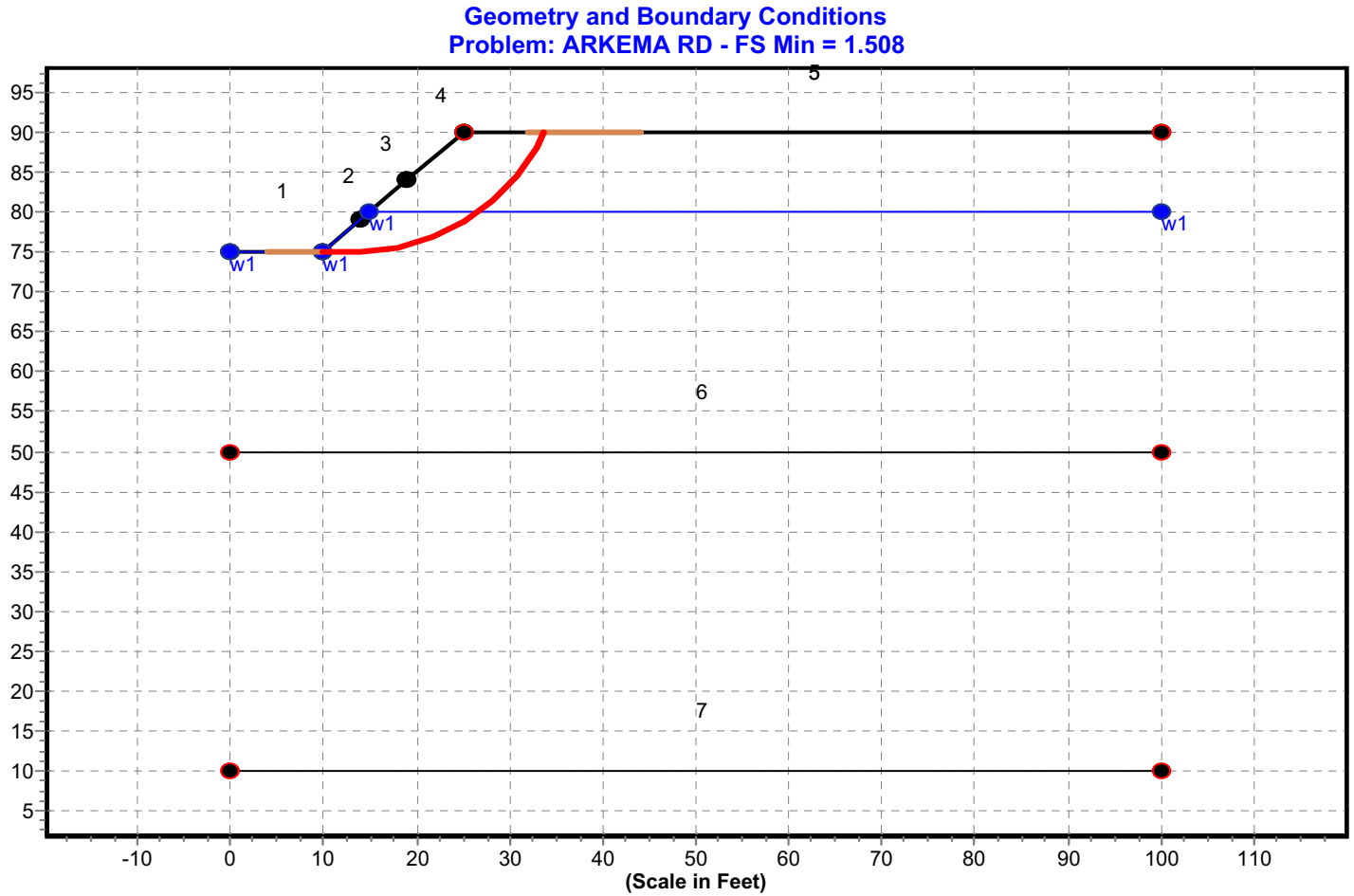
*** 1.626 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	13.90	74.09
3	17.90	74.09
4	21.79	75.00
5	25.38	76.77
6	28.47	79.31
7	30.90	82.49
8	32.55	86.13

```
    9         33.31       90.00

Circle Center At X =   15.9 ; Y =   91.5  and Radius,   17.5


      ***     1.628   ***



1

                Y            A     X     I     S            F     T


                0.00     19.80     39.60     59.40     79.20     99.00

X        0.00 +----*----+---------+----*----+-------*-+---------+
              -                                       .
              -                                      ..
              -                                    ..*
              -                                    .51 *
              -                                    .91.W
        19.80 +                                    ..24  *
              -                                    ..014.
              -                                     ..712.  *
              -                                     ...01215
              -                                      ....7611
              -                                       ......7
A       39.60 +                                        ......
              -                                          ....
              -
              -
              -
              -
X       59.40 +
              -
              -
              -
              -
              -
I       79.20 +
              -
              -
              -
              -
              -
S        99.00 +    *                    *              W    *
              -
              -
              -
              -
              -
       118.80 +
              -
              -
              -
              -
              -
F      138.60 +
              -
              -
              -
              -
```

```
                 -
T    158.40 +
```


Geometry and Boundary Conditions
Problem: ARKEMA RD - FS Min = 1.508
1
2
3
4
5
6
7
w1
w1
w1
w1
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
-10
0
10
20
30
40
50
60
70
80
90
100
110
(Scale in Feet)

Attachment 2
Deep GWBW with Static and Construction Loads, Short Term Condition

** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION ARKEMA

BOUNDARY COORDINATES

5 Top Boundaries
7 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	75.00	10.00	75.00	3
2	10.00	75.00	14.00	79.00	1
3	14.00	79.00	19.00	84.00	1
4	19.00	84.00	25.00	90.00	1
5	25.00	90.00	100.00	90.00	1
6	0.00	50.00	100.00	50.00	2
7	0.00	10.00	100.00	10.00	3

1

ISOTROPIC SOIL PARAMETERS

3 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	114.7	118.5	160.0	28.0	0.00	0.0	1
2	118.5	118.5	416.0	22.0	0.00	0.0	1
3	123.1	123.1	478.4	28.0	0.00	0.0	1

1

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 2 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	80.00
2	100.00	80.00

1

BOUNDARY LOAD(S)

1 Load(s) Specified

Load No.	X-Left (ft)	X-Right (ft)	Intensity (psf)	Deflection (deg)
1	47.00	62.00	234900.0	0.0

NOTE - Intensity Is Specified As A Uniformly Distributed
Force Acting On A Horizontally Projected Surface.

1

A Critical Failure Surface Searching Method, Using A Random
Technique For Generating Circular Surfaces, Has Been Specified.

250 Trial Surfaces Have Been Generated.

50 Surfaces Initiate From Each Of 5 Points Equally Spaced
Along The Ground Surface Between X = 4.00 ft.
and X = 10.00 ft.

Each Surface Terminates Between X = 28.00 ft.
and X = 46.00 ft.

4.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation.
The Angle Has Been Restricted Between The Angles Of -25.0
And 0.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial
Failure Surfaces Examined. They Are Ordered - Most Critical

First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 8 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.94
3	17.92	75.75
4	21.56	77.41
5	24.75	79.82
6	27.34	82.87
7	29.19	86.41
8	30.15	90.00

Circle Center At X = 12.3 ; Y = 93.0 and Radius, 18.1

*** 1.508 ***

Individual data on the 10 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.0	962.4	1058.7	1255.6	0.0	0.0	0.0	0.0	0.0
2	3.9	2589.6	0.0	1161.5	0.0	0.0	0.0	0.0	0.0
3	1.1	943.7	0.0	297.1	0.0	0.0	0.0	0.0	0.0
4	2.6	2510.9	0.0	556.2	0.0	0.0	0.0	0.0	0.0
5	3.2	3509.6	0.0	346.1	0.0	0.0	0.0	0.0	0.0
6	0.2	174.6	0.0	1.3	0.0	0.0	0.0	0.0	0.0
7	0.1	109.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	2.3	2280.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	1.9	1140.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	1.0	197.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.79
3	17.95	75.40
4	21.70	76.80
5	25.09	78.92
6	27.97	81.69
7	30.24	84.99
8	31.79	88.68
9	32.05	90.00

Circle Center At X = 13.0 ; Y = 94.4 and Radius, 19.6

*** 1.542 ***

1

Failure Surface Specified By 8 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	13.98	74.62
3	17.93	75.24
4	21.61	76.82
5	24.78	79.26
6	27.24	82.41
7	28.84	86.07
8	29.49	90.00

Circle Center At X = 13.5 ; Y = 90.6 and Radius, 16.0

*** 1.547 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.91
3	17.96	75.49
4	21.76	76.72
5	25.31	78.58
6	28.49	81.00
7	31.22	83.92
8	33.42	87.26
9	34.63	90.00

Circle Center At X = 12.5 ; Y = 98.6 and Radius, 23.8

*** 1.587 ***

1

Failure Surface Specified By 9 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |

1	8.50	75.00
2	12.50	74.95
3	16.43	75.71
4	20.12	77.25
5	23.42	79.51
6	26.20	82.39
7	28.34	85.77
8	29.75	89.51
9	29.83	90.00

Circle Center At X = 10.7 ; Y = 94.5 and Radius, 19.7

*** 1.626 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.58
3	16.44	75.10
4	20.17	76.54
5	23.46	78.82
6	26.12	81.81
7	28.01	85.34
8	29.01	89.21
9	29.03	90.00

Circle Center At X = 12.3 ; Y = 91.5 and Radius, 16.9

*** 1.647 ***

1

Failure Surface Specified By 9 Coordinate Points

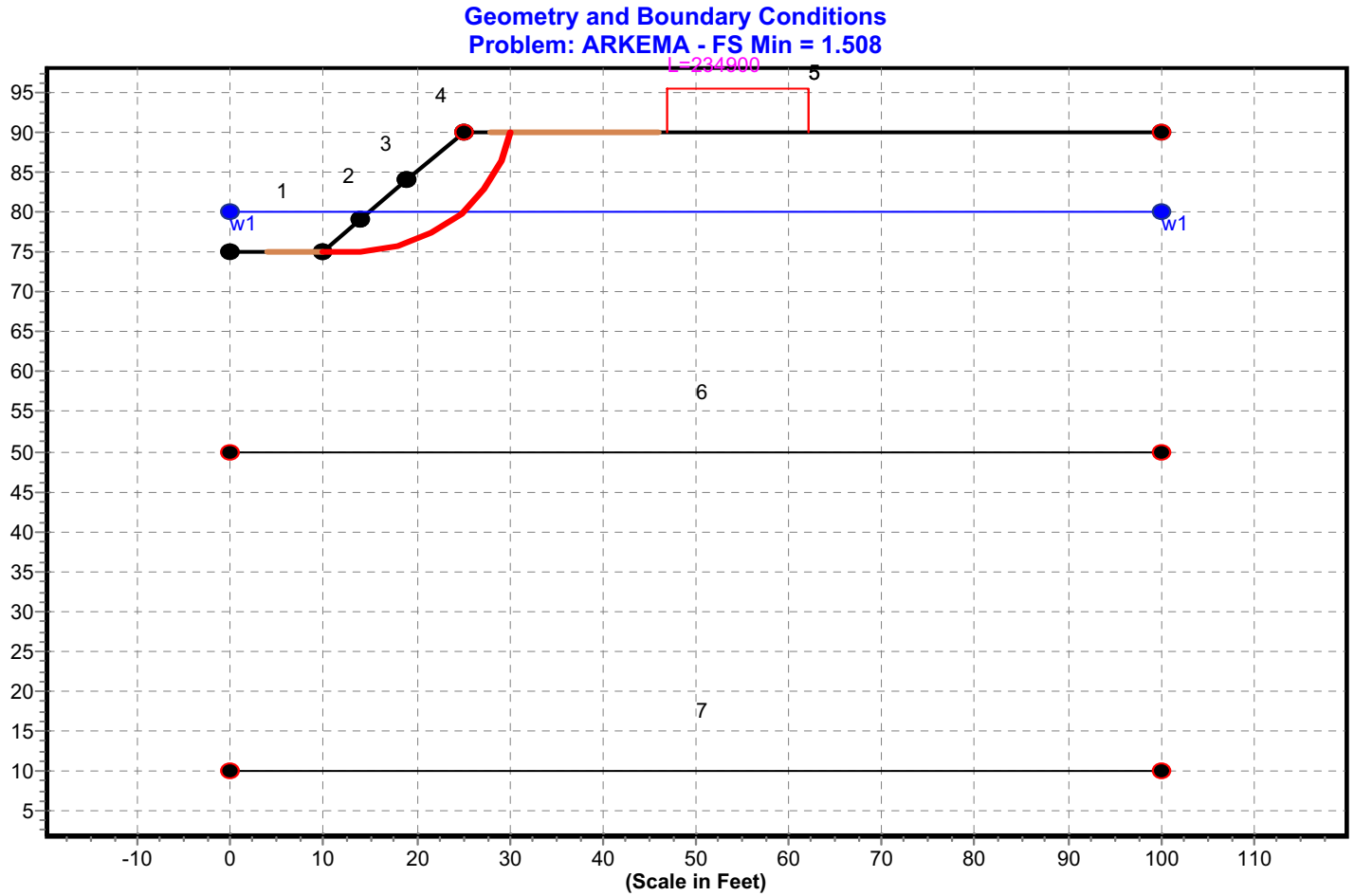
Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.46	74.43
3	16.44	74.76
4	20.25	76.00
5	23.67	78.07
6	26.54	80.86
7	28.69	84.23
8	30.03	88.00
9	30.25	90.00

Circle Center At X = 13.0 ; Y = 91.9 and Radius, 17.5

```
      ***     1.652   ***



Failure Surface Specified By  9 Coordinate Points

  Point      X-Surf      Y-Surf
   No.        (ft)        (ft)

    1          8.50       75.00
    2         12.45       74.39
    3         16.44       74.76
    4         20.22       76.06
    5         23.58       78.23
    6         26.32       81.15
    7         28.28       84.64
    8         29.34       88.49
    9         29.39       90.00

Circle Center At X =   13.0 ; Y =   90.9  and Radius,   16.6


      ***     1.656   ***



1

Failure Surface Specified By  9 Coordinate Points

  Point      X-Surf      Y-Surf
   No.        (ft)        (ft)

    1          8.50       75.00
    2         12.45       74.40
    3         16.45       74.67
    4         20.28       75.80
    5         23.78       77.74
    6         26.78       80.39
    7         29.12       83.63
    8         30.71       87.30
    9         31.23       90.00

Circle Center At X =   13.2 ; Y =   92.7  and Radius,   18.3


      ***     1.660   ***



Failure Surface Specified By  9 Coordinate Points

  Point      X-Surf      Y-Surf
   No.        (ft)        (ft)

    1          8.50       75.00
    2         12.47       74.51
    3         16.46       74.81
```

```
    4         20.31       75.89
    5         23.87       77.71
    6         27.00       80.19
    7         29.59       83.25
    8         31.51       86.75
    9         32.53       90.00

Circle Center At X =   13.0 ; Y =   94.7  and Radius,   20.2


      ***     1.661   ***



1

                Y            A     X     I     S            F     T


                0.00     21.06     42.13     63.19     84.26    105.32

X        0.00 +----*----+---------+---*-----+-----*-W-+---------+
              -                                     .
              -                                    .5
              -                                   ..*
              -                                  .31 *
              -                                  .71   *
        21.06 +                                  ..21.
              -                                  ...215   *
              -                                  ....417153
              -                                   .....2921
              -                                    .....4.4
              -                                     .......
A       42.13 +                                       .....
              -                                        .../1
              -
              -
              -
              -
X       63.19 +                                            1/
              -
              -
              -
              -
              -
I       84.26 +
              -
              -
              -
              -    *                   *             W    *
              -
S      105.32 +
              -
              -
              -
              -
              -
      126.38 +
              -
              -
              -
              -
              -
```

```
F    147.45 +
            -
            -
            -
            -
            -
T    168.51 +
```


Geometry and Boundary Conditions
Problem: ARKEMA - FS Min = 1.508
L=234900
5
4
3
2
1
w1
w1
6
7
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
-10
0
10
20
30
40
50
60
70
80
90
100
110
(Scale in Feet)

Attachment 3
Deep GWBW with Static and Construction Loads, Rapid Drawdown Condition

** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION ARKEMA

BOUNDARY COORDINATES

5 Top Boundaries
7 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	75.00	10.00	75.00	3
2	10.00	75.00	14.00	79.00	1
3	14.00	79.00	19.00	84.00	1
4	19.00	84.00	25.00	90.00	1
5	25.00	90.00	100.00	90.00	1
6	0.00	50.00	100.00	50.00	2
7	0.00	10.00	100.00	10.00	3

1

ISOTROPIC SOIL PARAMETERS

3 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	114.7	118.5	180.0	29.0	0.00	0.0	1
2	118.5	118.5	416.0	22.0	0.00	0.0	1
3	123.1	123.1	478.4	28.0	0.00	0.0	1

1

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	75.00
2	10.00	75.00
3	15.00	80.00
4	100.00	80.00

1

BOUNDARY LOAD(S)

1 Load(s) Specified

Load No.	X-Left (ft)	X-Right (ft)	Intensity (psf)	Deflection (deg)
1	47.00	62.00	234900.0	0.0

NOTE - Intensity Is Specified As A Uniformly Distributed
Force Acting On A Horizontally Projected Surface.

1

A Critical Failure Surface Searching Method, Using A Random
Technique For Generating Circular Surfaces, Has Been Specified.

250 Trial Surfaces Have Been Generated.

50 Surfaces Initiate From Each Of 5 Points Equally Spaced
Along The Ground Surface Between X = 4.00 ft.
and X = 10.00 ft.

Each Surface Terminates Between X = 28.00 ft.
and X = 46.00 ft.

4.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation.
The Angle Has Been Restricted Between The Angles Of -25.0
And 0.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 8 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.94
3	17.92	75.75
4	21.56	77.41
5	24.75	79.82
6	27.34	82.87
7	29.19	86.41
8	30.15	90.00

Circle Center At X = 12.3 ; Y = 93.0 and Radius, 18.1

*** 1.456 ***

Individual data on the 11 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.0	954.7	0.0	380.1	0.0	0.0	0.0	0.0	0.0
2	1.0	523.9	0.0	213.1	0.0	0.0	0.0	0.0	0.0
3	2.9	2059.6	0.0	845.5	0.0	0.0	0.0	0.0	0.0
4	1.1	943.7	0.0	297.1	0.0	0.0	0.0	0.0	0.0
5	2.6	2510.9	0.0	556.2	0.0	0.0	0.0	0.0	0.0
6	3.2	3509.6	0.0	346.1	0.0	0.0	0.0	0.0	0.0
7	0.2	174.6	0.0	1.3	0.0	0.0	0.0	0.0	0.0
8	0.1	109.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	2.3	2280.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	1.9	1140.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	1.0	197.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 8 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	13.98	74.62
3	17.93	75.24
4	21.61	76.82
5	24.78	79.26

6	27.24	82.41
7	28.84	86.07
8	29.49	90.00

Circle Center At X = 13.5 ; Y = 90.6 and Radius, 16.0

*** 1.482 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.79
3	17.95	75.40
4	21.70	76.80
5	25.09	78.92
6	27.97	81.69
7	30.24	84.99
8	31.79	88.68
9	32.05	90.00

Circle Center At X = 13.0 ; Y = 94.4 and Radius, 19.6

*** 1.500 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.58
3	16.44	75.10
4	20.17	76.54
5	23.46	78.82
6	26.12	81.81
7	28.01	85.34
8	29.01	89.21
9	29.03	90.00

Circle Center At X = 12.3 ; Y = 91.5 and Radius, 16.9

*** 1.557 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.91
3	17.96	75.49
4	21.76	76.72
5	25.31	78.58
6	28.49	81.00
7	31.22	83.92
8	33.42	87.26
9	34.63	90.00

Circle Center At X = 12.5 ; Y = 98.6 and Radius, 23.8

*** 1.557 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.50	74.95
3	16.43	75.71
4	20.12	77.25
5	23.42	79.51
6	26.20	82.39
7	28.34	85.77
8	29.75	89.51
9	29.83	90.00

Circle Center At X = 10.7 ; Y = 94.5 and Radius, 19.7

*** 1.557 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.45	74.39
3	16.44	74.76
4	20.22	76.06
5	23.58	78.23
6	26.32	81.15
7	28.28	84.64
8	29.34	88.49
9	29.39	90.00

Circle Center At X = 13.0 ; Y = 90.9 and Radius, 16.6

*** 1.565 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.46	74.43
3	16.44	74.76
4	20.25	76.00
5	23.67	78.07
6	26.54	80.86
7	28.69	84.23
8	30.03	88.00
9	30.25	90.00

Circle Center At X = 13.0 ; Y = 91.9 and Radius, 17.5

*** 1.570 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.45	74.40
3	16.45	74.67
4	20.28	75.80
5	23.78	77.74
6	26.78	80.39
7	29.12	83.63
8	30.71	87.30
9	31.23	90.00

Circle Center At X = 13.2 ; Y = 92.7 and Radius, 18.3

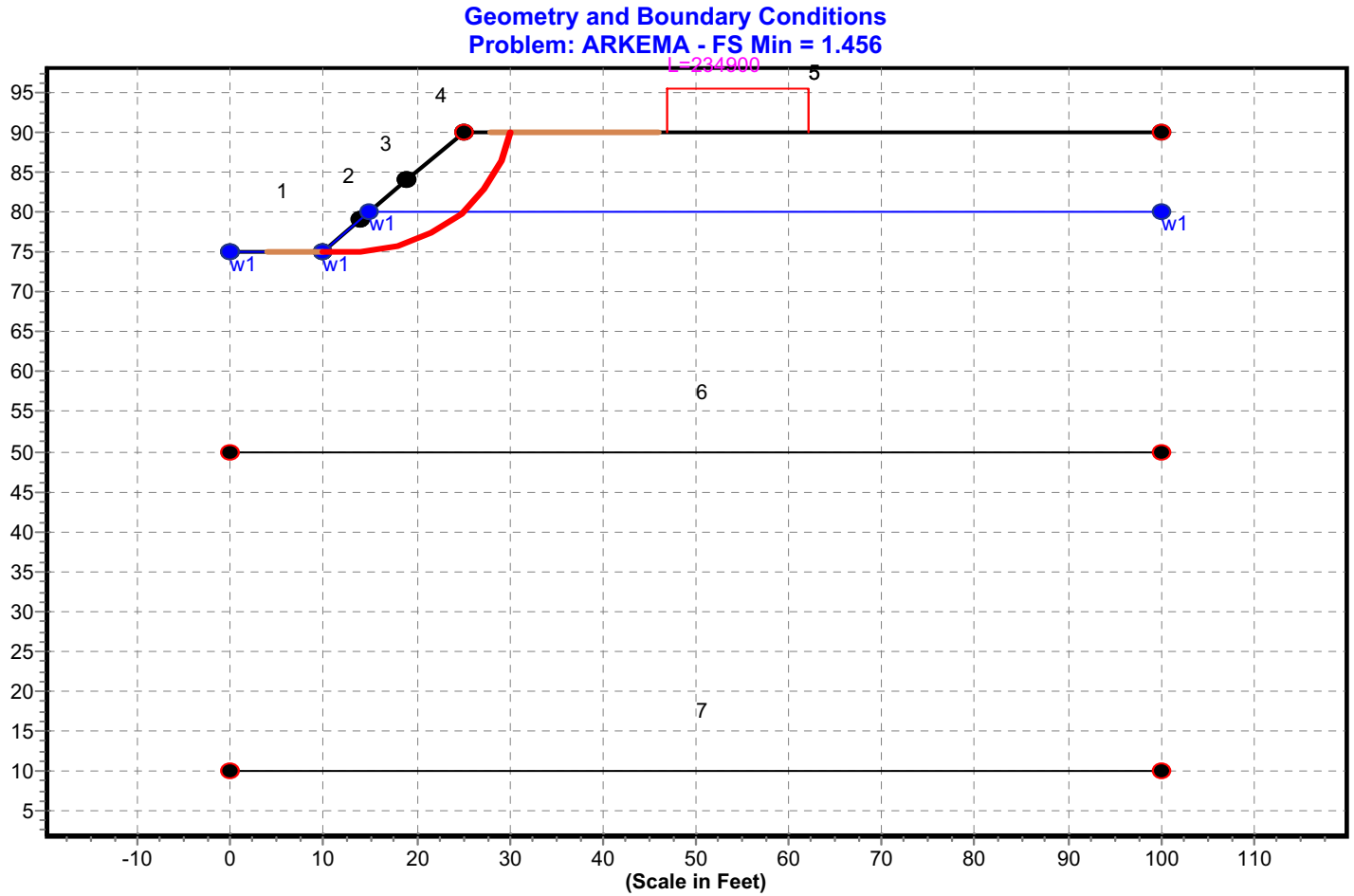
*** 1.585 ***

Failure Surface Specified By 9 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |

```
    1          8.50       75.00
    2         12.47       74.51
    3         16.46       74.81
    4         20.31       75.89
    5         23.87       77.71
    6         27.00       80.19
    7         29.59       83.25
    8         31.51       86.75
    9         32.53       90.00

Circle Center At X =   13.0 ; Y =   94.7  and Radius,   20.2


      ***     1.598   ***



1

                Y            A     X     I     S            F     T


                0.00     21.06     42.13     63.19     84.26    105.32

X        0.00 +----*----+---------+---*-----+-----*---+---------+
              -                                     .
              -                                    .4
              -                                   ..*
              -                                   .21 *
              -                                   .71   *
        21.06 +                                   ..21.
              -                                   ...314   *
              -                                   ....517142
              -                                    .....3931
              -                                     .....5.5
              -                                      .......
A       42.13 +                                        .....
              -                                           .../1
              -
              -
              -
              -
X       63.19 +                                              1/
              -
              -
              -
              -
              -
I       84.26 +
              -
              -
              -
              -    *                   *             W    *
              -
S      105.32 +
              -
              -
              -
              -
              -
       126.38 +
              -
```

```
                -
                -
                -
                -
F     147.45 +
                -
                -
                -
                -
                -
T     168.51 +
```


Geometry and Boundary Conditions
Problem: ARKEMA - FS Min = 1.456
L=234900
1
2
3
4
5
6
7
w1
w1
w1
w1
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
-10
0
10
20
30
40
50
60
70
80
90
100
110
(Scale in Feet)

Attachment 4
Deep GWBW with Static Loads,
Rapid Drawdown Condition

** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION ARKEMA

BOUNDARY COORDINATES

7 Top Boundaries
13 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	75.00	10.00	75.00	3
2	10.00	75.00	14.00	79.00	1
3	14.00	79.00	19.00	84.00	1
4	19.00	84.00	25.00	90.00	1
5	25.00	90.00	35.00	90.00	1
6	35.00	90.00	40.00	90.00	4
7	40.00	90.00	100.00	90.00	1
8	0.00	50.00	35.00	50.00	2
9	35.00	50.00	40.00	50.00	4
10	40.00	50.00	100.00	50.00	2
11	0.00	10.00	35.00	10.00	3
12	35.00	10.00	40.00	10.00	4
13	40.00	10.00	100.00	10.00	3

1

ISOTROPIC SOIL PARAMETERS

4 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.

1	114.7	118.5	180.0	29.0	0.00	0.0	1
2	118.5	118.5	416.0	22.0	0.00	0.0	1
3	123.1	123.1	478.4	28.0	0.00	0.0	1
4	75.0	80.0	0.0	18.0	0.00	0.0	1

1

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	75.00
2	10.00	75.00
3	15.00	80.00
4	100.00	80.00

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

250 Trial Surfaces Have Been Generated.

50 Surfaces Initiate From Each Of 5 Points Equally Spaced Along The Ground Surface Between X = 4.00 ft.
and X = 10.00 ft.

Each Surface Terminates Between X = 32.00 ft.
and X = 44.00 ft.

4.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -25.0 And 0.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.94
3	17.95	75.58
4	21.72	76.91
5	25.20	78.88
6	28.28	81.43
7	30.87	84.48
8	32.87	87.95
9	33.62	90.00

Circle Center At X = 12.3 ; Y = 97.5 and Radius, 22.7

*** 1.525 ***

Individual data on the 12 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.0	954.7	0.0	380.1	0.0	0.0	0.0	0.0	0.0
2	1.0	526.6	0.0	212.4	0.0	0.0	0.0	0.0	0.0
3	2.9	2125.8	0.0	868.2	0.0	0.0	0.0	0.0	0.0
4	1.1	946.9	0.0	294.6	0.0	0.0	0.0	0.0	0.0
5	2.7	2824.6	0.0	642.6	0.0	0.0	0.0	0.0	0.0
6	3.3	3984.6	0.0	508.6	0.0	0.0	0.0	0.0	0.0
7	0.2	260.7	0.0	17.1	0.0	0.0	0.0	0.0	0.0
8	1.4	1642.0	0.0	61.5	0.0	0.0	0.0	0.0	0.0
9	1.7	1839.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	2.6	2086.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	2.0	871.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.7	88.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.91
3	17.97	75.41
4	21.81	76.51
5	25.45	78.17
6	28.80	80.35
7	31.79	83.01
8	34.34	86.09
9	36.41	89.52
10	36.61	90.00

Circle Center At X = 12.6 ; Y = 101.4 and Radius, 26.6

*** 1.577 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.59
3	16.46	74.95
4	20.30	76.07
5	23.86	77.90
6	27.00	80.38
7	29.60	83.42
8	31.58	86.90
9	32.61	90.00

Circle Center At X = 12.6 ; Y = 95.4 and Radius, 20.8

*** 1.594 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.58
3	16.46	74.92
4	20.31	76.02
5	23.88	77.83
6	27.04	80.28
7	29.67	83.29
8	31.68	86.75
9	32.82	90.00

Circle Center At X = 12.7 ; Y = 95.5 and Radius, 20.9

*** 1.599 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00

2	12.50	74.95
3	16.45	75.55
4	20.26	76.79
5	23.81	78.62
6	27.02	81.01
7	29.80	83.88
8	32.08	87.17
9	33.42	90.00

Circle Center At X = 10.8 ; Y = 99.5 and Radius, 24.6

*** 1.605 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.43	74.24
3	16.43	74.35
4	20.31	75.32
5	23.89	77.10
6	27.00	79.61
7	29.50	82.74
8	31.26	86.33
9	32.15	90.00

Circle Center At X = 13.9 ; Y = 92.6 and Radius, 18.4

*** 1.616 ***

1

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.45	74.39
3	16.45	74.58
4	20.33	75.55
5	23.94	77.27
6	27.14	79.67
7	29.81	82.65
8	31.84	86.10
9	33.14	89.88
10	33.16	90.00

Circle Center At X = 13.5 ; Y = 94.5 and Radius, 20.2

*** 1.619 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.46	74.43
3	16.45	74.61
4	20.34	75.55
5	23.99	77.20
6	27.25	79.51
7	30.02	82.40
8	32.19	85.76
9	33.68	89.47
10	33.79	90.00

Circle Center At X = 13.5 ; Y = 95.4 and Radius, 21.0

*** 1.629 ***

1

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.39	74.06
3	16.39	74.00
4	20.30	74.85
5	23.92	76.54
6	27.07	79.00
7	29.60	82.10
8	31.37	85.69
9	32.29	89.58
10	32.29	90.00

Circle Center At X = 14.6 ; Y = 91.7 and Radius, 17.7

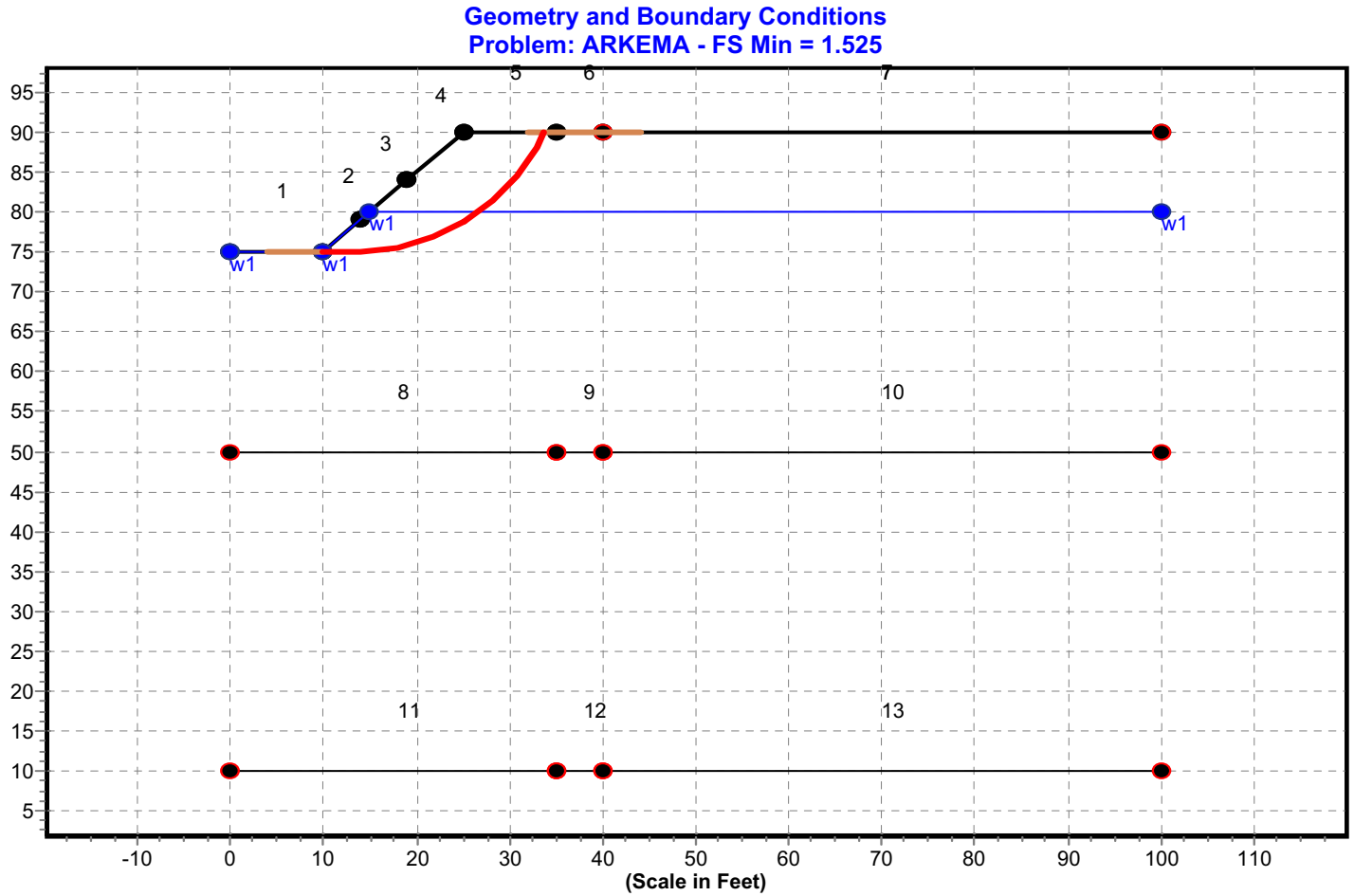
*** 1.642 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	13.90	74.09

```
    3         17.90       74.09
    4         21.79       75.00
    5         25.38       76.77
    6         28.47       79.31
    7         30.90       82.49
    8         32.55       86.13
    9         33.31       90.00

Circle Center At X =   15.9 ; Y =   91.5  and Radius,   17.5


      ***     1.645   ***



1

                Y            A     X     I     S            F     T


                0.00     19.80     39.60     59.40     79.20     99.00

X        0.00 +----*----+---------+----*----+-------*-+---------+
              -                                       .
              -                                      ..
              -                                     ..*
              -                                    .61 *
              -                                    .91.W
        19.80 +                                    ..35  *
              -                                    ..015.
              -                                     ..213.  *
              -                                     ...01316
              -                                      ....2211
              -    *                   *             ......*
A       39.60 +    *                   *              .....*
              -                                        ....
              -
              -
              -
              -
X       59.40 +
              -
              -
              -
              -
              -
I       79.20 +
              -
              -
              -
              -
              -
S        99.00 +    *                   *              W    *
              -
              -
              -
              -
              -
       118.80 +
              -
              -
              -
              -
```

```
                -
F     138.60 +
                -
                -
                -
                -
                -
T     158.40 +
```


Geometry and Boundary Conditions
Problem: ARKEMA - FS Min = 1.525
1
2
3
4
5
6
7
8
9
10
11
12
13
w1
w1
w1
w1
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
-10
0
10
20
30
40
50
60
70
80
90
100
110
(Scale in Feet)

Attachment 5
Deep GWBW with Static Loads,
Long Term Condition

** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION ARKEMA

BOUNDARY COORDINATES

7 Top Boundaries
13 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	75.00	10.00	75.00	3
2	10.00	75.00	14.00	79.00	1
3	14.00	79.00	19.00	84.00	1
4	19.00	84.00	25.00	90.00	1
5	25.00	90.00	35.00	90.00	1
6	35.00	90.00	40.00	90.00	4
7	40.00	90.00	100.00	90.00	1
8	0.00	50.00	35.00	50.00	2
9	35.00	50.00	40.00	50.00	4
10	40.00	50.00	100.00	50.00	2
11	0.00	10.00	35.00	10.00	3
12	35.00	10.00	40.00	10.00	4
13	40.00	10.00	100.00	10.00	3

1

ISOTROPIC SOIL PARAMETERS

4 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.

1	114.7	118.5	150.0	28.0	0.00	0.0	1
2	118.5	118.5	416.0	22.0	0.00	0.0	1
3	123.1	123.1	478.4	28.0	0.00	0.0	1
4	75.0	80.0	0.0	18.0	0.00	0.0	1

1

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 2 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	80.00
2	100.00	80.00

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

250 Trial Surfaces Have Been Generated.

50 Surfaces Initiate From Each Of 5 Points Equally Spaced Along The Ground Surface Between X = 4.00 ft.
and X = 10.00 ft.

Each Surface Terminates Between X = 32.00 ft.
and X = 44.00 ft.

4.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -25.0 And 0.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.94
3	17.95	75.58
4	21.72	76.91
5	25.20	78.88
6	28.28	81.43
7	30.87	84.48
8	32.87	87.95
9	33.62	90.00

Circle Center At X = 12.3 ; Y = 97.5 and Radius, 22.7

*** 1.520 ***

Individual data on the 11 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Earthquake Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.0	962.4	1058.7	1255.6	0.0	0.0	0.0	0.0	0.0
2	3.9	2658.5	0.0	1183.0	0.0	0.0	0.0	0.0	0.0
3	1.1	946.9	0.0	294.6	0.0	0.0	0.0	0.0	0.0
4	2.7	2824.6	0.0	642.6	0.0	0.0	0.0	0.0	0.0
5	3.3	3984.6	0.0	508.6	0.0	0.0	0.0	0.0	0.0
6	0.2	260.7	0.0	17.1	0.0	0.0	0.0	0.0	0.0
7	1.4	1642.0	0.0	61.5	0.0	0.0	0.0	0.0	0.0
8	1.7	1839.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	2.6	2086.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	2.0	871.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.7	88.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.91
3	17.97	75.41
4	21.81	76.51
5	25.45	78.17
6	28.80	80.35
7	31.79	83.01
8	34.34	86.09
9	36.41	89.52
10	36.61	90.00

Circle Center At X = 12.6 ; Y = 101.4 and Radius, 26.6

*** 1.568 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.50	74.95
3	16.45	75.55
4	20.26	76.79
5	23.81	78.62
6	27.02	81.01
7	29.80	83.88
8	32.08	87.17
9	33.42	90.00

Circle Center At X = 10.8 ; Y = 99.5 and Radius, 24.6

*** 1.609 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.59
3	16.46	74.95
4	20.30	76.07
5	23.86	77.90
6	27.00	80.38
7	29.60	83.42
8	31.58	86.90
9	32.61	90.00

Circle Center At X = 12.6 ; Y = 95.4 and Radius, 20.8

*** 1.616 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.58

3	16.46	74.92
4	20.31	76.02
5	23.88	77.83
6	27.04	80.28
7	29.67	83.29
8	31.68	86.75
9	32.82	90.00

Circle Center At X = 12.7 ; Y = 95.5 and Radius, 20.9

*** 1.620 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.45	74.39
3	16.45	74.58
4	20.33	75.55
5	23.94	77.27
6	27.14	79.67
7	29.81	82.65
8	31.84	86.10
9	33.14	89.88
10	33.16	90.00

Circle Center At X = 13.5 ; Y = 94.5 and Radius, 20.2

*** 1.645 ***

1

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.46	74.43
3	16.45	74.61
4	20.34	75.55
5	23.99	77.20
6	27.25	79.51
7	30.02	82.40
8	32.19	85.76
9	33.68	89.47
10	33.79	90.00

Circle Center At X = 13.5 ; Y = 95.4 and Radius, 21.0

*** 1.652 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.43	74.24
3	16.43	74.35
4	20.31	75.32
5	23.89	77.10
6	27.00	79.61
7	29.50	82.74
8	31.26	86.33
9	32.15	90.00

Circle Center At X = 13.9 ; Y = 92.6 and Radius, 18.4

*** 1.653 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	13.90	74.09
3	17.90	74.09
4	21.79	75.00
5	25.38	76.77
6	28.47	79.31
7	30.90	82.49
8	32.55	86.13
9	33.31	90.00

Circle Center At X = 15.9 ; Y = 91.5 and Radius, 17.5

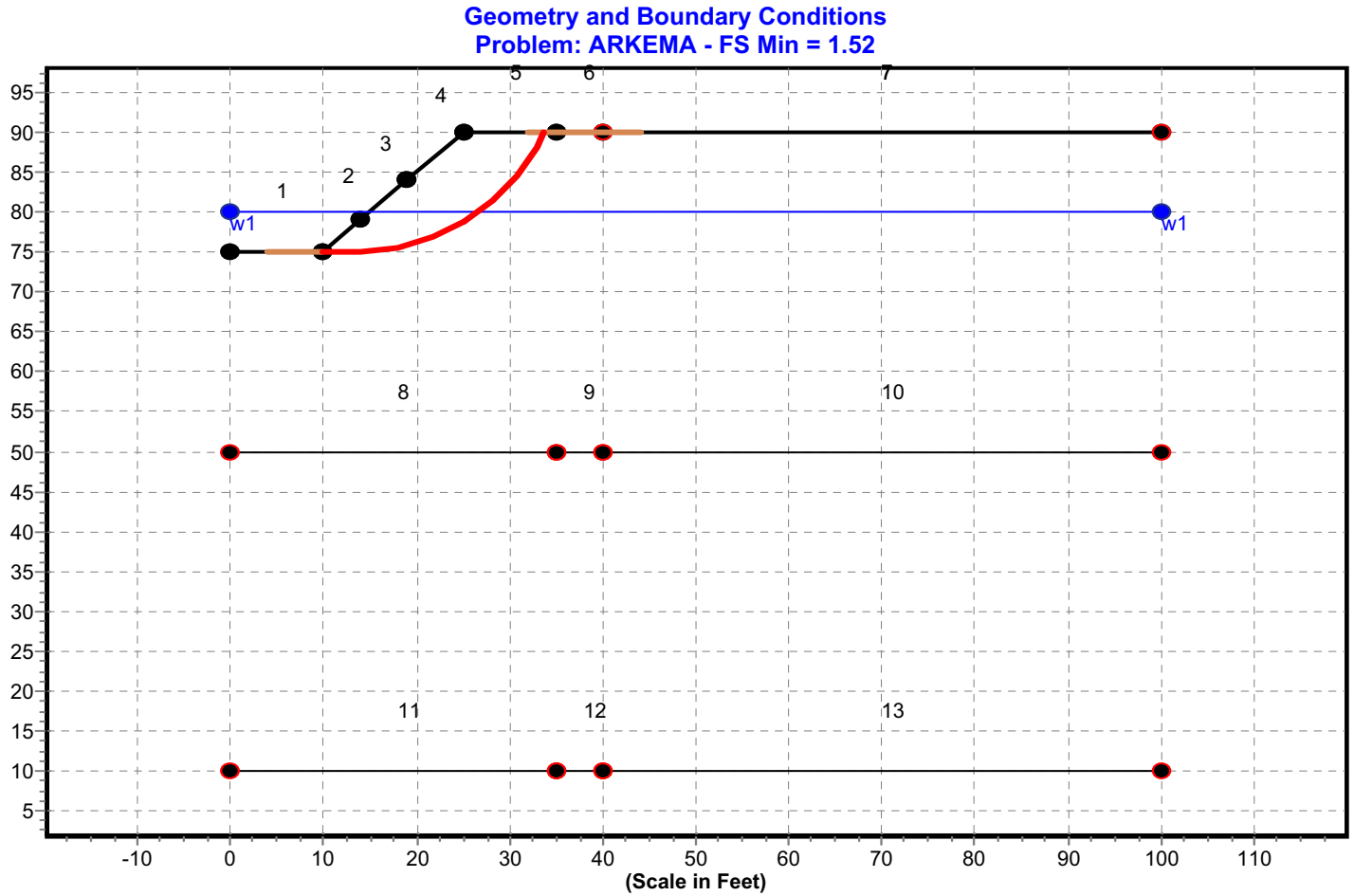
*** 1.658 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.56
3	16.47	74.77
4	20.37	75.64

```
    5         24.08       77.14
    6         27.50       79.23
    7         30.52       81.85
    8         33.07       84.93
    9         35.08       88.38
   10         35.70       90.00

Circle Center At X =   13.2 ; Y =   98.7  and Radius,   24.1


      ***     1.661   ***



1

                Y            A     X     I     S            F     T


                0.00     19.80     39.60     59.40     79.20     99.00

X        0.00 +----*----+---------+----*----+-------*-W---------+
              -                                       .
              -                                      ..
              -                                    ..*
              -                                    .81 *
              -                                    .91.
        19.80 +                                    ..43  *
              -                                    ..913.
              -                                     ..213.  *
              -                                     ...91318
              -                                      ....2211
              -    *                   *             ......*
A       39.60 +    *                   *              .....*
              -                                        ....
              -
              -
              -
              -
X       59.40 +
              -
              -
              -
              -
              -
I       79.20 +
              -
              -
              -
              -
              -
S        99.00 +    *                   *              W    *
              -
              -
              -
              -
              -
       118.80 +
              -
              -
              -
              -
              -
```

```
F    138.60 +
            -
            -
            -
            -
            -
T    158.40 +
```


Geometry and Boundary Conditions
Problem: ARKEMA - FS Min = 1.52
1
2
3
4
5
6
7
8
9
10
11
12
13
w1
w1
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
-10
0
10
20
30
40
50
60
70
80
90
100
110
(Scale in Feet)

Attachment 6
Shallow GWBW with Static Loads, Rapid Drawdown Condition

** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION ARKEMA

BOUNDARY COORDINATES

7 Top Boundaries
14 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	75.00	10.00	75.00	3
2	10.00	75.00	14.00	79.00	1
3	14.00	79.00	19.00	84.00	1
4	19.00	84.00	25.00	90.00	1
5	25.00	90.00	33.00	90.00	1
6	33.00	90.00	38.00	90.00	4
7	38.00	90.00	100.00	90.00	1
8	0.00	50.00	33.00	50.00	2
9	33.00	50.00	38.00	50.00	4
10	38.00	50.00	100.00	50.00	2
11	33.00	30.00	38.00	30.00	3
12	0.00	10.00	33.00	10.00	3
13	33.00	10.00	38.00	10.00	3
14	38.00	10.00	100.00	10.00	3

1

ISOTROPIC SOIL PARAMETERS

4 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.

1	114.7	118.5	180.0	29.0	0.00	0.0	1
2	118.5	118.5	420.0	22.0	0.00	0.0	1
3	123.1	123.1	478.4	28.0	0.00	0.0	1
4	75.0	80.0	0.0	18.0	0.00	0.0	1

1

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	75.00
2	10.00	75.00
3	15.00	80.00
4	100.00	80.00

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

250 Trial Surfaces Have Been Generated.

50 Surfaces Initiate From Each Of 5 Points Equally Spaced Along The Ground Surface Between X = 4.00 ft.
and X = 10.00 ft.

Each Surface Terminates Between X = 30.00 ft.
and X = 44.00 ft.

4.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -25.0 And 0.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.94
3	17.93	75.67
4	21.65	77.15
5	25.00	79.34
6	27.85	82.14
7	30.09	85.45
8	31.64	89.14
9	31.82	90.00

Circle Center At X = 12.3 ; Y = 95.1 and Radius, 20.2

*** 1.481 ***

Individual data on the 12 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.0	954.7	0.0	380.1	0.0	0.0	0.0	0.0	0.0
2	1.0	525.3	0.0	212.7	0.0	0.0	0.0	0.0	0.0
3	2.9	2094.5	0.0	857.3	0.0	0.0	0.0	0.0	0.0
4	1.1	944.9	0.0	295.4	0.0	0.0	0.0	0.0	0.0
5	2.6	2675.9	0.0	601.0	0.0	0.0	0.0	0.0	0.0
6	3.3	3892.1	0.0	437.9	0.0	0.0	0.0	0.0	0.0
7	0.0	5.4	0.0	0.3	0.0	0.0	0.0	0.0	0.0
8	0.7	791.3	0.0	19.2	0.0	0.0	0.0	0.0	0.0
9	2.2	2233.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	2.2	1596.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	1.5	480.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.2	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	13.98	74.62
3	17.95	75.14
4	21.70	76.53
5	25.04	78.73
6	27.81	81.62
7	29.86	85.05
8	31.09	88.86
9	31.19	90.00

Circle Center At X = 13.7 ; Y = 92.4 and Radius, 17.8

*** 1.502 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.58
3	16.46	75.01
4	20.25	76.27
5	23.69	78.30
6	26.63	81.02
7	28.92	84.30
8	30.47	87.99
9	30.84	90.00

Circle Center At X = 12.5 ; Y = 93.4 and Radius, 18.8

*** 1.567 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.50	74.95
3	16.44	75.63
4	20.20	77.01
5	23.64	79.05
6	26.65	81.68
7	29.14	84.82
8	31.01	88.35
9	31.53	90.00

Circle Center At X = 10.8 ; Y = 96.8 and Radius, 22.0

*** 1.569 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)

1	8.50	75.00
2	12.50	74.80
3	16.46	75.35
4	20.25	76.61
5	23.75	78.55
6	26.83	81.10
7	29.39	84.17
8	31.34	87.67
9	32.12	90.00

Circle Center At X = 11.6 ; Y = 96.4 and Radius, 21.6

*** 1.578 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.43	74.24
3	16.42	74.44
4	20.25	75.59
5	23.70	77.63
6	26.56	80.42
7	28.67	83.82
8	29.91	87.62
9	30.08	90.00

Circle Center At X = 13.6 ; Y = 90.8 and Radius, 16.6

*** 1.584 ***

1

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.49	74.76
3	16.47	75.16
4	20.34	76.20
5	23.99	77.83
6	27.33	80.04
7	30.27	82.74
8	32.74	85.89
9	34.68	89.39
10	34.90	90.00

Circle Center At X = 12.0 ; Y = 99.6 and Radius, 24.8

*** 1.586 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.50	74.91
3	16.47	75.41
4	20.32	76.50
5	23.96	78.16
6	27.31	80.34
7	30.30	82.99
8	32.86	86.07
9	34.94	89.49
10	35.15	90.00

Circle Center At X = 11.1 ; Y = 101.5 and Radius, 26.6

*** 1.587 ***

1

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.56
3	16.47	74.83
4	20.34	75.81
5	23.99	77.47
6	27.27	79.74
7	30.10	82.57
8	32.38	85.86
9	34.04	89.50
10	34.17	90.00

Circle Center At X = 13.0 ; Y = 96.8 and Radius, 22.3

*** 1.592 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00

2	12.46	74.43
3	16.45	74.69
4	20.30	75.77
5	23.84	77.63
6	26.92	80.18
7	29.40	83.32
8	31.17	86.91
9	31.96	90.00

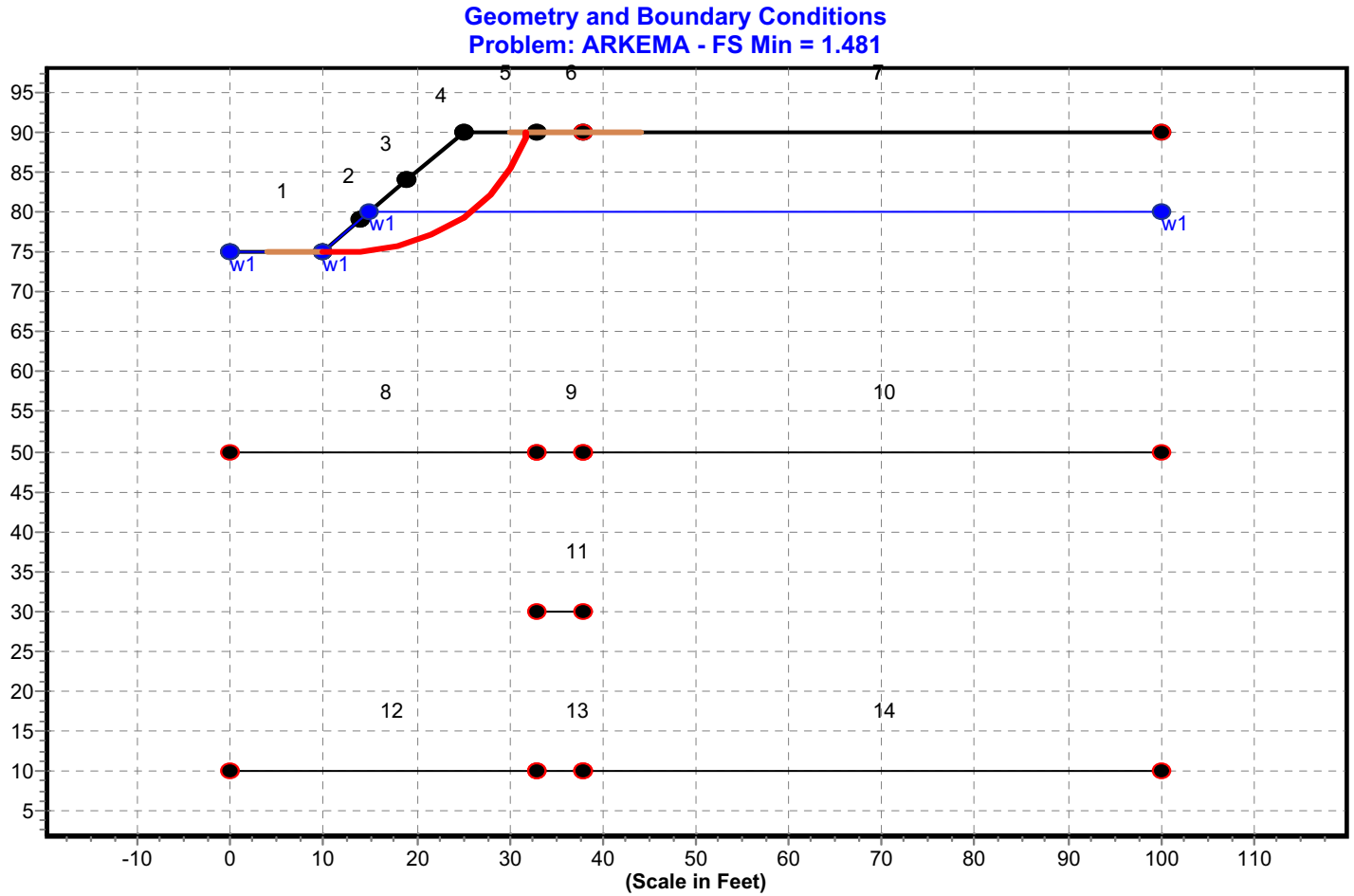
Circle Center At X = 13.2 ; Y = 93.6 and Radius, 19.1

*** 1.594 ***

1

```
            Y            A     X     I     S            F     T

            0.00     19.80     39.60     59.40     79.20     99.00

X      0.00 +----*----+---------+----*----+-------*-+---------+
            -                                      .
            -                                     ..
            -                                   ..*
            -                                   .61 *
            -                                   ..1 W
      19.80 +                                   ..63  *
            -                                   ...13
            -                                    ...11.. *
            -                                    .....6132
            -    *         *         *            .....7.*
            -                                      ......7
A     39.60 +    *         *         *             .....*
            -                                        ....
            -
            -
            -
            -
X     59.40 +
            -
            -
            -
            -
            -
I     79.20 +
            -
            -
            -
            -
            -
S      99.00 +    *                   *              W    *
            -
            -
            -
            -
            -
     118.80 +
            -
            -
            -
```

```
             -
             -
F    138.60 +
             -
             -
             -
             -
             -
T    158.40 +
```


Geometry and Boundary Conditions
Problem: ARKEMA - FS Min = 1.481
1
2
3
4
5
6
7
8
9
10
11
12
13
14
w1
w1
w1
w1
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
-10
0
10
20
30
40
50
60
70
80
90
100
110
(Scale in Feet)

Attachment 7
Shallow GWBW with Static Loads, Long Term Condition

** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION ARKEMA

BOUNDARY COORDINATES

7 Top Boundaries
14 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	75.00	10.00	75.00	3
2	10.00	75.00	14.00	79.00	1
3	14.00	79.00	19.00	84.00	1
4	19.00	84.00	25.00	90.00	1
5	25.00	90.00	33.00	90.00	1
6	33.00	90.00	38.00	90.00	4
7	38.00	90.00	100.00	90.00	1
8	0.00	50.00	33.00	50.00	2
9	33.00	50.00	38.00	50.00	4
10	38.00	50.00	100.00	50.00	2
11	33.00	30.00	38.00	30.00	3
12	0.00	10.00	33.00	10.00	3
13	33.00	10.00	38.00	10.00	3
14	38.00	10.00	100.00	10.00	3

1

ISOTROPIC SOIL PARAMETERS

4 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.

1	114.7	118.5	180.0	29.0	0.00	0.0	1
2	118.5	118.5	416.0	22.0	0.00	0.0	1
3	123.1	123.1	478.4	28.0	0.00	0.0	1
4	75.0	80.0	0.0	18.0	0.00	0.0	1

1

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 2 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	80.00
2	100.00	80.00

1

A Critical Failure Surface Searching Method, Using A Random
Technique For Generating Circular Surfaces, Has Been Specified.

250 Trial Surfaces Have Been Generated.

50 Surfaces Initiate From Each Of 5 Points Equally Spaced
Along The Ground Surface Between X = 4.00 ft.
and X = 10.00 ft.

Each Surface Terminates Between X = 30.00 ft.
and X = 44.00 ft.

4.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation.
The Angle Has Been Restricted Between The Angles Of -25.0
And 0.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial
Failure Surfaces Examined. They Are Ordered - Most Critical
First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.94
3	17.93	75.67
4	21.65	77.15
5	25.00	79.34
6	27.85	82.14
7	30.09	85.45
8	31.64	89.14
9	31.82	90.00

Circle Center At X = 12.3 ; Y = 95.1 and Radius, 20.2

*** 1.483 ***

Individual data on the 11 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.0	962.4	1058.7	1255.6	0.0	0.0	0.0	0.0	0.0
2	3.9	2625.9	0.0	1172.6	0.0	0.0	0.0	0.0	0.0
3	1.1	944.9	0.0	295.4	0.0	0.0	0.0	0.0	0.0
4	2.6	2675.9	0.0	601.0	0.0	0.0	0.0	0.0	0.0
5	3.3	3892.1	0.0	437.9	0.0	0.0	0.0	0.0	0.0
6	0.0	5.4	0.0	0.3	0.0	0.0	0.0	0.0	0.0
7	0.7	791.3	0.0	19.2	0.0	0.0	0.0	0.0	0.0
8	2.2	2233.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	2.2	1596.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	1.5	480.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.2	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	13.98	74.62
3	17.95	75.14
4	21.70	76.53
5	25.04	78.73
6	27.81	81.62
7	29.86	85.05
8	31.09	88.86
9	31.19	90.00

Circle Center At X = 13.7 ; Y = 92.4 and Radius, 17.8

*** 1.515 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.50	74.95
3	16.44	75.63
4	20.20	77.01
5	23.64	79.05
6	26.65	81.68
7	29.14	84.82
8	31.01	88.35
9	31.53	90.00

Circle Center At X = 10.8 ; Y = 96.8 and Radius, 22.0

*** 1.583 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.50	74.91
3	16.47	75.41
4	20.32	76.50
5	23.96	78.16
6	27.31	80.34
7	30.30	82.99
8	32.86	86.07
9	34.94	89.49
10	35.15	90.00

Circle Center At X = 11.1 ; Y = 101.5 and Radius, 26.6

*** 1.595 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.50	74.80

3	16.46	75.35
4	20.25	76.61
5	23.75	78.55
6	26.83	81.10
7	29.39	84.17
8	31.34	87.67
9	32.12	90.00

Circle Center At X = 11.6 ; Y = 96.4 and Radius, 21.6

*** 1.595 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.49	74.76
3	16.47	75.16
4	20.34	76.20
5	23.99	77.83
6	27.33	80.04
7	30.27	82.74
8	32.74	85.89
9	34.68	89.39
10	34.90	90.00

Circle Center At X = 12.0 ; Y = 99.6 and Radius, 24.8

*** 1.599 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.58
3	16.46	75.01
4	20.25	76.27
5	23.69	78.30
6	26.63	81.02
7	28.92	84.30
8	30.47	87.99
9	30.84	90.00

Circle Center At X = 12.5 ; Y = 93.4 and Radius, 18.8

*** 1.600 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.56
3	16.47	74.83
4	20.34	75.81
5	23.99	77.47
6	27.27	79.74
7	30.10	82.57
8	32.38	85.86
9	34.04	89.50
10	34.17	90.00

Circle Center At X = 13.0 ; Y = 96.8 and Radius, 22.3

*** 1.612 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	13.90	74.09
3	17.90	74.18
4	21.75	75.27
5	25.20	77.28
6	28.05	80.08
7	30.11	83.51
8	31.26	87.35
9	31.36	90.00

Circle Center At X = 15.5 ; Y = 89.9 and Radius, 15.9

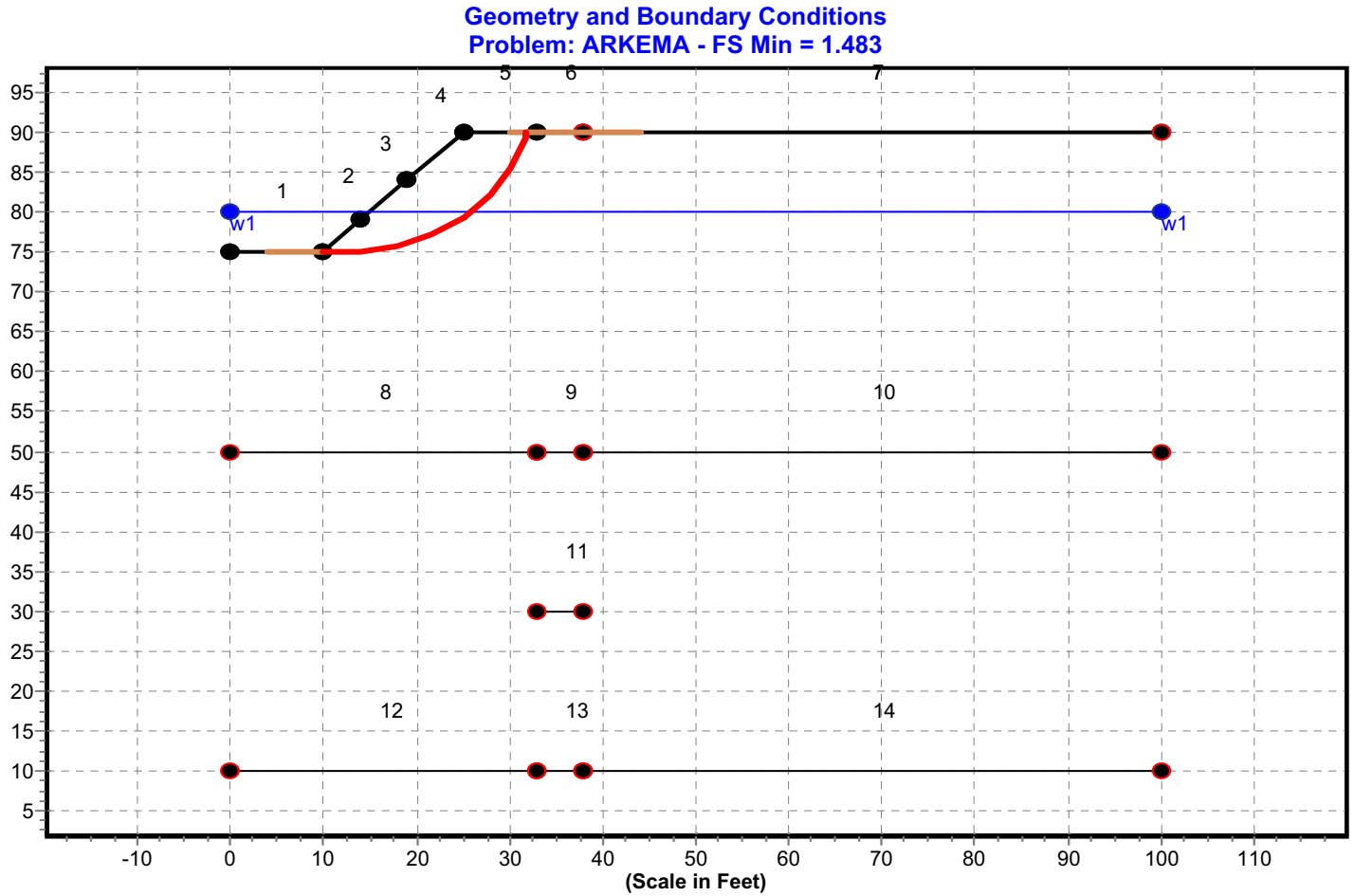
*** 1.618 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.47	74.51
3	16.46	74.75
4	20.34	75.73

```
    5         23.97       77.40
    6         27.24       79.71
    7         30.02       82.59
    8         32.23       85.92
    9         33.78       89.61
   10         33.86       90.00

Circle Center At X =   13.2 ; Y =   96.1  and Radius,   21.6


      ***     1.618   ***



1

                Y            A     X     I     S            F     T


                0.00     19.80     39.60     59.40     79.20     99.00

X        0.00 +----*----+---------+----*----+-------*-W---------+
              -                                      .
              -                                     ..
              -                                    ..*
              -                                   .91 *
              -                                   .91
        19.80 +                                   ..63  *
              -                                   ..913
              -                                    ..911.. *
              -                                    ...9.4152
              -    *         *         *            .....4.*
              -                                      ......4
A       39.60 +    *         *         *              .....*
              -                                         ....
              -
              -
              -
              -
X       59.40 +
              -
              -
              -
              -
              -
I       79.20 +
              -
              -
              -
              -
              -
S        99.00 +    *                   *              W    *
              -
              -
              -
              -
              -
       118.80 +
              -
              -
              -
              -
              -
```

```
F    138.60 +
            -
            -
            -
            -
            -
T    158.40 +
```


Geometry and Boundary Conditions
Problem: ARKEMA - FS Min = 1.483
1
2
3
4
5
6
7
8
9
10
11
12
13
14
w1
w1
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
-10
0
10
20
30
40
50
60
70
80
90
100
110
(Scale in Feet)

Attachment 8
Clearance Trench Excavation Scenario

** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION ARKEMA

BOUNDARY COORDINATES

9 Top Boundaries
11 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	75.00	10.00	75.00	3
2	10.00	75.00	14.00	79.00	1
3	14.00	79.00	19.00	84.00	1
4	19.00	84.00	25.00	90.00	1
5	25.00	90.00	35.00	90.00	1
6	35.00	90.00	85.00	65.00	1
7	85.00	65.00	95.00	65.00	1
8	95.00	65.00	145.00	90.00	1
9	145.00	90.00	170.00	90.00	1
10	0.00	50.00	170.00	50.00	2
11	0.00	10.00	170.00	10.00	3

1

ISOTROPIC SOIL PARAMETERS

3 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	114.7	118.5	180.0	29.0	0.00	0.0	1
2	118.5	118.5	416.0	22.0	0.00	0.0	1

```
  3   123.1    123.1     478.4     28.0    0.00       0.0      1
1


1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED


Unit Weight of Water =  62.40


Piezometric Surface No.  1 Specified by  6 Coordinate Points


  Point      X-Water     Y-Water
   No.         (ft)        (ft)

    1          0.00       80.00
    2         55.00       80.00
    3         85.00       65.00
    4         95.00       65.00
    5        125.00       80.00
    6        170.00       80.00
1


A Critical Failure Surface Searching Method, Using A Random
Technique For Generating Circular Surfaces, Has Been Specified.


250 Trial Surfaces Have Been Generated.


 50 Surfaces Initiate From Each Of  5 Points Equally Spaced
Along The Ground Surface Between  X =   4.00 ft.
                              and  X =  10.00 ft.


Each Surface Terminates Between   X =  32.00 ft.
                            and   X =  44.00 ft.


 4.00 ft. Line Segments Define Each Trial Failure Surface.


Restrictions Have Been Imposed Upon The Angle Of Initiation.
The Angle Has Been Restricted Between The Angles Of -25.0
And   0.0 deg.


1


Following Are Displayed The Ten Most Critical Of The Trial
Failure Surfaces Examined.  They Are Ordered - Most Critical
First.


* * Safety Factors Are Calculated By The Modified Bishop Method * *


Failure Surface Specified By  9 Coordinate Points
```

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.94
3	17.95	75.56
4	21.74	76.86
5	25.24	78.78
6	28.37	81.28
7	31.02	84.27
8	33.12	87.68
9	34.04	90.00

Circle Center At X = 12.4 ; Y = 98.1 and Radius, 23.2

*** 1.686 ***

Individual data on the 11 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.0	962.4	1058.7	1255.6	0.0	0.0	0.0	0.0	0.0
2	4.0	2665.1	0.0	1185.2	0.0	0.0	0.0	0.0	0.0
3	1.0	947.4	0.0	294.5	0.0	0.0	0.0	0.0	0.0
4	2.7	2854.7	0.0	651.2	0.0	0.0	0.0	0.0	0.0
5	3.3	4002.0	0.0	522.0	0.0	0.0	0.0	0.0	0.0
6	0.2	315.5	0.0	22.2	0.0	0.0	0.0	0.0	0.0
7	1.5	1859.1	0.0	74.2	0.0	0.0	0.0	0.0	0.0
8	1.6	1718.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	2.7	2196.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	2.1	967.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.9	123.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	13.98	74.62
3	17.96	75.04
4	21.78	76.23
5	25.28	78.16
6	28.33	80.75
7	30.81	83.89
8	32.61	87.46
9	33.30	90.00

Circle Center At X = 13.9 ; Y = 94.7 and Radius, 20.1

*** 1.708 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.59
3	16.46	74.95
4	20.31	76.05
5	23.87	77.87
6	27.02	80.33
7	29.65	83.35
8	31.66	86.81
9	32.76	90.00

Circle Center At X = 12.6 ; Y = 95.5 and Radius, 20.9

*** 1.771 ***

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.50	74.95
3	16.46	75.54
4	20.27	76.74
5	23.85	78.54
6	27.09	80.88
7	29.92	83.70
8	32.27	86.94
9	33.82	90.00

Circle Center At X = 10.8 ; Y = 100.0 and Radius, 25.2

*** 1.772 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.48	74.58
3	16.46	74.91
4	20.32	75.99

5	23.89	77.78
6	27.07	80.21
7	29.73	83.20
8	31.79	86.63
9	33.01	90.00

Circle Center At X = 12.7 ; Y = 95.7 and Radius, 21.1

*** 1.776 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.45	74.39
3	16.45	74.57
4	20.34	75.53
5	23.96	77.22
6	27.18	79.58
7	29.89	82.53
8	31.96	85.95
9	33.33	89.71
10	33.37	90.00

Circle Center At X = 13.6 ; Y = 94.7 and Radius, 20.4

*** 1.800 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.43	74.24
3	16.43	74.35
4	20.31	75.31
5	23.89	77.09
6	27.01	79.60
7	29.51	82.72
8	31.28	86.31
9	32.19	90.00

Circle Center At X = 13.9 ; Y = 92.6 and Radius, 18.5

*** 1.805 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.46	74.43
3	16.46	74.59
4	20.35	75.50
5	24.01	77.12
6	27.31	79.38
7	30.13	82.22
8	32.37	85.53
9	33.97	89.20
10	34.15	90.00

Circle Center At X = 13.6 ; Y = 95.8 and Radius, 21.4

*** 1.810 ***

1

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	10.00	75.00
2	14.00	74.91
3	17.97	75.37
4	21.84	76.38
5	25.53	77.93
6	28.97	79.97
7	32.10	82.47
8	34.84	85.37
9	37.16	88.64
10	37.27	88.86

Circle Center At X = 12.7 ; Y = 103.5 and Radius, 28.6

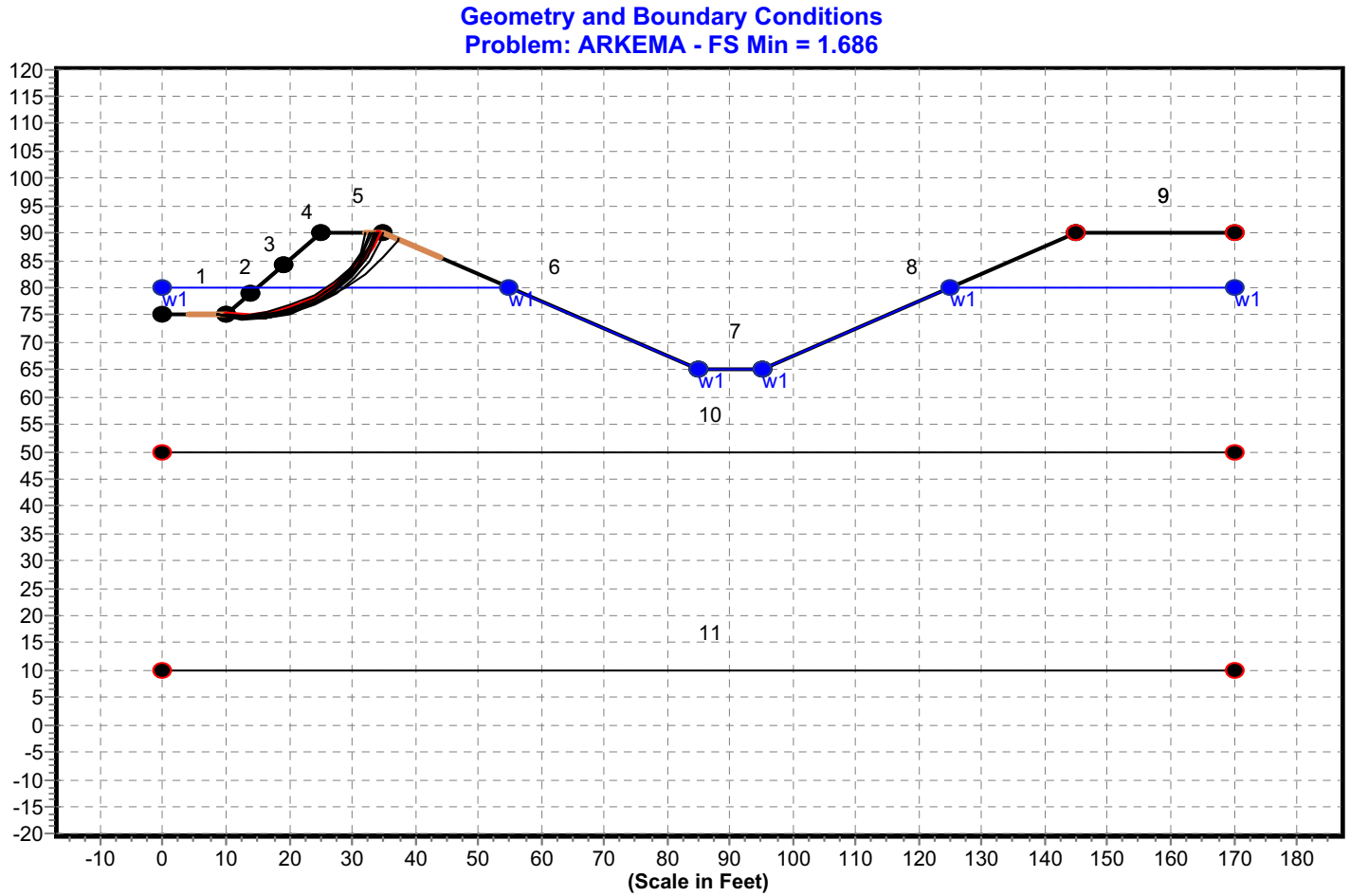
*** 1.810 ***

Failure Surface Specified By 10 Coordinate Points

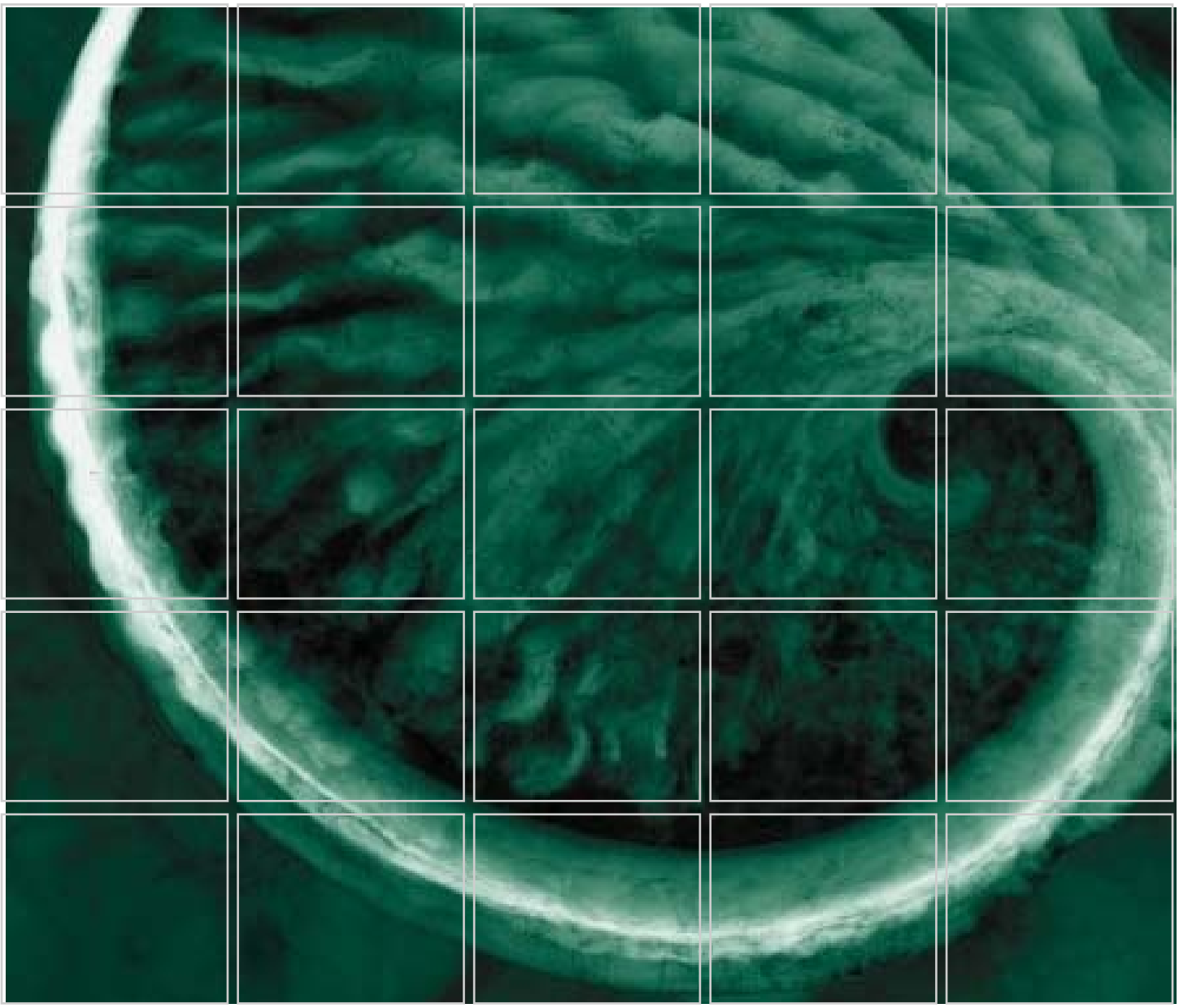
Point No.	X-Surf (ft)	Y-Surf (ft)
1	8.50	75.00
2	12.45	74.40
3	16.45	74.51
4	20.37	75.34
5	24.07	76.85

```
     6         27.44       79.00
     7         30.38       81.72
     8         32.78       84.92
     9         34.57       88.50
    10         35.01       90.00

Circle Center At X =   13.8 ; Y =   96.5  and Radius,   22.1


      ***     1.833   ***



1

                Y            A     X     I     S            F     T


                0.00     21.25     42.50      63.75     85.00    106.25

X        0.00 +----*----+---------+---*-----+----*--W-+---------+
              -                                  .
              -                                 .3
              -                                 .*
              -                                 .1.*
              -                                 .21   *
        21.25 +                                 .71.
              -                                 ..61.   *
              -                                 ...613.
              -                                  ...02112
              -                                  .....9.*
              -                                    .....9
A        42.50 +                                     ....
              -
              -
              -
              -                                      W
              -
X       63.75 +
              -
              -
              -
              -
              -
I       85.00 +                              *
              -
              -
              -                              *
              -
              -
S      106.25 +
              -
              -
              -
              -
              -                                      W
       127.50 +
              -
              -
              -
              -
              -                                          *
F      148.75 +
```

```
                -
                -
                -
                -
                -
T     170.00 +     *                   *              W    *
```


Geometry and Boundary Conditions
Problem: ARKEMA - FS Min = 1.686
1
2
3
4
5
6
7
8
9
10
11
w1
(Scale in Feet)

Appendix C
Slurry Materials Testing Report



DRAFT Slurry Materials Testing Report

Arkema, Inc. Facility
Portland, Oregon

March 2008

Prepared for:
Legacy Site Services LLC

www.erm.com

Delivering sustainable solutions in a more competitive world

ERM

Legacy Site Services LLC

DRAFT Slurry Materials Testing Report

Arkema, Inc. Facility
Portland, Oregon

March 2008

Project No. 0063837

DRAFT

Brendan Robinson, P.E.
Project Engineer

DRAFT

E. Doyon Main
GWBW Evaluation Task Manager

ERM-West, Inc.
915 118th Avenue S.E., Suite 130
Bellevue, Washington 98005
T: 425-462-8591
F: 425-455-3573

TABLE OF CONTENTS

1.0	***INTRODUCTION***		***1***
	1.1	***BACKGROUND INFORMATION***	***1***
		1.1.1 Site Background	*1*
		1.1.2 Hydrogeology	*2*
2.0	***FIELD PROCEDURES***		***4***
	2.1	***WATER SAMPLING AND FIELD TESTING***	***4***
	2.2	***SOIL SAMPLING AND FIELD TESTING***	***5***
3.0	***SLURRY MATERIALS TESTING PROCEDURES AND RESULTS***		***7***
	3.1	***GROUNDWATER SAMPLING RESULTS***	***7***
	3.2	***SLURRY COMPONENT MATERIALS TESTING***	***8***
		3.2.1 Slurry Mix Water Sample Testing	*8*
		3.2.2 Clay Additive Testing	*8*
		3.2.3 Soil Sample Testing	*9*
		3.2.4 Clay Slurry Mixture Testing	*10*
	3.3	***CLAY SLURRY BACKFILL TESTING***	***12***
	3.4	***CLAY-CEMENT SLURRY TESTING***	***13***
4.0	***SUMMARY AND CONCLUSIONS***		***15***
5.0	***REFERENCES***		***17***

LIST OF APPENDICES

APPENDIX A BORING LOGS

APPENDIX B CLAY ADDITIVE MANUFACTURER SPECIFICATION SHEETS

APPENDIX C MATERIALS TESTING LABORATORY REPORTS

APPENDIX D ANALYTICIAL TESTING LABORATORY REPORTS

***LIST OF FIGURES* (*Figures immediately follow the text*)**

1 Site Layout and Sampling Locations

LIST OF TABLES (Tables immediately follow the figures)

1	*Soil Boring Summary*
2	*Groundwater Field Parameter and Analytical Results*
3	*Clay Additive Index Property Results*
4	*Native Soil Classification and Index Property Results*
5	*Slurry Mix Test Results*
6	*Slurry Backfill Mixture Test Results*

THIS PAGE INTENTIONALLY LEFT BLANK

1.0 INTRODUCTION

ERM-West, Inc. (ERM) has prepared this report on behalf of Legacy Site Services LLC (LSS) to summarize the results of slurry materials testing performed in support of the Groundwater Source Control Interim Remedial Measure (IRM) at the Arkema Inc. (Arkema) facility located in Portland, Oregon (the "Site").

The primary purpose of the slurry materials testing was to perform pre-design testing and investigations as part of the Focused Feasibility Study (FFS) for the planned groundwater barrier wall (GWBW). Some of the data obtained by this task will also aid in the geotechnical engineering analysis and design of the groundwater extraction system.

The testing described in this report was designed to evaluate the performance and feasibility of a ground water barrier wall constructed using vibrated-beam slurry wall technology or slurry trench GWBW construction technology. In addition, ground water and soil data obtained can be useful in evaluating the feasibility and effectiveness of a sheet pile barrier wall technology for possible use to construct a GWBW.

The sampling and testing was conducted in accordance with *Scope of Work for Geotechnical Investigation and Slurry Compatibility Testing in Support of the Groundwater Source Control Interim Remedial Measure*, ERM, 23 March 2007. Additional soil sampling and testing were approved by the Oregon Department of Environmental Quality (ODEQ) on 30 April 2007.

1.1 BACKGROUND INFORMATION

The Site history is documented in the *Uplands Remedial Investigation Report Lots 3 & 4 and Tract A* (RI report) (ERM 2005). A brief description of the historical activities and sources of groundwater impacts are provided below.

1.1.1 Site Background

The Site is located at 6400 N.W. Front Avenue in Portland, Oregon, along the west bank of the Willamette River, at approximately river mile 7.5. The Site occupies approximately 55 acres. The surface is generally flat, with surface elevations of approximately 25 to 39 feet North American

Vertical Datum 1988 (NAVD88), except for the relatively steep river bank adjacent to the river.

The site operated as a sodium chlorate plan between 1941 and 2001. For the most part, the plant manufactured chlorine, sodium hydroxide, hydrogen, hydrochloric acid, and sodium chlorate. Other products and processes were added and discontinued over time, including: dichlorodiphenyltrichloroethane (DDT), ammonia, and ammonium perchlorate. All plant have been decommissioned and demolished, with the exception of the main office building on the site.

The Site is consists of four lots of land (Figure 1). The majority of prior industrial activity occurred on the two southernmost lots (i.e., Lots 3 and 4). Limited plant historical activity has occurred on the two northernmost lots (i.e., Lots 1 and 2). Additional information regarding historical activities occurring on each lot is presented in the RI report.

Affected groundwater is divided into two areas, the Acid Plant Area and Chlorate Area, based on the previous manufacturing activities that occurred in each area.

The Acid Plant Area is the part of the Site in which DDT was manufactured. The soil and groundwater in the Acid Plant area is affected predominantly by organic constituents, most notably by chemical monochlorobenzene (MCB). MCB has been found in both dissolved phase and as a separate phase dense non-aqueous phase liquid (DNAPL) (ERM, 2005).

The Chlorate Area is the part of the Site in which chlorate was manufactured and in which solid salt was received, stored, and dissolved during processing. The Chlorate Area is located in the southern part of the Site. Soil and groundwater in the Chlorate Area is generally affected by chloride, perchlorate, and hexavalent chromium.

1.1.2 Hydrogeology

This section provides a summary of the hydrogeology of the Site. A full description of the hydrogeology of the Site is presented in the RI Report and the FFS.

Groundwater occurs in five zones beneath the Site: a shallow unconfined upper zone (the Shallow Zone) and two confined to semi-confined lower zones (the Intermediate Zone and the Deep Zone), a gravel alluvium zone (the Gravel Zone), and basalt bedrock (the Basalt). The gravel zone is

laterally discontinuous at the Site, and is only present in the region of Lots 1 and 2. Groundwater at the Site flows towards the Willamette River in the Shallow, Intermediate, Deep, and Basalt Zones. There is no evidence of cross-gradient groundwater flow northwards from Lots 3 and 4 to Lots 1 and 2.

The shallow unconfined groundwater zone is present in the fill and upper sand alluvium to a maximum depth of 38 feet below ground surface. A thin discontinuous silt horizon separates the Shallow Zone from the Intermediate Zone throughout most of the Site and is referred to as the Shallow-Intermediate Silt. The Intermediate Zone comprises the upper portion of the semi-confined to confined zone at the Site and is characterized by sand alluvium. The Intermediate Zone occurs at depths between 36 to 50 feet below ground surface.

The interval between the Intermediate Zone and the underlying bedrock basalt is the Deep Zone. This zone consists of predominately fine grained deposits. The top of the Deep Zone occurs at approximately 40 to 50 feet below ground surface throughout the Site. The thickness of the Deep Zone ranges from approximately 5 to 45 feet and is generally controlled by the topography of the basalt bedrock at the Site (i.e. the top surface of the Deep Zone is relatively level compared to the varying elevation of the bottom surface at the Basalt).

The entire Site is underlain by basalt bedrock The top of the basalt occurs at depths ranging between 47 and 105 feet below ground surface. The shallowest occurrence of basalt is near the river bank at a location north of the boundary between Lot 2 and Lot 3. A shallow ridge of basalt extends along the river bank to the southeastern corner of the Site, with the basalt contact deepening to the southwest toward Front Avenue.

.

THIS PAGE INTENTIONALLY LEFT BLANK

2.0 FIELD PROCEDURES

Field sampling was performed in accordance with the procedures outlined in the *Scope of Work for Geotechnical Investigation and Slurry Compatibility Testing in Support of the Groundwater Source Control Interim Remedial Measure* (ERM 2007). Those procedures address soil and groundwater sample collection techniques, documentation, and quality assurance/quality control protocols.

Soil, groundwater, and Site potable water samples were collected, documented, and submitted to the Sierra Testing Laboratories, Inc. (STL) laboratory located in El Dorado Hills, California for slurry materials testing. Groundwater samples were collected, documented, and submitted to the TestAmerica Laboratories, Inc. (TA) laboratory located in Portland, Oregon, for chemical analytical analysis.

2.1 WATER SAMPLING AND FIELD TESTING

Representative samples of organics-affected (OA) groundwater were collected from MWA-67si, a monitoring well screened in the Shallow Zone in the Acid Plant Area of the Site. Representative samples of chloride-affected (CA) ground water were collected fromMWA-30, a monitoring well screened in the Shallow Zone in the Chlorate Area of the Site. Each sample was split for chemical analysis and for use in the slurry materials testing. Groundwater sampling locations were based on the proximity to the corresponding CA and OA soil sampling locations near the proposed GWBW route.

Groundwater samples for use in the slurry compatibility testing were collected in pre-cleaned, one-gallon polyethylene cube-containers, using a submersible pump (i.e. a "Whale" Pump) and disposable polyethylene tubing. A minimum of three well volumes was purged prior to sample collection. Field test measurements of pH, specific conductance, dissolved oxygen, and redox potential were recorded during sample collection.

Samples submitted to the analytical laboratory were collected in pre-cleaned, appropriately preserved sampling containers. The groundwater samples were analyzed for specific gravity; total suspended solids, total dissolved solids, specific conductance, oil and grease, total organic carbon, and total organic halogens.

Site potable water was collected directly from the on site public water supply source (i.e. the City of Portland public water supply), for by the sully materials testing laboratory use as slurry mix water source.

2.2 *SOIL SAMPLING AND FIELD TESTING*

A cone penetrometer testing (CPT) rig was used in four locations (CPT-1 through CPT-4) to collect data used for stratigraphic and lithologic interpretation (e.g., soil behavior type, soil strength characteristics, and depth to refusal, interpreted when at a depth corresponding to prior data as the depth to the top of the basalt). The parameters measured and recorded while pushing the CPT tool into the formation included tip resistance, sleeve friction, and formation pore pressure. The CPT drilling locations are shown on Figure 1. The results of the CPT drilling are discussed in Groundwater Barrier Wall Geotechnical Evaluation Report (ERM, 2008).

Mud rotary drilling was implemented to collect representative samples from locations near the projected groundwater barrier wall route. The samples were collected for slurry compatibility testing, for soil strength testing, and to verify the interpretation of the CPT data. ERM collected organics affected (OA) soil and chloride affected (CA) soil from borings B-120 and B-121 respectively (Figure 1).

At each location, ERM collected continuous representative samples of the soil from the ground surface to the total depth of each boring. The total depth of each of the two borings was at the contact with basalt. ERM obtained disturbed soil samples at 2-foot depth intervals using a California sampler. A Standard Penetration Test (SPT) was performed at intervals in accordance with ASTM D1586 to evaluate in situ soil strength. SPT tests were performed at intervals of five feet or less from the ground surface to the basalt contact. Disturbed soil samples were collected fro the SPT sampler. In addition, soil samples were collected at apparent cohesive soil intervals (i.e. in the Shallow-Intermediate Silt Zone) using Shelby tubes to allow examination and, if practical, testing of the undisturbed soil (Groundwater Barrier Wall Geotechnical Evaluation Report (ERM, 2008).

The boring logs and soil sample collection logs are included in Appendix A. A summary of the lithology encountered in each boring is shown in Table 1.

The lithologic unit contact depths and thicknesses observed the CPTs and in B-210 and B-121 are in the range of those expected along the proposed GWBW route.

THIS PAGE INTENTIONALLY LEFT BLANK

3.0 SLURRY MATERIALS TESTING PROCEDURES AND RESULTS

The slurry materials testing measured properties of slurry and slurry backfill components and mixturesimportant to evaluation of potential for performance of a soil-slurry GWBW including:

- Properties of representative samplers of materials (i.e. slurry mix water, clay and clay-cement slurry additives, and discrete-interval and depth-composite native soil) that may be used to make slurry and slurry backfill mixtures, including appropriate control sample testing; and

- properties of various mixtures of clay and slurry mix water to make slurry mixtures.

The procedures used and the results of the slurry materials testing are described below.

3.1 GROUNDWATER SAMPLING RESULTS

On 6 April 2007, groundwater samples were collected from monitoring wells MWA-30 and MWA-67si. The field parameter and analytical results are presented in Table 2.

Monochlorobenze (MCB) was detected in MWA-67si at a concentration of 198,000 µg/L. This level of MCB is consistent with previous detections of MCB from this and other monitoring wells in the Acid Plant Area. Other VOCs, including carbon tetrachloride, chloroform, and tetrachloroethene were detected in this groundwater sample. The chlorinated pesticide DDT was also detected. These compounds have previously been detected in this and surrounding monitoring wells (ERM 2007). Moderate concentrations of chloride, TDS, arsenic, chromium, iron, and manganese were detected, that were within the range of concentrations previously detected in the Acid Plant Area. The groundwater sample from MWA-67si was considered representative of typical organics affected (OA) groundwater conditions.

Significant chloride and TDS concentrations (39,400 mg/L and 66,000 mg/L respectively) were detected in the sample collected from MWA-30.

These levels of chloride and TDS have been previously observed in MWA-30 and other proximate wells in the Chlorate Area. The concentrations of VOCs, arsenic, chromium, iron, and manganese detected in the MWA-30 groundwater sample are within the range of concentrations observed within the Chlorate Area (ERM 2007). The groundwater sample from MWA-30 was considered representative of typical chloride affected (CA) groundwater conditions.

3.2 SLURRY COMPONENT MATERIALS TESTING

Slurry and slurry backfill component materials tested included slurry mix water, slurry clay additives, and discrete interval and composite native soil samples.

3.2.1 Slurry Mix Water Sample Testing

Site potable water samples were analyzed with a portable test meter at the laboratory for the following parameters:

- pH ; and
- Specific conductance.

3.2.2 Clay Additive Testing

Three proven and commercially available slurry additives were considered as GWBW slurry components:

- Bentonite clay powder (BPM Materials, Inc., "Bara-kade" product supplied by the manufacturer in commercial packaging was used for the testing);
- Attapulgite clay powder (Floridin, Inc. "Florigel H-Y" product supplied by the manufacturer in commercial packaging was used for the testing); and
- Specialty clay-cement material (local formulation Liquid Earth Support, Inc. "Impermix" product supplied by the manufacturer was used for the testing);

The material specifications and material safety data sheets for each of the commercial clay additives used (bentonite and attapulgite) are included in Appendix B.

The clay-cement additive was not analyzed for index properties because of its necessary activity on mixture and suitability of mixed and cured testing to demonstrate effectiveness of clay-cement additive.

The bentonite and attapulgite clay additive samples mixed with deionized water (control sample) and analyzed for the following index properties:

- Water content in accordance with ASTM D2216;
- Atterberg limits in accordance with ASTM D4318; and
- Free swell in accordance with ASTM D5890.

The bentonite and attapulgite clay additives were mixed with deionized water (DI), organics affected groundwater (OGW), and chloride affected groundwater (CGW) and then analyzed for Atterberg limits. The results are presented in Table 3.

The index properties (moisture content, free swell) of the commercial clay slurry products received at the laboratory were in the same range of values published by the commercial manufacturers for those respective products (presented in Appendix B).

The Atterberg limits for both clay additives decreased when site groundwater was used to mix the slurry when compared to DI. The greatest effect on the index properties was observed when the CGW was used as mix water. The greatest decrease in index properties was observed in the bentonite clay additive.

Both clay additive products made adequate clay slurry with adequate slurry index properties as described below.

3.2.3 Soil Sample Testing

Representative soil samples from each of the four lithologic zones were analyzed for the following parameters:

- Water content in accordance with ASTM D2216;
- Atterberg limits in accordance with ASTM D4318; and
- Particle size distribution in accordance with ASTM D422, including hydrometer.

The results of the native soil characterization testing are shown in Table 4.

Individual soil samples had index properties typical of a range of sandy to clayey soil. Most of the soil samples, which were collected from the Shallow Zone and the Intermediate Zone, were found to have index properties typical of a sandy silt or silty sand.

Composite soil samples had index properties that were typical of sandy silt with some clay.

ERM used the results of these analyses to classify the discrete soil samples and to verify that the composite samples made by mixing discrete interval soil samples are reasonably representative of the type of soil expected as confirmed by the subsequent testing of the composite soil samples.

3.2.4 Clay Slurry Mixture Testing

This task included evaluation of both the clay-water slurry mixtures that could be used to support an open trench during construction of a GWBW at the Site. .

To evaluate the slurry mix, bentonite and attapulgite clay additives were mixed (at a ratio of least 5% by weight clay additive) with each of four slurry mix waters:

- laboratory-grade deionized (DI) water (as a control);
- site potable water (probable slurry mix water source at the Site);
- a mixture of 85% site potable water with 15% OGW groundwater (representative of a reasonable worst case for slurry in a slurry trench excavated in the part of the Site with organics-affected ground water and soil); and
- a mixture of 85% site potable water with 15% CGW groundwater (representative of a reasonable worst case for slurry in a slurry trench excavated in the part of the Site with chloride-affected ground water and soil).

The amount of each clay additive was adjusted to produce a slurry mixture that achieved the following target acceptance criteria after mixing and, to evaluate stability of the mixture, at intervals in the subsequent day:

- slurry unit weight between 64.5 and 69.0 pounds per cubic foot (pcf) when tested in accordance with API RP 13B-1; and

- slurry Marsh funnel viscosity greater than or equal to 40 seconds when tested in accordance with API RP 13B-1.

Each clay-mix water slurry was mixed using a suitable high-shear mechanical mixer (i.e. not using diffused air injection) and in order to achieve thorough mixing, at a low speed that keeps solids in suspension without entraining air or forming bubbles in or on the surface of the mixture. The mixtures were continuously mixed at low speed during initial mixing and throughout the subsequent testing.

Each mixture was tested immediately after mixing and at 24 hours for the following parameters:

- pH by portable instrument; and

- specific conductance by portable instrument.

Each mixture was tested immediately after mixing and at intervals of 0.5, 1, 2, 4, 8, and 24 hours after mixing for the following parameters:

- unit weight in accordance with API RP 13B-1;

- Marsh funnel viscosity in accordance with API RP 13B-1;

The results of the slurry mix testing are presented in Table 5.

In general, both clay additive products made adequate clay slurry with adequate slurry index properties.

The results of the slurry mix testing indicate that bentonite clay made adequate clay slurry when mixed with each of the four slurry mix water samples.

The testing showed that it was necessary to increase the amount of bentonite in the mixture containing CGW in order for the slurry to meet the target acceptance criteria.

Attapulgite clay made adequate slurry at a mix ratio of 6% by weight when mixed with site potable water. However, it was necessary to increase the amount of attapulgite in the mixtures containing site

groundwater in order for the mixtures to achieve the target acceptance criteria.

ERM used the results of the slurry mix testing to identify the weight ratio of clay additive appropriate for making slurry used to adjust the range of soil-slurry mixtures for the subsequent slurry backfill testing.

3.3 CLAY SLURRY BACKFILL TESTING

This task included testing mixtures of soil and clay slurry to measure the ability of the components to make an effective and stable low permeability soil-slurry backfill achieving the target slump and unit weight acceptance criteria and to measure the resulting hydraulic conductivity ofeach mixture using a range of unaffected and affected water as permeants.

Four test mixtures were prepared by mixing each of the two composite soil samples (i.e. the OA composite soil sample from the Acid Plant area and the CA composite soil sample from the Chlorate Plant area) mixed with each of the two clay slurry mixtures (i.e. bentonite slurry and attapulgite slurry). A fifth mixture was prepared by mixing an aliquot of DNAPL affected soil, collected from shallow-intermediate silt during a re-drilling attempt of B-120, with the bentonite clay slurry mixture.

Each mixture was prepared at rates necessary to achieve the following target acceptance criteria for slurry backfill mixture unit weight and slump after mixing:

- Unit weight 15 pcf greater than the corresponding slurry unit weight when tested in accordance with API RP 13B-1; and

- Slump between 4 and 6 inches when tested in accordance with ASTM C143.

Where practical, the mixtures were designed to also achieve secondary quality criteria:

- Particle sizes passing the No. 200 U.S. Standard sieve are greater than or equal to 30% and more than 15% of the particle sizes are smaller than 0.002 mm when tested in accordance with ASTM D422 (including hydrometer); and

- Water content between 25% and 35% when tested in accordance with ASTM D2216.

Each slurry back-fill mixture was placed in a hydraulic conductivity test cell and subjected to hydraulic conductivity in accordance with ASTM D5084. Each of the four composite soil slurry backfill mixtures was tested using DI water as a control permeant.

Each of the composite soil slurry backfill mixtures and the DNAPL affected soil slurry mixture were subjected to hydraulic conductivity testing using the corresponding affected groundwater (i.e. OGW was used a permeant for OA and DA soil slurry mixtures). This testing was designed to represent a reasonable worst case scenario exposure of each clay additive to affected soil and similarly affected groundwater.

The slurry backfill mixtures hydraulic conductivity testing results are shown in Table 6.

All composite soil slurry backfill mixtures achieved the target acceptance criteria for slump and unit weight criteria, with the exception of the DNAPL-affected (DA) soil slurry mixture, which had a slump of 7 inches instead of the 4- to 6-inch slump target. It was not practical to repeat the testing due to the very limited quantity of DNAPL-affected soil available from sampling the relatively thin layer, indicated in some past sampling to have DNAPL.

Hydraulic conductivity test results were generally greater in samples tested with site groundwater as permeant compared to the samples tested with DI water as permeant (i.e. control samples). All the samples tested with site groundwater had hydraulic conductivities within a range of approximately 10^{-8} to 10^{-9} cm/sec.

3.4 CLAY-CEMENT SLURRY TESTING

Two pairs of soil-clay-cement slurry backfill mixtures were prepared by adding aliquots of a clay-cement additive (Liquid Earth Support, Inc. "Impermix" supplied by the manufacturer) to aliquots of each of the two composite soil mixtures and each of the two correspondingly affected ground water samples (i.e. an aliquot of CA composite soil sample mixed with CGW and, separately, an aliquot of OA composite soil sample mixed with OGW, making a total of two slurry backfill mixtures and making a total of four test specimens):

- "Impermix" at the supplier's recommended water:additive mix ratio;

- CA or OA composite soil sample at 15% of the "Impermix" mix weight;

- Site PW at 90% of the "Impermix" supplier's recommended total water:additive mix ratio; and

- CGW (for the mixture with CA soil) or OGW (for the mixture with OA soil) at 10% of the "Impermix" supplier's recommended total water:additive mix ratio).

The "Impermix" test specimens were mixed, molded, and cured in accordance with the "Impermix" supplier's instructions approved by ERM. As recommended by the "Impermix" supplier, each of the "Impermix" test specimens was cured for approximately 60 days after mixing prior to extruding, preparing, and subjecting the test specimen to hydraulic conductivity testing.

Each "Impermix" test specimen was placed in a hydraulic conductivity test cell and subjected to hydraulic conductivity testing in accordance with ASTM D5084. One of each of the two types "Impermix" test specimens (OA or CA soil) were tested using DI water as a control permeant. The remaining two samples were tested using the corresponding site groundwater as permeant (i.e. OGW was used in the specimen made with OA soil, CGW was used in the specimen made with CA soil)

The results of the clay-cement hydraulic testing are shown in Table 6.

All "Impermix" clay-cement slurry test specimens made a cured soil-slurry backfill sample with hydraulic conductivity suitable for construction of a plastic concrete GWBW with a suitable low hydraulic conductivity of approximately 10^{-8} cm/sec.

4.0 SUMMARY AND CONCLUSIONS

The slurry materials testing laboratory confirmed receipt of the samples and performed testing in stages. Testing included:

- Clay additive index testing (clay-cement additive was not subjected to index testing because of its necessary activity on mixture and suitability of mixed and cured testing to demonstrate effectiveness of clay-cement additive);
- Slurry mix sample index testing;
- Individual and composite sample classification testing of native soil used to make slurry backfill samples;
- Slurry backfill mix sample index testing; and
- Hydraulic conductivity and related index testing of slurry backfill mixtures (tests were done after curing for clay-cement slurry mixtures as the mixture makes a plastic concrete material).

Analysis of the test results lead to the following conclusions:

- The index properties of the commercial clay slurry products received at the laboratory were in the same range of values published by the commercial manufacturers for those respective products.
- Plasticity and swell-related properties of clay additives were somewhat adversely affected by affected ground water compared to results of testing with deionized water;
- Both clay additive products made adequate clay slurry with slurry index properties that achieved the target acceptance criteria for unit weight and viscosity;
- Individual soil samples had index properties typical of a range of sandy to clayey soil. Most of the soil samples, which were collected from the Shallow Zone and the Intermediate Zone, were found to have index properties typical of a sandy silt or silty sand.
- Composite soil samples had index properties that were typical of sandy silt with some clay.

- Mixtures of either of the two composite soil samples with either of the two clay slurries made soil-slurry backfill samples that achieved the target acceptance criteria for slump and unit weight and were found to have suitably low hydraulic conductivity needed for construction of an effective GWBW at the Site.

- Mixtures of the DNAPL-affected soil sample with the bentonite clay slurry sample made a soil-slurry backfill sample that achieved the target acceptance criteria for unit weight and marginally exceeded the target acceptance criteria for slump and was found to have a suitably low and stable hydraulic conductivity, indicating that DNAPL had nor significant adverse effect on the effectiveness of a slurry wall made with similar materials..

- Cured mixtures of both of the two composite soil samples with the clay-cement additive made a cured clay-cement slurry backfill sample that was found to have a suitably low hydraulic conductivity needed for construction of an effective GWBW at the site.

5.0 REFERENCES

ERM 2005 *Uplands Remedial Investigation Report Lots 3 & 4 and Tract A, Arkema, Inc. Portland Facility*, Environmental Resources Management, Portland, Oregon, December 2005.

ERM 2006 *Draft Acid Plant Area DNAPL Sampling Summary Report*, Environmental Resources Management, Bellevue, Washington, April 2006.

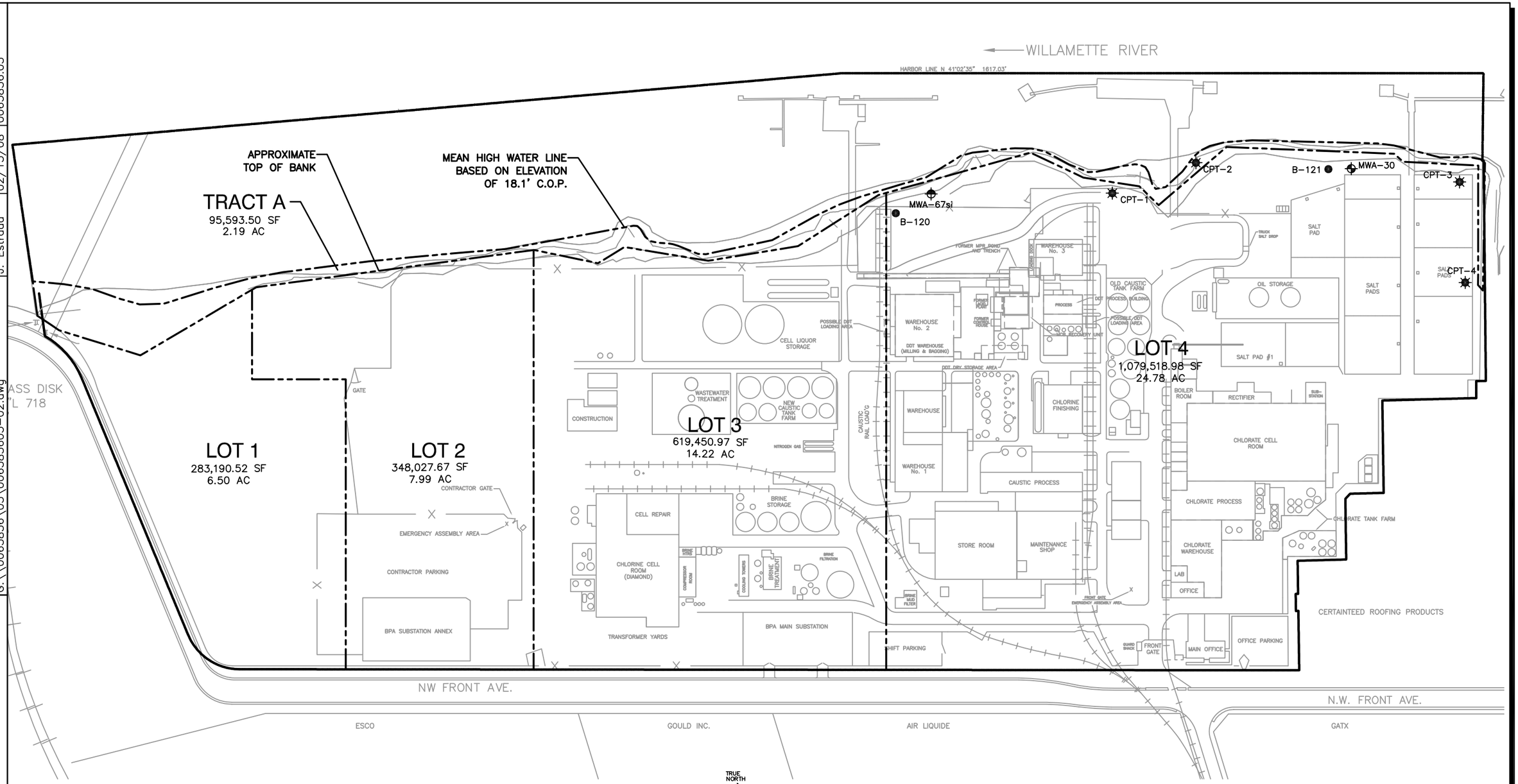
ERM 2007 *Draft Sitewide Groundwater Monitoring Report – April 2007 Monitoring Event*, Environmental Resources Management, Bellevue, Washington, September 2007.

ERM 2008 *Groundwater Barrier Wall Geotechnical Evaluation Report,* Environmental Resources Management, ERM, 2008.

THIS PAGE INTENTIONALLY LEFT BLANK

Figures

Project No. 0063836.03
Date: 02/15/08
Drawn By: J. Estrada
CAD File: G:\0063836\03\0063836603-02.dwg



LEGEND

- Existing Shallow Zone Monitoring Well
- Existing Shallow–Intermediate Zone Monitoring Well
- Existing Fractual Basalt Zone Monitoring Well
- Mud Rotary Boring
- Cone Penetrometer Boring
- Site Boundary
- Approximate Lot Boundary

TRUE NORTH
PLANT NORTH
0 200
FEET

Note:
Most buildings and structures noted on this diagram have been demolished and/or removed.

Figure 1
Site Layout and Sampling Locations
Geotechnical Evaluation and Slurry Compatibility Testing
Arkema Inc.
Portland, Oregon
ERM 02/08

Tables

Table 1
Soil Boring Summary
Soil and Slurry Compatibility Testing
Arkema, Inc.
Portland, Oregon

Boring	**Units**	**B-120**	**B-121**
Location		Acid Plant Area	Chlorate Area
Contaminants		Organics	Chloride
Surface Elevation	(ft amsl)	35.81	38.35
Lithologic Depths[1]			
Fill (Silty Sand/Sandy Silt)	(ft bgs)	23	26
Shallow Zone (Silty Sand)	(ft bgs)	34	29
Shallow-Intermediate (Silt)	(ft bgs)	35	31
Intermediate Zone (Sand with Silt)	(ft bgs)	45	44
Deep Zone (Sandy Silt)	(ft bgs)	50.5	87
Total Depth Drilled	(ft bgs)	50.5	87

Notes:
[1] - Depth to bottom of lithologic unit
ft = Feet
amsl = Above Mean Sea Level (NAVD 88)
bgs = Below Ground Surface

Table 2
Groundwater Field Parameter and Analytical Results
Soil and Slurry Compatibility Testing
Arkema, Inc.
Portland, Oregon

Analyte	Units	MWA-67si	MWA-30
Field Parameters			
pH		5.16	7.04
Temperature	(deg. C)	17.04	16.59
Specific Conductance	(mS/cm)	10.14	80
ORP	(mV)	-112.5	-197.3
Dissolved Oxygen	(mg O_2/L)	0.36	0.25
Metals			
Arsenic	mg/L	0.0105	0.0185
Chromium	mg/L	0.0306	0.388
Iron	mg/L	25.6	7.32
Manganese	mg/L	3.26	0.886
Pesticides			
DDT	ug/L	0.664	ND (<0.0481)
VOCs			
Benzene	ug/L	ND (<90)	0.13
Carbon Disulfide	ug/L	ND (<140)	0.25
Carbon Tetrachloride	ug/L	1220	ND (<0.06)
Chlorobenzene	ug/L	198000	0.9
Chloroform	ug/L	1910	4.15
Naphthalene	ug/L	ND (<90)	0.92
Tetrachloroethene	ug/L	2080	ND (<0.11)
Toluene	ug/L	ND (<110)	0.65
1,2,4-Trimethylbenzene	ug/L	ND (<80)	0.09
o-Xylene	ug/L	ND (<70)	0.14
Methane	ug/L	NA	13.9
Inorganic			
Chloride	mg/L	2730	39400
Perchlorate	ug/L	ND (<4000)	ND (<80)
Conventional Parameters			
Oil & Grease	mg/L	ND (<4.85)	ND (<4.85)
Total Dissolved Solids	mg/L	9150	66000
Total Organic Carbon	mg/L	67	12.6
Total Suspended solids	mg/L	ND (<10)	ND (<10)
Specific Gravity		1.01	1.05

Notes
ND = Not Detected
NA = Not Analyzed
DDT = dichlorodiphenyltrichloroethane
ORP = Oxidation-Reduction Potential

Table 3
Clay Additive Index Property Results
Soil and Slurry Compatibility Testing
Arkema, Inc.
Portland, Oregon

Clay Additive	Moisture Content[1]	Mix Water	Free Swell	Atterberg Limits		
	%		mL/2g	LL	PL	PI
Bentonite	12.4	DI	12.0	426	45	381
		OGW	----	283	39	244
		CGW	----	109	41	68
Attapulgite	6.2	DI	6.0	243	94	149
		OGW	----	242	87	155
		CGW	----	175	91	84

Notes:
[1] - Material as supplied by manufacturer
DI = Deionized Water
CGW = Chloride affected groundwater
OGW = Organics affected groundwater

Table 4
Native Soil Classification and Index Property Results
Soil and Slurry Compatibility Testing
Arkema, Inc.
Portland, Oregon

Soil		**OA Soil**	**OA Soil**	**OA Soil**	**CA Soil**	**OA Soil**	**CA Soil**
Aquifer		Shallow	Shallow-Intermediate Silt	Intermediate	Deep	----	----
Sample ID		OA Soil, ST2, B120	OA Soil, S-IB2, B120	OA Soil, IT2, B120	OA Soil, DB2, B121	OA Soil, Full Depth	CA Soil, Full Depth
Depth	**(ft bgs)**	28-34	34-35	41-44	67-72	Full Depth	Full Depth
Material Description		Silty Sand	Silt	Poorly Graded Sand with Silt	Sandy Silt	Silty Sand	Sandy Silt
USCS Classification		SM	ML	SP-SM	ML	SM	ML
Unit Weight	**lb/ft3 (Dry)**	87	66.2	83.9	94		
	lb/ft3 (Dry)	114.7	104.1	112.1	123.1		
Moisture Content	**%**	31.8	57.4	33.7	31	8.9	9
Particle Size, Incl. Hydrometer	**%<#40**	92.7	99.7	96.9	99.8	81.8	93.8
	%<#200	16.6	97.3	9.2	61.9	45.6	52.5
	% Silt	10.7	80.5	3.2	48.5	39.3	37.9
	% Clay	5.9	16.8	6	13.4	6.3	14.6
Atterberg Limits	**LL**	NV	NV	NV	NV	21	NV
	PL	NP	NP	NP	NP	NP	NP
	PI	NP	NP	NP	NP	NP	NP
pH	**DI**	4.95	5.47	9.97	6.8		
	CaCl	3	3.24	7.03	6.05		

Notes:
lb/ft^3 = Pounds per cubic foot
% = Percent
ft bgs = feet below ground surface
DI = Deionized Water
CaCl = Calcium Chloride
PW = Site Potable Water
CGW = Chloride affected groundwater
OGW = Organics affected groundwater
CA = Chloride Affected Soil
OA = Organics Affected Soil

Missing Data

Table 5
Slurry Mix Test Results
Soil and Slurry Compatibility Testing
Arkema, Inc.
Portland, Oregon

Clay Additive	Mix Water	% Clay	Time (Hours)	Mud Balance Viscosity (lbs/ft^3)	Marsh Funnel Viscosity (sec)	pH	SC (uS/cm)
Bentonite	DI water	7.5%	0	65.2	35.8	9.87	760
			0.5	65.2	36.0		
			1	65.0	37.0		
			2	64.5	37.0		
			4	64.2	37.5		
			8	64.5	37.5		
			24	64.8	38.0	9.75	810
	PW water	6.1%	0	67.2	40.2	9.82	783
			0.5	67.0	40.5		
			1	66.9	41.2		
			2	66.8	41.4		
			4	67.0	41.3		
			8	67.2	41.4		
			24	67.4	41.6		
			48	67.4	41.5		
			72	67.4	41.6	9.61	874
	85% PW water and 15% OGW	6.2%	0	66.5	35.0	8.81	327
			0.5	66.5	36.0		
			1	67.0	36.0		
			2	65.0	36.0		
			4	64.5	37.0		
			8	64.3	38.0		
			24	63.7	41.0		
			48	64.0	41.0		
			72	64.1	42.0	8.77	361
	85% PW water and 15% CGW	9.0%	0	66.5	36.0	8.43	16940
			0.5	66.5	36.0		
			1	66.7	37.0		
			2	66.0	38.0		
			4	65.1	39.0		
			8	65.6	41.0		
			24	66.8	44.0		
			48	67.0	45.0		
			72	67.1	45.0	8.40	16900
Attapulgite	DI water	6.0%	0	66.2	30.0	10.03	110
			0.5	66.0	30.0		
			1	65.9	31.0		
			2	65.4	33.0		
			4	65.0	33.0		
			8	65.0	32.0		
			24	64.9	32.0	9.85	110
	PW water	6.0%	0	67.2	36.0	9.87	142
			0.5	67.3	36.0		
			1	67.6	37.0		
			2	67.7	37.0		
			4	68.0	39.0		
			8	68.1	40.0		
			24	68.1	41.0		
			48	68.1	41.0		
			72	68.1	41.0	9.81	141
	85% PW water and 15% OGW	14.3%	0	67.0	37.0	9.31	207
			0.5	67.0	37.0		
			1	66.8	39.0		
			2	66.4	39.0		
			4	67.3	39.0		
			8	67.5	39.0		
			24	67.7	40.0		
			48	67.9	40.0		
			72	67.9	41.0	9.26	212
	85% PW water and 15% CGW	14.2%	0	67.1	53.0	9 .29	14910
			0.5	67.1	53.0		
			1	67.7	60.0		
			2	68.0	63.0		
			4	68.2	65.0		
			8	68.0	65.0		
			24	67.7	64.0		
			48	67.8	64.0		
			72	67.9	64.0	9.27	15010

Notes:
lb/ft^3 = Pounds per cubic foot
% = Percent
ft bgs = feet below ground surface
DI = Deionized Water
PW = Site Potable Water
CGW = Chloride affected groundwater
OGW = Organics affected groundwater
CA = Chloride Affected Soil
OA = Organics Affected Soil

Table 6
Slurry Backfill Mixture Test Results
Soil and Slurry Compatibility Testing
Arkema, Inc.
Portland, Oregon

Sample Location	**Units**	**Chlorate Area**	**Acid Plant Area**	**Chlorate Area**	**Acid Plant Area**	**Acid Plant Area**	**Chlorate Area**	**Acid Plant Area**
Boring ID		**B-121**	**B-120**	**B-121**	**B-120**	**B-120**	**B-121**	**B-120**
Affected Soil Type Sample ID		CA CA-A-PW	OA OA-A-PW	CA CA-B-PW	OA OA-B-PW	DA DA-B-PW	CA Impermix/CAsoil	OA Impermix/OAsoil
Soil Interval		Full Depth Composite	Full Depth Composite	Full Depth Composite	Full Depth Composite	Shallow-Intermediate Silt	Full Depth Composite	Full Depth Composite
Clay Additive		Attapulgite	Attapulgite	Bentonite	Bentonite	Bentonite	Clay-Cement	Clay-Cement
Mix Water		PW	PW	PW	PW	PW	90% PW & 10% CGW	90% PW & 10% OGW
Unit Weight	(lbs/ft^3)	109.1	111.2	109.5		109.2	-----	-----
Slump	(inches)	5.9	5.7	5.5		7.0	-----	-----
Particle Size, Incl. Hydrometer	%<#40	98.1	86.0	94.1	87.9	-----	-----	-----
	%<#200	78.0	44.9	53.8	38.6	-----	-----	-----
	% Silt	57.7	28.1	43.1	24.8	-----	-----	-----
	% Clay	20.3	16.8	10.7	13.8	-----	-----	-----
Mixture Moisture Content[1]	%	47.8	39.7	43.7	31.7	43.4	-----	-----
DI Permeant								
Pre-Test Mositure Content[2]	%	31.9	27	31.1	24.9	-----	143.8	135.1
Unit Weight (Dry)	lbs/ft3	96.5	100.7	93.9	102.7	-----	31.8	32.3
Flow Volume	cc	6	4.25	11.8	2.75	-----	0.72	1.05
Height	cm	5.13	5.31	4.19	6.27	-----	7.7	8.2
Diameter	cm	5.08	5.08	5.08	5.08	-----	7.54	7.62
Water Mass	lbs	30.8	27.2	29.2	25.6	-----	45.7	43.6
Void Ratio		0.49	0.44	0.47	0.41	-----	0.73	0.70
Cell Volume	cc	104.0	107.6	84.9	127.1	-----	343.8	374.0
Void Volume	cc	51.3	46.9	39.7	52.1	-----	252.0	261.5
Flow Vol/Cell Volume		0.117	0.091	0.297	0.053	-----	0.003	0.004
Hydraulic Conductivity	cm/sec	2.34E-07	1.89E-07	1.25E-07	2.48E-07	-----	1.33E-08	1.77E-08
CGW Permeant								
Pre-Test Mositure Content[2]	%	30.4	-----	29.6	-----	-----	161.4	-----
Unit Weight (Dry)	lbs/ft3	96.2	-----	98.3	-----	-----	29.7	-----
Flow Volume	cc	3.4	-----	1.65	-----	-----	0.78	-----
Height	cm	5	-----	4.95	-----	-----	7.62	-----
Diameter	cm	5.08	-----	5.08	-----	-----	7.62	-----
Water Mass	lbs	29.2	-----	29.1	-----	-----	47.9	-----
Void Ratio		0.47	-----	0.47	-----	-----	0.77	-----
Cell Volume	cc	101.3	-----	100.3	-----	-----	347.5	-----
Void Volume	cc	47.5	-----	46.8	-----	-----	267.0	-----
Flow Vol/Cell Volume		0.105	-----	0.106	-----	-----	0.029	-----
Hydraulic Conductivity	cm/sec	7.85E-08	-----	3.93E-08	-----	-----	5.19E-08	-----
OGW Permeant								
Pre-Test Mositure Content[2]	%	-----	26.3	-----		35.1	-----	126.3
Unit Weight (Dry)	lbs/ft3	-----	101.1	-----		76	-----	34.4
Flow Volume	cc	-----	1.85	-----		2.1	-----	0.34
Height	cm	-----	5.05	-----		6.45	-----	7.75
Diameter	cm	-----	5.08	-----		5.08	-----	7.62
Water Mass	lbs	-----	26.6	-----	0.0	-----	-----	43.4
Void Ratio		-----	0.43	-----	0.00	-----	-----	0.70
Cell Volume	cc	-----	102.4	-----	0.0	-----	-----	353.4
Void Volume	cc	-----	43.6	-----	0.0	-----	-----	246.1
Flow Vol/Cell Volume		-----	0.116	-----	#DIV/0!	-----	-----	0.031
Hydraulic Conductivity	cm/sec	-----	3.76E-08	-----		1.70E-08	-----	1.78E-08

Notes:
[1] - Moisture content measured immediately after mixing
[2] - Moisture content measured after sample extruded, pressurised, and allowed to dewater
lb/ft^3 = Pounds per cubic foot
% = Percent
----- = Not Analyzed
DI = Deionized Water
PW = Site Potable Water
CGW = Chloride affected groundwater
OGW = Organics affected groundwater
CA = Chloride Affected Soil
OA = Organics Affected Soil
DA = Dense Non-Aqueous Phase Liquid Affected Soil

Missing Data

Appendix A
Boring Logs

ERM
6650 SW Redwood Lane
Suite 300
Portland, Oregon 97224
(503) 542-8007

BOREHOLE LOG

Site Id: B-120

Project Number: 0063836.02

Project Name: Arkema, Inc.

Location: Portland, Oregon

Contractor: Boart Longyear

Drilling Method: Hollow Stem Auger/Mud Rotary

Sampling Method: California/Split Spoon/Shelby Tube

Total Depth: 50.50'

Borehole Dia.: 10.00in (HSA), 5.88in (Mud Rotary)

Logged By: B. Robinson

Initial Water Level: ~25.00'

Date(s): 04/04/07 – 04/05/07

Depth (ft)	Graphic Log	USCS Code	Bulk Sample	Sample Recovery	Blow Count	Soil Description and Observations
		SM	HAND DUG			1.0" Gravel surface, underlain by Geotextile. GRAVELLY SANDY SILT (SM): dark brown to black, slightly moist.
5		ML		CA 50%	0 1 3 4	GRAVELLY SANDY SILT (ML): dark yellow brown, fine to medium gravel, fine to coarse sand, moist (fill).
				SPT 72%	0 1 2	
				CA 15%	1 4 4 5	
10				SPT 55%	4 10 13	SANDY SILT (ML): fine to coarse sand, wet.
				CA 40%	2 3 8 4	Some fine gravel.
				SPT 100%	2 3 3 2	
15				CA 65%	4 4 5 5	
				SPT 44%	4 6	SANDY GRAVELLY SILT (ML): dark yellow brown, fine to coarse sand, fine to coarse gravel, soft (fill).
				SHEL	PUSH	
20				CA 55%	1 1 6 6	
				SPT 100%	6 17 17 8	
		SP		CA 100%	11 13 19 9	SAND (SP): dark brown to yellow brown, fine grained, trace fines, moist. Wet below 25.0'.
25	▽			SPT 70%	14 2	2.0" thick SILTY SAND at 25.0', some red staining. 1.0" thick SANDY SILT at 26.0'. Heaving sand at 26.0'.
				CA 70%	6 10 12 13	
				CA 75%	14 14 5 7	
30				SPT 61%	10 22 14 12	SAND (SP): dark gray brown to dark gray, fine to medium grained, occasional silt lenses (0.25–1.0" thick), medium dense, sweet odor becoming stronger with depth, slight sheen at 33.0', wet.
				CA 67%	14 3 5 6	
		ML		SPT 78%	16 16 15 16	SILT (ML): dark olive brown, with fine silt, soft, moist.
35		SP		CA 67%	SHEL PUSH	SAND (SP): dark gray, fine to medium grained, trace to some silt, medium dense, sweet odor, wet.
		ML		THIN WALL SAMP	PUSH	SILT (ML): observed on tooling, poor recovery.
		SP			2 4	SAND (SP): fine grained, trace silt, loose, rotten egg odor, wet.

ERM
6650 SW Redwood Lane
Suite 300
Portland, Oregon 97224
(503) 542-8007

BOREHOLE LOG

Site Id: B-120

Project Number: 0063836.02

Project Name: Arkema, Inc.

Location: Portland, Oregon

Contractor: Boart Longyear

Drilling Method: Hollow Stem Auger/Mud Rotary

Sampling Method: California/Split Spoon/Shelby Tube

Total Depth: 50.50'

Borehole Dia.: 10.00in (HSA), 5.88in (Mud Rotary)

Logged By: B. Robinson

Initial Water Level: ~25.00'

Date(s): 04/04/07 – 04/05/07

Depth (ft)	Graphic Log	USCS Code	Bulk Sample	Sample Recovery	Blow Count	Soil Description and Observations
				SPT 67%	7 7 10	
				CA 75%	3 5 7 9	
				SPT 75%	3 4 4 13	
45		ML				SILT (ML): olive brown, soft, moist to wet.
		SP		CA 83%	19 20 13	SAND (SP): very fine grained, some silt, medium dense, wet.
		ML		SHEL	PUSH	SANDY SILT (ML): olive brown, very fine sand, soft, wet.
50				CA 75%	8 5 50/5	Total Depth – 50.5' bgs (Basalt chips in shoe)
55						
60						
65						
70						
75						

ERM
6650 SW Redwood Lane
Suite 300
Portland, Oregon 97224
(503) 542-8007

BOREHOLE LOG

Project Number: 0063836.02

Project Name: Arkema, Inc.

Location: Portland, Oregon

Contractor: Boart Longyear

Drilling Method: Hollow Stem Auger/Mud Rotary

Sampling Method: California/Split Spoon/Shelby Tube

Total Depth: 87.00'

Borehole Dia.: 10.00in (HSA), 5.88in (Mud Rotary)

Logged By: B. Robinson

Initial Water Level: ~27.00'

Date(s): 04/04/07 – 04/05/07

Depth (ft)	Graphic Log	USCS Code	Bulk Sample	Sample Recovery	Blow Count	Soil Description and Observations
		GM	HAND DUG			SANDY SILTY GRAVEL (GM): brown, fine to medium gravel, fine to coarse sand, slightly moist.
5				CA 66%	12 9 9	
		SP		SPT 61%	9 6 6 6	SAND (SP): fine to medium grained, some silt, medium dense, moist.
				CA 92%	10 10 10 14	
10		SM		SPT 100%	12 9 10 10	SILTY SAND (SM): dark yellow brown, fine to medium sand, loose to medium dense, slightly moist to moist.
				CA 79%	10 10 9 9	
				SPT 61%	9 6 6 6	Decreasing silt below 14.0'.
15				CA 83%	14 17 19 24	
				SPT 88%	12 15 15	Laminated silty sand and sandy silt below 18.0'.
				TWALL	PUSH	
20				SHEL	PUSH	
				CA 92%	15 26 23 24	
				SPT 88%	7 11 16 16	
		ML				CLAYEY SILT (ML): gray, with fine sand (3.0" thick).
		SM		CA 87%	13 7 6 2	Very moist at 25.0'.
25		ML				SANDY CLAYEY SILT (ML): dark gray, very fine sand, some wood, very soft, moist to wet.
				SPT 88%	1 2 13 9	
		SP				SAND (SP): dark brown, fine to medium grained, trace silt, medium dense, wet.
		ML		CA 83%	12 18 8 5	SANDY SILT (ML): gray, very fine sand, some orange staining, wet.
		SP				SAND (SP): fine to medium grained (2.0" thick).
30		ML		CA 75%	7 7	SANDY CLAYEY SILT (ML): dark gray, very fine sand, wet.
		SP		THIN WALL	PUSH	SAND (SP): dark brown, fine to medium grained, medium dense, wet.
				CA 62%	14 13 13 15	
35				SPT 67%	2 9 21 17	
				CA 75%	24 18 16	
				SPT 67%	3 3 9 9	
		ML				SILT (ML): olive brown (2.0" thick).
		SP				SAND WITH SILT (SP): brown, fine to medium grained, medium dense, wet.

ERM
6650 SW Redwood Lane
Suite 300
Portland, Oregon 97224
(503) 542-8007

BOREHOLE LOG

Project Number: 0063836.02

Project Name: Arkema, Inc.

Location: Portland, Oregon

Contractor: Boart Longyear

Drilling Method: Hollow Stem Auger/Mud Rotary

Sampling Method: California/Split Spoon/Shelby Tube

Total Depth: 87.00'

Borehole Dia.: 10.00in (HSA), 5.88in (Mud Rotary)

Logged By: B. Robinson

Initial Water Level: ~27.00'

Date(s): 04/04/07 – 04/05/07

Depth (ft)	Graphic Log	USCS Code	Bulk Sample	Sample Recovery	Blow Count	Soil Description and Observations
				CA 83%	10 13 17	
				SPT 83%	5 6 9 9	
				CA 87%	20 15 8	SANDY SILT (ML): yellow brown and light brown, very fine sand, medium dense, moist.
45		ML		SPT 33%	3 7 7 8	SANDY CLAYEY SILT (ML): olive brown, fine sand, soft, wet.
				CA 66%	9 9 12	
				SPT 50%	3 3 4	
50				SHEL	PUSH	
		SM		CA 83%	7 6 7 7	SILTY SAND (SM): olive gray, fine sand, loose to medium dense, wet.
				SPT 77%	5 3 10	
55				CA 42%	9 16 27 25	
				SPT 100%	6 7 8	
				CA 75%	14 14 14 14	CLAYEY SILT (ML): light yellow brown, some fine sand, wet.
60		ML		SPT 100%	5 7 8	SANDY SILT (ML): dark olive brown, fine sand, some clay, loose to medium dense, wet.
				CA 88%	18 18 24 30	
				SPT 88%	5 6 10	
65				SHEL	PUSH	
				CA 75%	5 10 10 14	No clay below 67.0', loose.
				SPT 58%	5 7 10	6.0" thick SILT at 70.0', some fine sand, trace clay, grading to SILTY SAND (SM): medium dense to dense.
70		SM		CA 75%	20 20 25 30	2.0" thick CLAYEY SILT at 72.0'.
				SPT 89%	6 10 11	
		ML/SM		CA 88%	6 16 20 23	SANDY SILT/SILTY SAND (ML/SM): dark gray, alternating layers, some carbonized organics, medium dense, unconsolidated, rotten egg odor, wet.
75				SPT 94%	8 18 4	
				CA 83%	22 40 46 50	
					13	

ERM
6650 SW Redwood Lane
Suite 300
Portland, Oregon 97224
(503) 542-8007

BOREHOLE LOG

Site Id: B-121

Project Number: 0063836.02

Project Name: Arkema, Inc.

Location: Portland, Oregon

Contractor: Boart Longyear

Drilling Method: Hollow Stem Auger/Mud Rotary

Sampling Method: California/Split Spoon/Shelby Tube

Total Depth: 87.00'

Borehole Dia.: 10.00in (HSA), 5.88in (Mud Rotary)

Logged By: B. Robinson

Initial Water Level: ~27.00'

Date(s): 04/04/07 – 04/05/07

Depth (ft)	Graphic Log	USCS Code	Bulk Sample	Sample Recovery	Blow Count	Soil Description and Observations
				SPT 89%	15 17	
				SHEL	PUSH	
				CA 83%	17 43 43 40	Occasional layers of fine SAND WITH SILT.
85		SP		SPT 77%	9 23 20 26	SAND (SP): fine sand, with some silt, dense, wet.
				CA 42%	28 50/5	Some thin lenses of CLAYEY SILT at 86.0–87.0'.
						Total Depth – 87.0' bgs. Basalt chips in shoe.
90						
95						
100						
105						
110						
115						

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES
5540 Robert J. Mathews, Suite 1 El Dorado Hills, CA 95762
PH: 916.939.3400 FX: 916.939.3507

Laboratory Test Request

Project Name: Arkema Soil and Slurry Compatibility
Project Location: Portland, Oregon
Client Name: ERM
Client Project No.: 63836.03
Client Contact: Brendan Robinson

STL Job No.:
Date Received:
Tests Listed By:
Results Due By:
Disposal Date:

Sample Type Code:
ST - shelby, BT - brass, BG - baggie, BK - bulk
SS - stainless, AL - acetate, CC - cylinder

Test Legend:
Ordered ☐ Prepared ☒ Completed ☒ Printed ☒

Sample ID	Depth	Sample Type	Moisture Content - D2216	Moisture & Density - D2937	Atterburg Limit - D4318	Sieve Analysis - D422 / C136		Compaction - D1557 / D698		Consolidation - D2435		Permeability - D5084 / D2434	Unconfined Compression - D2166	Direct Shear (DS) - D3080	Triaxial Shear (UU) - D2850	Triaxial Shear (CU) - D4767						STL Sample Number	Notes
B-121 5-10	5-10	BG																					
B-121 10-15.5	10-15.5	BG																					
B-121 15.5-19	15.5-19	BG																					
B-121 19-25	19-25	BG																					
B-121 25-27	25-27	BG																					
B-121 27-29	27-29	BG																					
B-121 29-31	29-31	BG																					
B-121 31-32	31-32	SS																					
B-121 32-39	32-39	BG																					
B-121 39-44	39-44	BG																					
B-121 44-49	44-49	BG																					
B-121 49-50	49-50	SS																					
B-121 51-53	51-53	BG																					
B-121 53-59	53-59	BG																					
B-121 59-60	59-60	SS																					

Apr 05 07 12:47p 916-939-6641 p.3

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES
5040 Robert J. Mathews, Suite 1 El Dorado Hills, CA 95762
PH: 916.939.3460 / FX: 916.939.3507

Laboratory Test Request

Project Name:
Project Location:
Client Name:
Client Project No.:
Client Contact:

STL Job No.:
Date Received:
Tests Listed By:
Results Due By:
Disposal Date:

Sample Type Code:
ST - shelby, BT - brass, BG - baggie, BK - bulk
SS - stainless, AL - acetate, CC - cylinder

Test Legend:
Ordered ☐ Prepared ☐ Completed ☒ Printed ☒

Sample ID	Depth	Sample Type	Moisture Content - D2216	Moisture & Density - D2937	Atterberg Limit - D4318	Sieve Analysis - D422 / C136		Compaction - D1557 / D698		Consolidation - D2435		Permeability - D5084 / D2434	Unconfined Compression - D2166	Direct Shear (DS) - D3080	Triaxial Shear (UU) - D2850	Triaxial Shear (CU) - D4767						STL Sample Number	Notes
B-121 62-65	62-65	BG																					
B-121 67-72	67-72	BG																					
B-121 72-74	72-74	BG																					
B-121 75-80	75-80	BG																					
B-121 82-83	82-83	SS																					
B-121 84-87	84-87	BG																					

Apr 05 07 12:47p 916-939-6641 p.3

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES
5040 Robert J. Mathews, Suite 1 El Dorado Hills, CA 95762
PH: 916.939.3460 / FX 916.939.3507

Laboratory Test Request

Apr 05 07 12:47p 916-939-6641 p.3

Project Name: Arkema Soil and Slurry Compatibility
Project Location: Portland, Oregon
Client Name: ERM
Client Project No.: 63836-03
Client Contact: Brendan Robinson

STL Job No.:
Date Received:
Tests Listed By:
Results Due By:
Disposal Date:

Sample Type Code:
ST - shelby, BT - brass, BG - baggie, BK - bulk
SS - stainless, AL - acetate, CC - cylinder

Test Legend:
Ordered ☐ Prepared ☒ Completed ☒ Printed ☒

Sample ID	Depth	Sample Type	Moisture Content - D2216	Moisture & Density - D2937	Atterberg Limit - D4318	Sieve Analysis - D422 / C136		Compaction - D1557 / D698		Consolidation - D2435		Permeability - D5084 / D2434	Unconfined Compression - D2166	Direct Shear (DS) - D3080	Triaxial Shear (UU) - D2850	Triaxial Shear (CU) - D4767						STL Sample Number	Notes
B-120 5-10	5-10	BG				/																	
B-120 10-15	10-15	BG																					
B-120 15-19	15-19	BG																					
B-120 20-23	20-23	BG																					
B-120 22-27	22-27	BG																					
B-120 27-28	27-28	BG																					
B-120 28-34	28-34	BG																					
B-120 34-35	34-35	BG																					
B-120 35-37	35-37	BG																					
B-120 39-40	39-40	BG																					
B-120 41-44	41-44	BG																					
B-120 44.5-45.5	44.5-45.5	BG																					
B-120 46-47	46-47	BG																					
B-120 49-50.5	49-50.5	BG																					

Appendix B
Clay Additive Manufacturer
Specification Sheets

BARA-KADE® SP Slurry Trench and Soil Sealing Grade – 200 Mesh

Created: 05/20/98
Category: Product Data Sheet

A high quality, untreated sodium bentonite used in slurry wall construction, soil sealing, and other hydraulic barriers. This product meets all API 13A Section 10 specifications for an untreated bentonite. Due to its fine particle size, it is primarily used with pugmill mixing methods for soil/bentonite liner projects.

Typical Physical Properties*

	TYPICAL	SPECIFICATION
SCREEN ANALYSIS		
Dry Screen, percent minus 200 mesh	77	
Wet Screen, percent plus 200 mesh	2	
SLURRY PROPERTIES (6% Suspension)		
Viscosity, FANN® 600 rpm	22	
Apparent Viscosity, cps	11	
Yield - 42 gal bbl of 15 cps slurry/ton	84	
Filter cake, in.	3/32	
Plastic Viscosity (PV)	8	
Yield Point, lb./100 ft^2	6	
Filtrate, 30 minutes @ 100 psi, ml	11	
Marsh Funnel, seconds/quart	36	
SLURRY PROPERTIES (6.7% SUSPENSION), API 13A, Sec. 5		
Yield Point/Plastic Viscosity Ratio	1.3	1.5 max
Plastic Viscosity	16	10.0 min
Filtrate Loss, 30 minutes at 100 psi	10	12.5 max
OTHER PROPERTIES		
Moisture, percent	9	
Swell Index (ml)	28	
Plate Water Absorption, wt % @ 20° C/18 hr	850	
Specific Gravity	2.7	
pH, 6% suspension	9.2	
Bulk Density (lbs per ft^3) uncompacted	49	
Bulk Density (lbs per ft^3) compacted	72	

* The typical physical values listed are not to be construed as rigid specifications.
BARA-KADE and FANN are registered trademarks of Halliburton Energy Services, Inc.
Revision Date: August 30, 2004

Because the conditions of use of this product are beyond the seller's control, the product is sold without warranty either express or implied and upon condition that purchaser make its own test to determine the suitability for purchaser's application. Purchaser assumes all risk of use and handling of this product. This product will be replaced if defective in manufacture or packaging or if damaged. Except for such replacement, seller is not liable for any damages caused by this product or its use. The statements and recommendations made herein are believed to be accurate. No guarantee of their accuracy is made, however.

BPM Minerals LLC
3000 N Sam Houston Pkwy E, Houston, TX 77032-3219
(281) 871-7900, Fax (281) 871-7940
www.bentonite.com

MATERIAL SAFETY DATA SHEET

Product Trade Name: **BARA-KADE® BENTONITE**

Revision Date: 31-Mar-2005

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Product Trade Name: BARA-KADE® BENTONITE
Synonyms: None
Chemical Family: Mineral
Application: Additive

Manufacturer/Supplier
BPM Minerals LLC
3000 N Sam Houston Parkway East
Houston, TX 77032

Telephone: (281) 871-7900
Fax: (281) 871-7940
Emergency Telephone: (800) 666-9260 or (713) 753-3000

Prepared By
Chemical Compliance
Telephone: 1-580-251-4335

2. COMPOSITION/INFORMATION ON INGREDIENTS

SUBSTANCE	CAS Number	PERCENT	ACGIH TLV-TWA	OSHA PEL-TWA
Crystalline silica, cristobalite	14464-46-1	0 - 1%	0.05 mg/m^3	1/2 x $\frac{10\ mg/m^3}{\%SiO2 + 2}$
Crystalline silica, tridymite	15468-32-3	0 - 1%	0.05 mg/m^3	1/2 x $\frac{10\ mg/m^3}{\%SiO2 + 2}$
Crystalline silica, quartz	14808-60-7	1 - 5%	0.05 mg/m^3	$\frac{10\ mg/m^3}{\%SiO2 + 2}$
Bentonite	1302-78-9	60 - 100%	Not applicable	Not applicable

More restrictive exposure limits may be enforced by some states, agencies, or other authorities.

3. HAZARDS IDENTIFICATION

Hazard Overview

CAUTION! - ACUTE HEALTH HAZARD
May cause eye and respiratory irritation.

DANGER! - CHRONIC HEALTH HAZARD
Breathing crystalline silica can cause lung disease, including silicosis and lung cancer. Crystalline silica has also been associated with scleroderma and kidney disease.

This product contains quartz, cristobalite, and/or tridymite which may become airborne without a visible cloud. Avoid breathing dust. Avoid creating dusty conditions. Use only with adequate ventilation to keep exposures below recommended exposure limits. Wear a NIOSH certified, European Standard EN 149, or equivalent respirator when using this product. Review the Material Safety Data Sheet (MSDS) for this product, which has been provided to your employer.

4. FIRST AID MEASURES

Inhalation If inhaled, remove from area to fresh air. Get medical attention if respiratory irritation develops or if breathing becomes difficult.

Skin Wash with soap and water. Get medical attention if irritation persists.

Eyes In case of contact, immediately flush eyes with plenty of water for at least 15 minutes and get medical attention if irritation persists.

Ingestion Under normal conditions, first aid procedures are not required.

Notes to Physician Treat symptomatically.

5. FIRE FIGHTING MEASURES

Flash Point/Range (F):	Not Determined
Flash Point/Range (C):	Not Determined
Flash Point Method:	Not Determined
Autoignition Temperature (F):	Not Determined
Autoignition Temperature (C):	Not Determined
Flammability Limits in Air - Lower (%):	Not Determined
Flammability Limits in Air - Upper (%):	Not Determined

Fire Extinguishing Media All standard firefighting media.

Special Exposure Hazards Not applicable.

Special Protective Equipment for Fire-Fighters Not applicable.

NFPA Ratings: Health 0, Flammability 0, Reactivity 0
HMIS Ratings: Flammability 0, Reactivity 0, Health 0*

6. ACCIDENTAL RELEASE MEASURES

Personal Precautionary Measures Use appropriate protective equipment. Avoid creating and breathing dust.

Environmental Precautionary Measures None known.

Procedure for Cleaning / Absorption Collect using dustless method and hold for appropriate disposal. Consider possible toxic or fire hazards associated with contaminating substances and use appropriate methods for collection, storage and disposal.

7. HANDLING AND STORAGE

Handling Precautions This product contains quartz, cristobalite, and/or tridymite which may become airborne without a visible cloud. Avoid breathing dust. Avoid creating dusty conditions. Use only with adequate ventilation to keep exposure below recommended exposure limits. Wear a NIOSH certified, European Standard En 149, or equivalent respirator when using this product. Material is slippery when wet.

Storage Information Use good housekeeping in storage and work areas to prevent accumulation of dust. Close container when not in use. Do not reuse empty container.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Engineering Controls Use approved industrial ventilation and local exhaust as required to maintain exposures below applicable exposure limits listed in Section 2.

Respiratory Protection Wear a NIOSH certified, European Standard EN 149, or equivalent respirator when using this product.

Hand Protection Normal work gloves.

Skin Protection Wear clothing appropriate for the work environment. Dusty clothing should be laundered before reuse. Use precautionary measures to avoid creating dust when removing or laundering clothing.

Eye Protection Wear safety glasses or goggles to protect against exposure.

Other Precautions None known.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical State:	Solid
Color:	Various
Odor:	Odorless
pH:	8-10
Specific Gravity @ 20 C (Water=1):	2.65
Density @ 20 C (lbs./gallon):	Not Determined
Bulk Density @ 20 C (lbs/ft3):	50-70
Boiling Point/Range (F):	Not Determined
Boiling Point/Range (C):	Not Determined
Freezing Point/Range (F):	Not Determined
Freezing Point/Range (C):	Not Determined
Vapor Pressure @ 20 C (mmHg):	Not Determined
Vapor Density (Air=1):	Not Determined
Percent Volatiles:	Not Determined
Evaporation Rate (Butyl Acetate=1):	Not Determined
Solubility in Water (g/100ml):	Insoluble
Solubility in Solvents (g/100ml):	Not Determined
VOCs (lbs./gallon):	Not Determined
Viscosity, Dynamic @ 20 C (centipoise):	Not Determined
Viscosity, Kinematic @ 20 C (centistrokes):	Not Determined
Partition Coefficient/n-Octanol/Water:	Not Determined
Molecular Weight (g/mole):	Not Determined

10. STABILITY AND REACTIVITY

Stability Data: Stable

Hazardous Polymerization: Will Not Occur

Conditions to Avoid	None anticipated
Incompatibility (Materials to Avoid)	Hydrofluoric acid.
Hazardous Decomposition Products	Amorphous silica may transform at elevated temperatures to tridymite (870 C) or cristobalite (1470 C).
Additional Guidelines	Not Applicable

11. TOXICOLOGICAL INFORMATION

Principle Route of Exposure Eye or skin contact, inhalation.

Inhalation

Inhaled crystalline silica in the form of quartz or cristobalite from occupational sources is carcinogenic to humans (IARC, Group 1). There is sufficient evidence in experimental animals for the carcinogenicity of tridymite (IARC, Group 2A).

Breathing silica dust may cause irritation of the nose, throat, and respiratory passages. Breathing silica dust may not cause noticeable injury or illness even though permanent lung damage may be occurring. Inhalation of dust may also have serious chronic health effects (See "Chronic Effects/Carcinogenicity" subsection below).

Skin Contact May cause mechanical skin irritation.

Eye Contact May cause eye irritation.

Ingestion None known

Aggravated Medical Conditions Individuals with respiratory disease, including but not limited to asthma and bronchitis, or subject to eye irritation, should not be exposed to quartz dust.

Chronic Effects/Carcinogenicity

Silicosis: Excessive inhalation of respirable crystalline silica dust may cause a progressive, disabling, and sometimes-fatal lung disease called silicosis. Symptoms include cough, shortness of breath, wheezing, non-specific chest illness, and reduced pulmonary function. This disease is exacerbated by smoking. Individuals with silicosis are predisposed to develop tuberculosis.

Cancer Status: The International Agency for Research on Cancer (IARC) has determined that crystalline silica inhaled in the form of quartz or cristobalite from occupational sources can cause lung cancer in humans (Group 1 - carcinogenic to humans) and has determined that there is sufficient evidence in experimental animals for the carcinogenicity of tridymite (Group 2A - possible carcinogen to humans). Refer to IARC Monograph 68, Silica, Some Silicates and Organic Fibres (June 1997) in conjunction with the use of these minerals. The National Toxicology Program classifies respirable crystalline silica as "Known to be a human carcinogen". Refer to the 9th Report on Carcinogens (2000). The American Conference of Governmental Industrial Hygienists (ACGIH) classifies crystalline silica, quartz, as a suspected human carcinogen (A2).

There is some evidence that breathing respirable crystalline silica or the disease silicosis is associated with an increased incidence of significant disease endpoints such as scleroderma (an immune system disorder manifested by scarring of the lungs, skin, and other internal organs) and kidney disease.

Other Information For further information consult "Adverse Effects of Crystalline Silica Exposure" published by the American Thoracic Society Medical Section of the American Lung Association, American Journal of Respiratory and Critical Care Medicine, Volume 155, pages 761-768 (1997).

Toxicity Tests

Oral Toxicity: Not determined

Dermal Toxicity: Not determined

Inhalation Toxicity: Not determined

Primary Irritation Effect: Not determined

Carcinogenicity Refer to IARC Monograph 68, Silica, Some Silicates and Organic Fibres (June 1997).

Genotoxicity: Not determined

Reproductive / Developmental Toxicity: Not determined

12. ECOLOGICAL INFORMATION

Mobility (Water/Soil/Air) Not determined

Persistence/Degradability Not determined

Bio-accumulation Not Determined

Ecotoxicological Information

Acute Fish Toxicity: TLM96: 10000 ppm (Oncorhynchus mykiss)
Acute Crustaceans Toxicity: Not determined
Acute Algae Toxicity: Not determined

Chemical Fate Information Not determined

Other Information Not applicable

13. DISPOSAL CONSIDERATIONS

Disposal Method Bury in a licensed landfill according to federal, state, and local regulations.

Contaminated Packaging Follow all applicable national or local regulations.

14. TRANSPORT INFORMATION

Land Transportation

DOT
Not restricted

Canadian TDG
Not restricted

ADR Not restricted

Air Transportation

ICAO/IATA Not restricted

Sea Transportation

IMDG
Not restricted

Other Shipping Information

Labels: None

15. REGULATORY INFORMATION

US Regulations

US TSCA Inventory	All components listed on inventory.
EPA SARA Title III Extremely Hazardous Substances	Not applicable
EPA SARA (311,312) Hazard Class	Acute Health Hazard Chronic Health Hazard
EPA SARA (313) Chemicals	This product does not contain a toxic chemical for routine annual "Toxic Chemical Release Reporting" under Section 313 (40 CFR 372).
EPA CERCLA/Superfund Reportable Spill Quantity For This Product	Not applicable.
EPA RCRA Hazardous Waste Classification	If product becomes a waste, it does NOT meet the criteria of a hazardous waste as defined by the US EPA.
California Proposition 65	The California Proposition 65 regulations apply to this product.
MA Right-to-Know Law	One or more components listed.
NJ Right-to-Know Law	One or more components listed.
PA Right-to-Know Law	One or more components listed.

Canadian Regulations

Canadian DSL Inventory	All components listed on inventory.
WHMIS Hazard Class	D2A Very Toxic Materials (Crystalline silica)

16. OTHER INFORMATION

The following sections have been revised since the last issue of this MSDS
Not applicable

Additional Information

For additional information on the use of this product, contact your local Halliburton representative.

For questions about the Material Safety Data Sheet for this or other Halliburton products, contact Chemical Compliance at 1-580-251-4335.

Disclaimer Statement

This information is furnished without warranty, expressed or implied, as to accuracy or completeness. The information is obtained from various sources including the manufacturer and other third party sources. The information may not be valid under all conditions nor if this material is used in combination with other materials or in any process. Final determination of suitability of any material is the sole responsibility of the user.

*****END OF MSDS*****

Floridin

UNIQUE CLAY MINERALS FOR ENVIRONMENTAL APPLICATIONS

FLORIGEL® H-Y

(Attapulgite Clay)

FOR SLURRY TRENCH CUT OFF WALLS

APPLICATIONS

Forms the slurry to stabilize the open trench and is added to the backfill to reduce the permeability of the final wall.

BENEFITS

- A 4-5% clay slurry will:
  1. Result in a minimum Marsh Funnel viscosity of 40 sec.
  2. Result in a slurry density of 64.1 pcf in fresh water.
  3. Allow salt water to be used as the make up water.
  4. Suspend a 20/30 mesh sand better than sodium bentonite.
- When 2% clay is added to the backfill in slurry form, the permeability is reduced by about a factor of 25.
- In either of the above applications, FLORIGEL® H-Y is more stable than sodium bentonite when in contact with saturated chlorinated hydrocarbons and with:
  1. High conductance fluids - high electrolyte concentration and low dielectric constant.
  2. Fluids with increased cation valence.
  3. Basic organic fluids and concentrated organic acids.
  4. Polar and non-polar organic fluids.

  The better stability of FLORIGEL® H-Y in contact with the above fluids results from its spicular particle shape, versus plate shaped particles for bentonite, and FLORIGEL® H-Y's lower cation exchange capacity.

PHYSICAL PROPERTIES (Typical Values)

Free Moisture, %	13.4
Bulk Density (loose), pcf	42.3
Specific Gravity	2.55
Cation Exchange Capacity, meq/100 gm	20-30
pH - Fresh Water	9.8
Salt Water	8.8
Liquid Limit, %	351
Plasticity Index, %	253
Expansion Index per ASTM D4829-88; 50% saturation	368
Minimum Coef. of Permeability in Water at Optimum Moisture Content of 35.5% (Clay Only), cm/sec	10^{-8} - 10^{-9}
Viscostiy (High Shear Mixed)	
API yield, bbls/ton	135
At 4½% clay concentration - distilled water	
Marsh Funnel, sec	40
FANN Viscometer	
Apparent Viscosity, cps	24
Plastic Viscosity, cps	6
Yield Point, lb/100 sq. ft.	35
Water Loss, cc - Fresh Water	110
Sea Water	100

Screen Analysis, %	
-50 mesh	97
-100 mesh	82
-200 mesh	50
-324 mesh	32

Dispersed Particles Size Distribution, %		
Clay:	$10 - 60 \times 10^{-4}$ mm	88
Silt:	$6 - 80 \times 10^{-3}$ mm	7
Sand:	$8 - 500 \times 10^{-2}$ mm	5

USED IN THE FOLLOWING PROJECTS:

1. A chemical plant along the Texas Gulf Coast was situated over saline ground water with an inorganic chloride background of 3,000-32,000 ppm. Chlorinated hydrocarbon concentrations of 3,300 ppm existed. Backfill admixtures with 2% bentonite were 8 times more permeable than non dispersed FLORIGEL® H-Y, and 17 times more permeable than chemically dispersed FLORIGEL® H-Y; thus, FLORIGEL® H-Y was used for the slurry and backfill admixture.

2. A clay barrier around an old landfill in San Francisco Bay was leaking a toxic leachate into the Bay. The leachate destroyed both conventional and treated sodium bentonite, but did not effect attapulgite clay. The contractor, GeoCon Inc., used FLORIGEL® H-Y both for the slurry and backfill additive to construct a 40' deep by 5' wide wall with a maximum permeability of 10^{-7} cm/sec.

3. The owner of a landfill had constructed a lagoon and accepted a variety of hazardous wastes. Leachates with the following analysis showed up in several monitoring wells.

Compound	Concentration - ppb
Phenolics	10,500-26,000
Phenol	18,000-74,000
Ethylene Chloride	0-40
Acetone	2,600-5,700
Benzene	190-1,100
Toluene	1,300-5,200
Xylene & Ethylbenzene	90-7,100
Gasoline	13,000-65,000

Contact with this leachate caused serious cracks with standard and "contaminant resistant" bentonite, but not with FLORIGEL® H-Y. The permeability of 1.5-4.5% bentonite admixtures with the backfill actually increased as the bentonite content increased. Also, the slurry made with bentonite flocculated and fell out of suspension. The project was successfully constructed by GeoCon Inc. using attapulgite clay for the slurry and backfill admixture.

MINERAL DESCRIPTION	TYPICAL CHEMICAL ANALYSIS*, %			
Attapulgite Mineral	Si as SiO_2	66.2	Ca as CaO	2.9
Hydrous Magnesium Aluminum Silicate	Mg as MgO	9.7	P as Pa_2O_5	1.0
Fuller's Earth	Al as Al_2O_3	11.7	K as K_2O	1.1
Spicular Structure	Fe as Fe_2O_3	4.0	C as CO_2	2.6

*Although the elements are reported as oxides they are actually present as complex aluminosilicates.

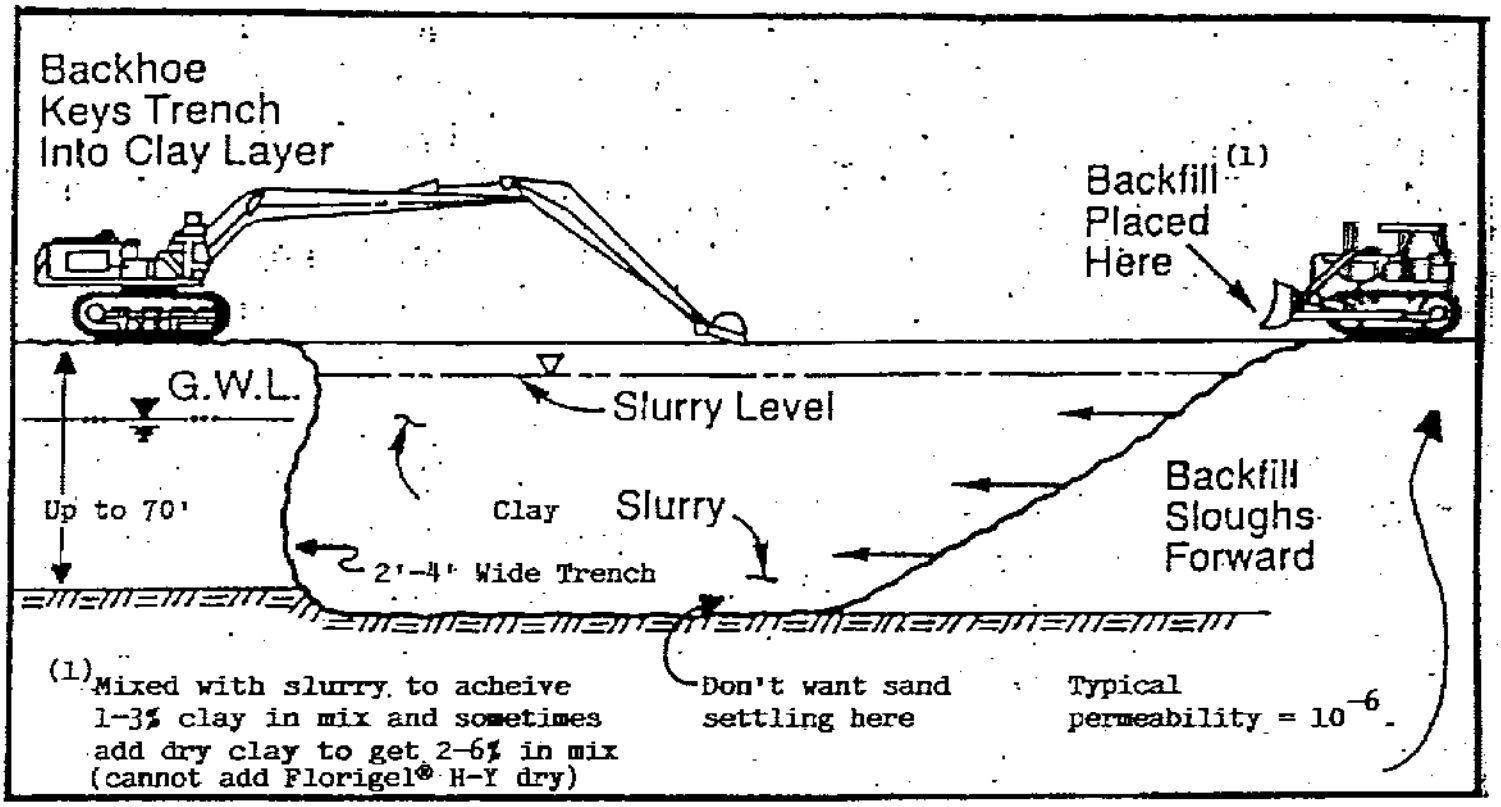
AVAILABLE from Quincy, FL, in 50 lb. bags, bulk bags, and bulk.

This information is based on data believed to be accurate but no warranty of accuracy is to be implied. Manner of use is the sole risk and liability of the user.

9/02/93

REG. U.S. PAT. & TM. OFF. BY FLORIDIN COMPANY

SLURRY TRENCH CUTOFF WALLS



Clay Performance Criteria & Phase I Ardaman Results on Florigel® H-Y, Sepiogel A, Imvite 1016 (saponite) and Sodium Bentonite

1. Sufficient slurry density to prevent trench walls from sloughing or collapsing - 64 pcf min. Requires 4½ - 5% clay.

2. Sufficient viscosity to maintain uniform density for 2-3 days (keep clay in suspension). Marsh Funnell must be about 40 sec. Requires usages of 3% H-Y, 4% Sep A, 5% Imvite 1016, and 6% bentonite.

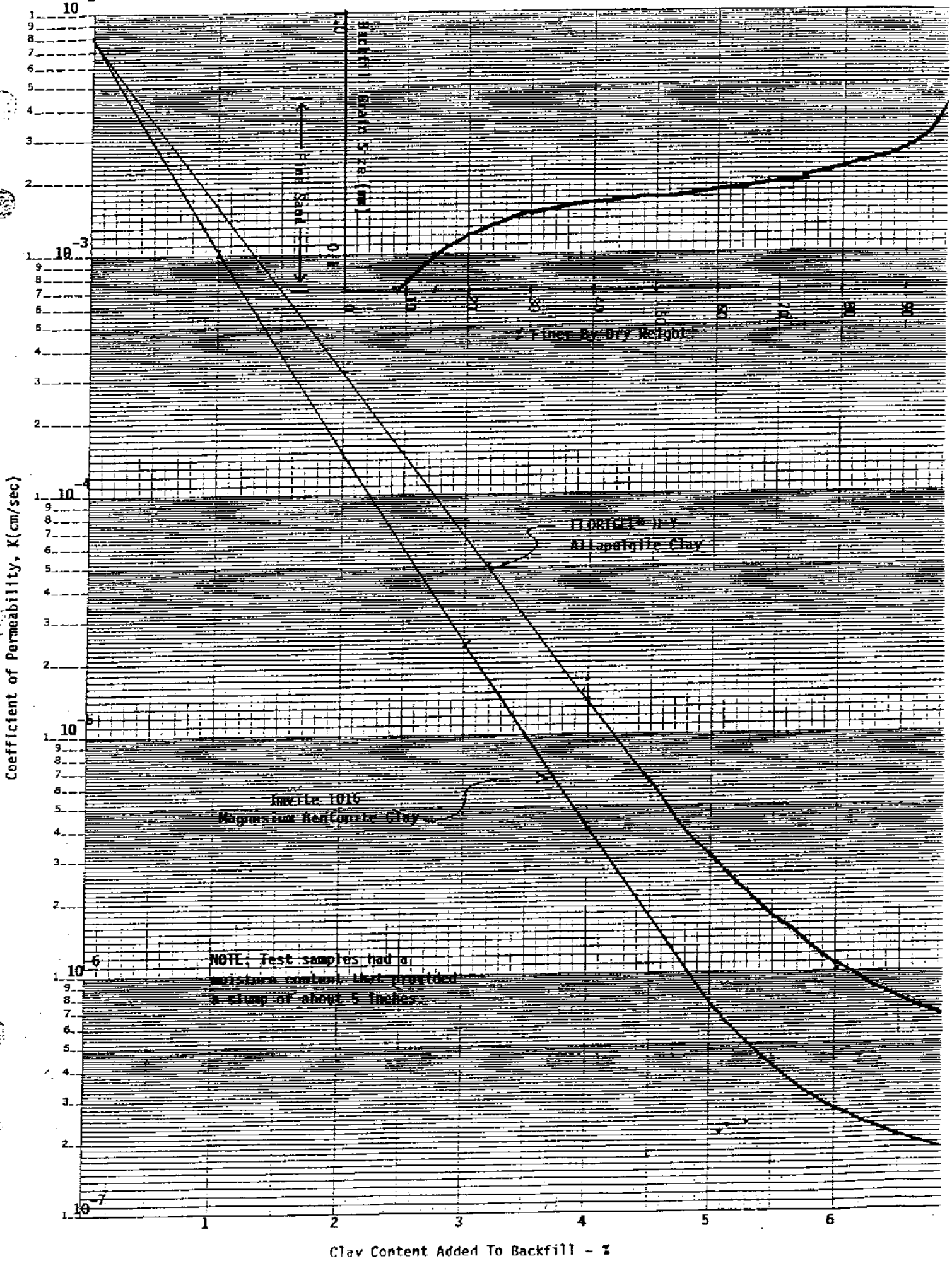
3. Plastic viscosity must be less than 20cps so that slurry can be pumped, will mix well in backfill, and backfill will displace. All are 2-10 cps at 6% concentration.

4. Yield stress must be high enough to suspend sand particles. H-Y the best and Imvite 1016 & bentonite the worst, but all satisfactory.

5. No aging problem for all clays for 7 days - degeneration of slurry or viscosity increasing to level affecting workability.

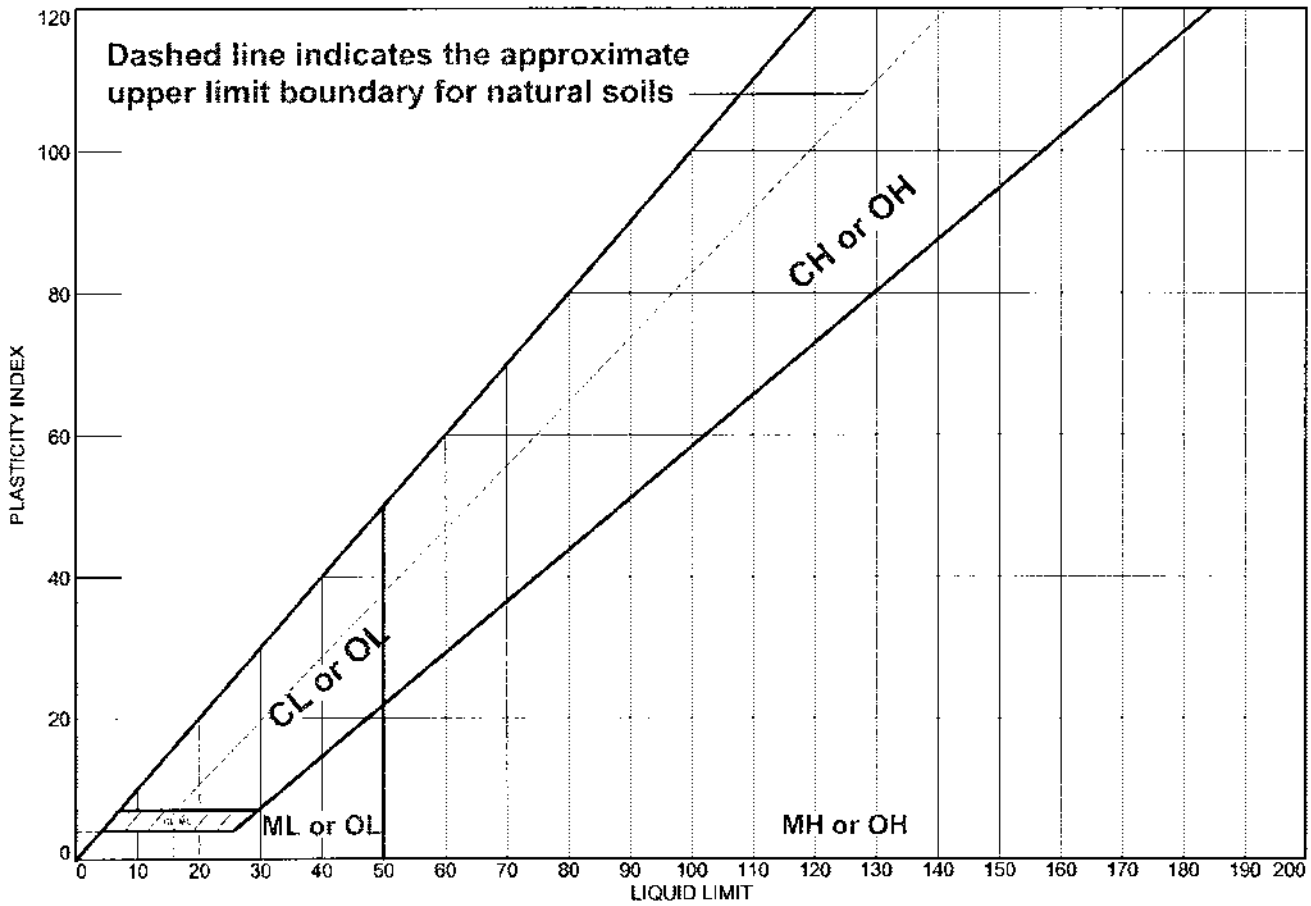
6. Best results require high shear mixture of H-Y & Sep A, 24 hour hydration of bentonite, and some of both for Imvite 1016. (see back).

Reduction in Permeability of Slurry Trench Wall Using Floridin Clays



Appendix C
Materials Testing Laboratory Reports

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Bentonite w/DI Water	426	45	381			

Project No. 07-167 **Client:** ERM

Project: Arkema Portland Harbor Site

Portland, OR

●**Location:** Bentonite w/DI Water **Sample Number:** 6/12/07

Remarks:

●Section 14

SIERRA TESTING LABS, INC.

El Dorado Hills, CA

Figure

Tested By: AM **Checked By:** CMW

SWELL INDEX OF CLAY COMPONENTS OF GEOSYNTHETIC CLAY LINERS

Swell Index, mL /2 g
12.0

Test Method: ASTM D5890-06

SAMPLE IDENTIFICATION: Bentonite Clay
SAMPLE DESCRIPTION: - #100 Bentonite Clay

LABORATORY NO. :

PROJECT NUMBER:	07-167	June 12, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland Oregon

SLURRY MIX TEST RESULTS

Sample Name: Attapulgite with PW H2O

Mix Proportions: PW H_2O _ 3304.4 ml + Attapulgite _ 209.4 g

Initial pH Reading: 9.87
Initial Conductivity Reading (uS): 142

Time (hrs)	Density (pcf)	Marsh (sec)
0.0	67.2	36.0
0.5	67.3	36.0
1.0	67.6	37.0
2.0	67.7	37.0
4.0	68.0	39.0
8.0	68.1	40.0
24.0	68.1	41.0
48.0	68.1	41.0
72.0	68.1	41.0

Final pH Reading: 9.81
Final Conductivity Reading (uS): 141

Notes:

Conductivity - Range 10-19990 uS, Resolution 10 uS, Accuracy +/- 0.5%
pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: Multi Meter (Extech 341450)

PROJECT NUMBER:	07-167	September 21, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

SLURRY MIX TEST RESULTS

Sample Name: Bentonite with PW H2O + 15% CGW

Mix Proportions: PW _ 2550 ml + CGW _ 450 ml + Bentonite _ 300 g

Initial pH Reading: 8.43
Initial Conductivity Reading (uS): 16940

Time (hrs)	Density (pcf)	Marsh (sec)
0.0	66.5	36.0
0.5	66.5	36.0
1.0	66.7	37.0
2.0	66.0	38.0
4.0	65.1	39.0
8.0	65.6	41.0
24.0	66.8	44.0
48.0	67.0	45.0
72.0	67.1	45.0

Final pH Reading: 8.40
Final Conductivity Reading (uS): 16900

Notes:

Conductivity - Range 10-19990 uS, Resolution 10 uS, Accuracy +/- 0.5%
pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: Multi Meter (Extech 341450)

PROJECT NUMBER:	07-167	December 19, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

SLURRY MIX TEST RESULTS

Sample Name: Attapulgite with PW H2O + 15% OGW

Mix Proportions: PW _ 2550 ml + OGW _ 450 ml + Attapulgite _ 500 g

Initial pH Reading: 9.31
Initial Conductivity Reading (uS): 207

Time (hrs)	Density (pcf)	Marsh (sec)
0.0	67.0	37.0
0.5	67.0	37.0
1.0	66.8	39.0
2.0	66.4	39.0
4.0	67.3	39.0
8.0	67.5	39.0
24.0	67.7	40.0
48.0	67.9	40.0
72.0	67.9	41.0

Final pH Reading: 9.26
Final Conductivity Reading (uS): 212

Notes:

Conductivity - Range 10-19990 uS, Resolution 10 uS, Accuracy +/- 0.5%
pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: Multi Meter (Extech 341450)

PROJECT NUMBER:	07-167	December 18, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

SLURRY MIX TEST RESULTS

Sample Name: Attapulgite with DI H2O

Mix Proportions: DI H_2O _ 2893.1 ml + Attapulgite _ 184.7 g

Initial pH Reading: 10.03
Initial Conductivity Reading (uS): 110

Time (hrs)	Density (pcf)	Marsh (sec)
0.0	66.2	30.0
0.5	66.0	30.0
1.0	65.9	31.0
2.0	65.4	33.0
4.0	65.0	33.0
8.0	65.0	32.0
24.0	64.9	32.0

Final pH Reading: 9.85
Final Conductivity Reading (uS): 110

Notes:

Conductivity - Range 10-19990 uS, Resolution 10 uS, Accuracy +/- 0.5%
pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: Multi Meter (Extech 341450)

PROJECT NUMBER:	07-167	July 18, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

SLURRY MIX TEST RESULTS

Sample Name: Bentonite with DI H2O

Mix Proportions: DI H_2O 3702.5 ml + Bentonite _ 300 g

Initial pH Reading: 9.87
Initial Conductivity Reading (uS): 760

Time (hrs)	Density (pcf)	Marsh (sec)
0.0	65.2	35.8
0.5	65.2	36.0
1.0	65.0	37.0
2.0	64.5	37.0
4.0	64.2	37.5
8.0	64.5	37.5
24.0	64.8	38.0

Final pH Reading: 9.75
Final Conductivity Reading (uS): 810

Notes:

Conductivity - Range 10-19990 uS, Resolution 10 uS, Accuracy +/- 0.5%
pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: Multi Meter (Extech 341450)

PROJECT NUMBER:	07-167	July 18, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIAL TESTING ENGINEERS

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

SLURRY MIX TEST RESULTS

Sample Name: Bentonite with PW H2O

Mix Proportions: PW H_2O _ 3098.4 ml + Bentonite _ 200.3 g

Initial pH Reading: 9.82
Initial Conductivity Reading (uS): 783

Time (hrs)	Density (pcf)	Marsh (sec)
0.0	67.2	40.2
0.5	67.0	40.5
1.0	66.9	41.2
2.0	66.8	41.4
4.0	67.0	41.3
8.0	67.2	41.4
24.0	67.4	41.6
48.0	67.4	41.5
72.0	67.4	41.6

Final pH Reading: 9.61
Final Conductivity Reading (uS): 874

Notes:

Conductivity - Range 10-19990 uS, Resolution 10 uS, Accuracy +/- 0.5%
pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: Multi Meter (Extech 341450)

PROJECT NUMBER:	07-167	September 21, 2007	Arkema Portland Harbor Site Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

SLURRY MIX TEST RESULTS

Sample Name: Attapulgite with PW H2O + 15% CGW

Mix Proportions: PW _ 2550 ml : CGW _ 450 ml + Attapulgite _ 500 g

Initial pH Reading: 9.29
Initial Conductivity Reading (uS): 14910

Time (hrs)	Density (pcf)	Marsh (sec)
0.0	67.1	53.0
0.5	67.1	53.0
1.0	67.7	60.0
2.0	68.0	63.0
4.0	68.2	65.0
8.0	68.0	65.0
24.0	67.7	64.0
48.0	67.8	64.0
72.0	67.9	64.0

Final pH Reading: 9.27
Final Conductivity Reading (uS): 15010

Notes:

Conductivity - Range 10-19990 uS, Resolution 10 uS, Accuracy +/- 0.5%
pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: Multi Meter (Extech 341450)

PROJECT NUMBER:	07-167	December 18, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

SLURRY MIX TEST RESULTS

Sample Name: Bentonite with PW H2O

Mix Proportions: PW H_2O _ 3151.4 ml + Bentonite _ 201.7 g

Initial pH Reading: 9.75
Initial Conductivity Reading (uS): 760

Time (hrs)	Density (pcf)	Marsh (sec)
0.0	65.2	37.0
0.5	64.8	37.5
1.0	65.0	38.0
2.0	64.8	37.0
4.0	64.9	38.0
8.0	65.2	38.0
24.0	65.0	38.5

Final pH Reading: 9.54
Final Conductivity Reading (uS): 830

Notes:

Conductivity - Range 10-19990 uS, Resolution 10 uS, Accuracy +/- 0.5%
pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: Multi Meter (Extech 341450)

PROJECT NUMBER:	07-167	July 18, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

SLURRY MIX TEST RESULTS

Sample Name: Bentonite with PW H2O + 15% OGW

Mix Proportions: PW _ 2550 ml + OGW _ 450 ml + Bentonite _ 200 g

Initial pH Reading: 8.81
Initial Conductivity Reading (uS): 327

Time (hrs)	Density (pcf)	Marsh (sec)
0.0	66.5	35.0
0.5	66.5	36.0
1.0	67.0	36.0
2.0	65.0	36.0
4.0	64.5	37.0
8.0	64.3	38.0
24.0	63.7	41.0
48.0	64.0	41.0
72.0	64.1	42.0

Final pH Reading: 8.77
Final Conductivity Reading (uS): 316

Notes:

Conductivity - Range 10-19990 uS, Resolution 10 uS, Accuracy +/- 0.5%
pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: Multi Meter (Extech 341450)

PROJECT NUMBER:	07-167	December 19, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Impermix/OA/DI, 6/26/07 Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Cast Cylinder
Remarks: 45 Day Test , DI water permeant

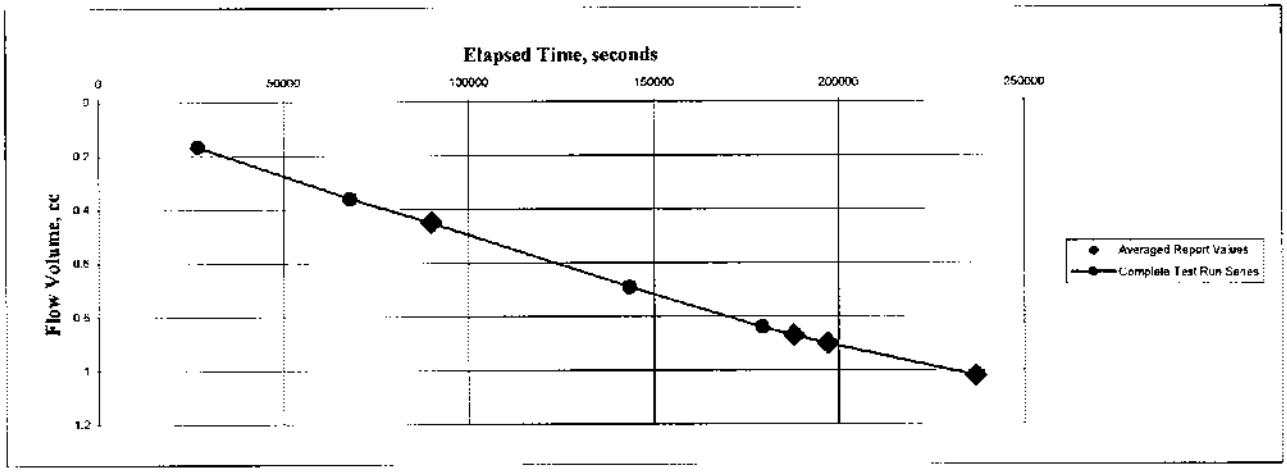
TEST RESULTS

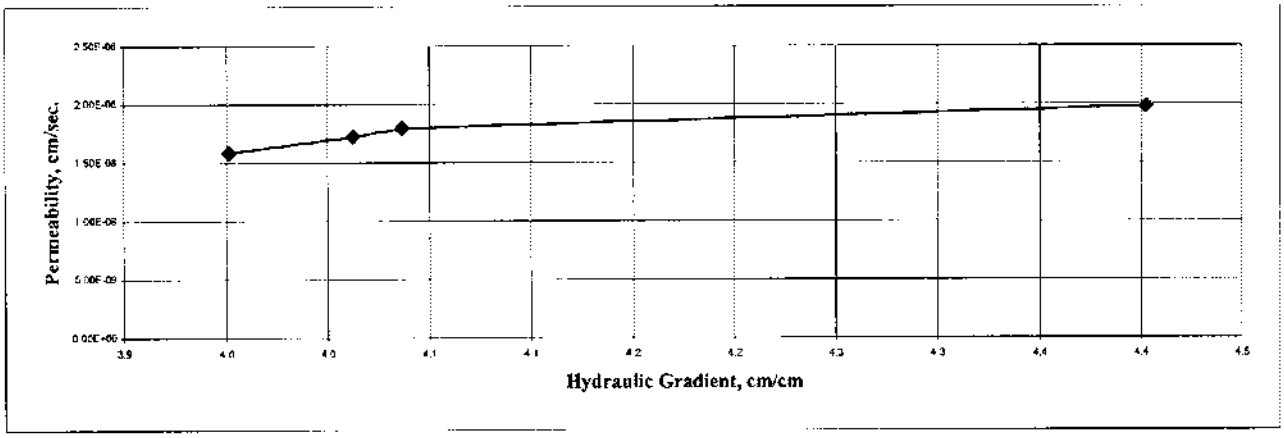
Permeability, cm/sec.: 1.77E-08 **Average Hydraulic Gradient: 4.1**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	8.20	Specimen Height, cm:	8.20
Specimen Diameter, cm:	7.62	Specimen Diameter, cm:	7.62
Dry Unit Weight, pcf:	32.3	Dry Unit Weight, pcf:	32.3
Moisture Content, %	135.1	Moisture Content, %	136.1
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	August 10, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SPECIALISTS

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Impermix/CAsoil, 6/26/07 Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Cast Cylinder
Remarks: 45 Day Test , CGW Permeant

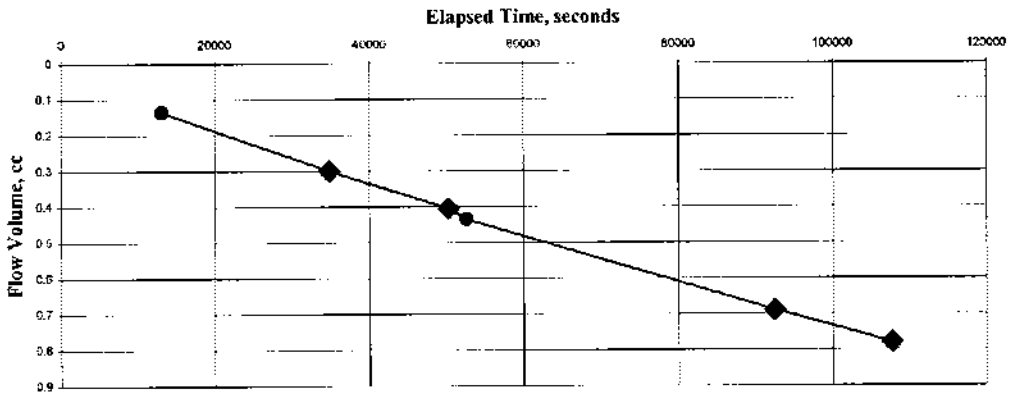
TEST RESULTS

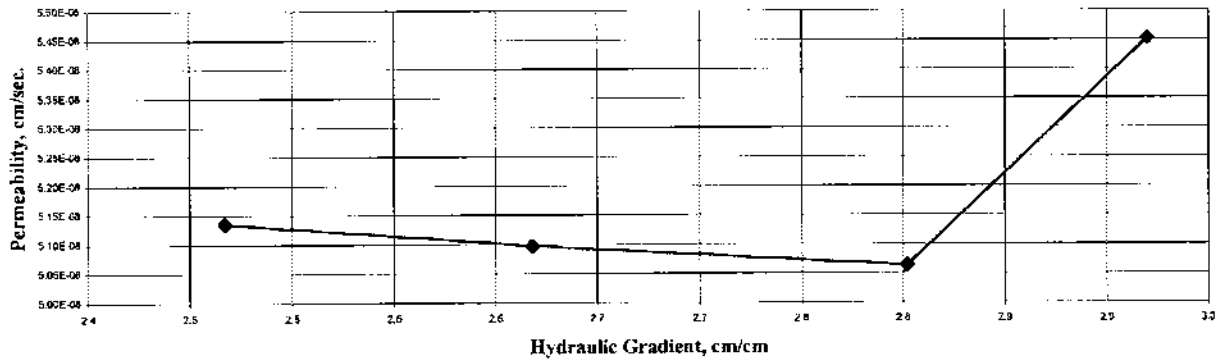
Permeability, cm/sec.: 5.19E-08 **Average Hydraulic Gradient: 2.7**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	7.62	Specimen Height, cm:	7.62
Specimen Diameter, cm:	7.62	Specimen Diameter, cm:	7.62
Dry Unit Weight, pcf:	29.7	Dry Unit Weight, pcf:	29.7
Moisture Content, %	161.4	Moisture Content, %	162.6
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	August 10, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Impermix/CAsoil, 6/26/07 Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Cast Cylinder
Remarks: 45 Day Test , DI water permeant

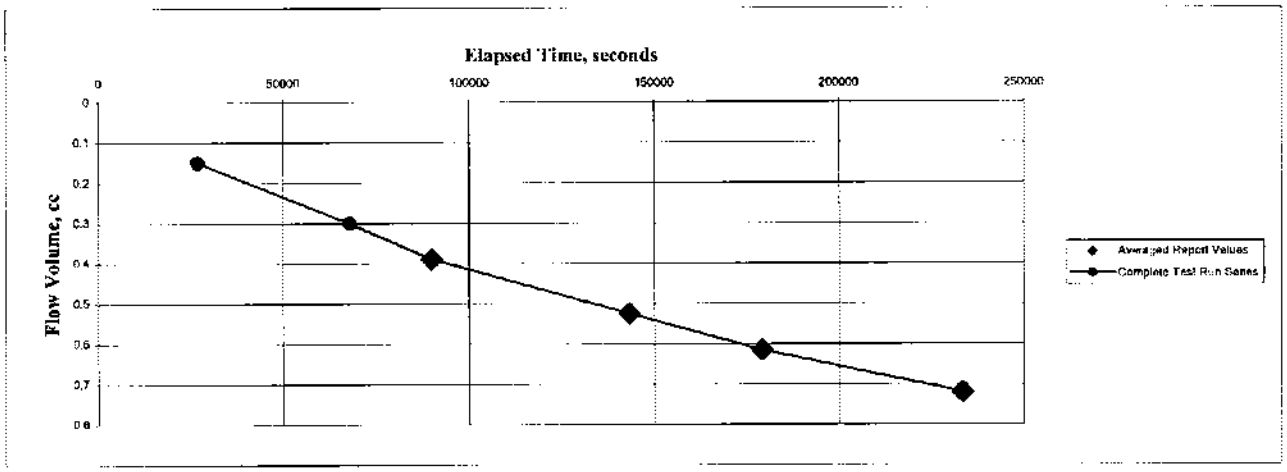
TEST RESULTS

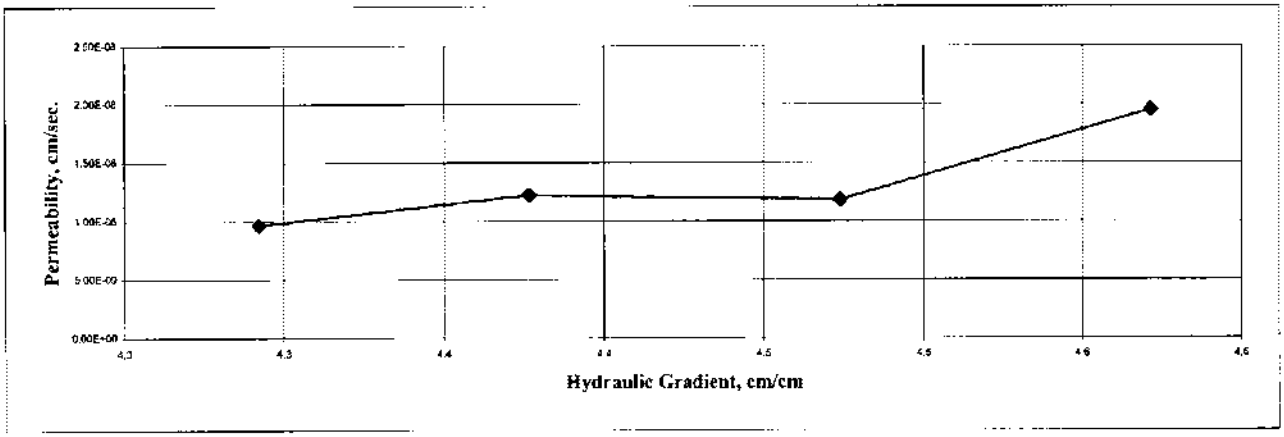
Permeability, cm/sec.: 1.33E-08 **Average Hydraulic Gradient: 4.4**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	7.70	Specimen Height, cm:	7.70
Specimen Diameter, cm:	7.54	Specimen Diameter, cm:	7.54
Dry Unit Weight, pcf:	31.8	Dry Unit Weight, pcf:	32.3
Moisture Content, %	143.8	Moisture Content, %	144.7
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	August 10, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SPECIALISTS

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Impermix/OA, 6/26/07 Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Cast Cylinder
Remarks: 45 Day Test , OGW permeant

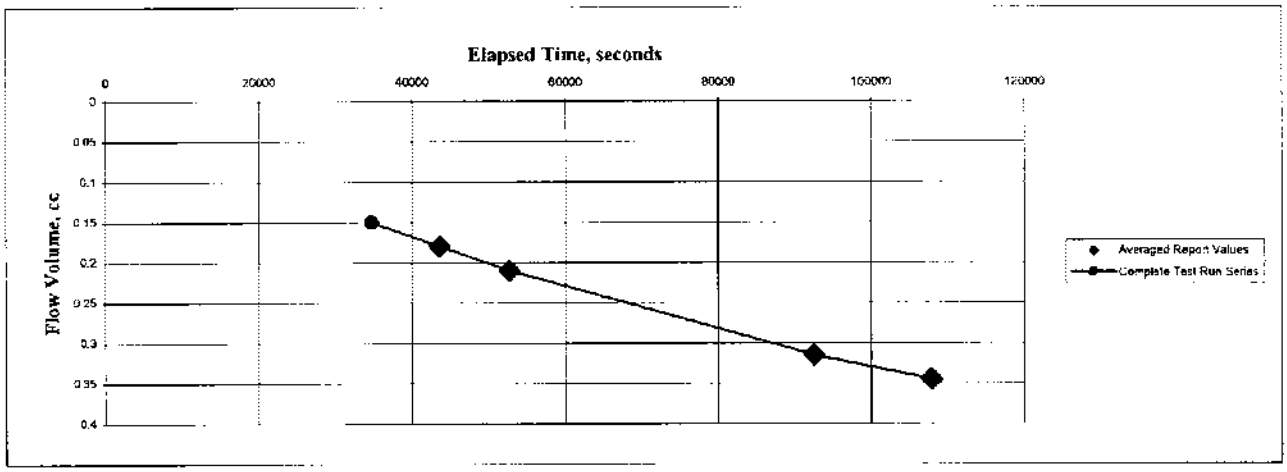
TEST RESULTS

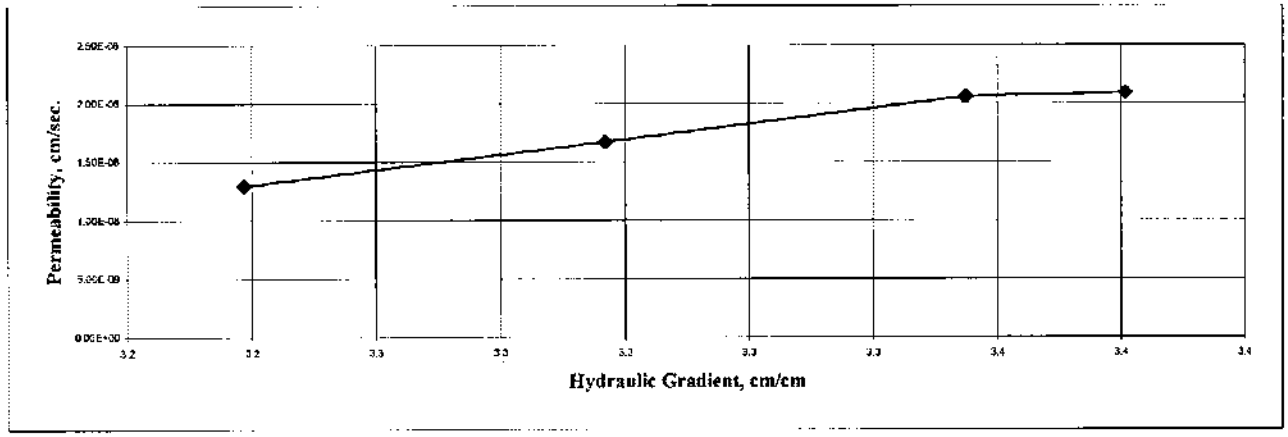
Permeability, cm/sec.: 1.78E-08 **Average Hydraulic Gradient: 3.3**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	7.75	Specimen Height, cm:	7.75
Specimen Diameter, cm:	7.62	Specimen Diameter, cm:	7.62
Dry Unit Weight, pcf:	34.4	Dry Unit Weight, pcf:	34.4
Moisture Content, %	126.3	Moisture Content, %	127.0
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	August 10, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

SLURRY MIX DESIGN PARAMETERS

Sample Identification	Mix No.	Slump (in.)	Wet Unit Weight (pcf)
DA-B-PW	#5	7.00	109.2

Test Method: ASTM C 143 and API 13B

PROJECT NUMBER:	07-167	October 24, 2007

SILHA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Mix #5-DA w/Bentonite/PW Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Slurry Sample
Remarks: OGW Water permeant

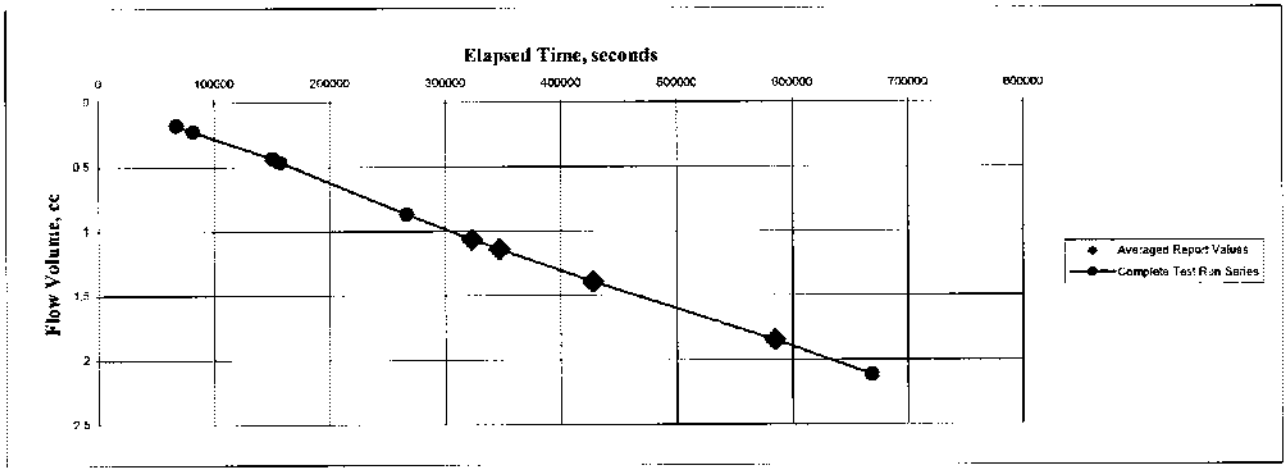
TEST RESULTS

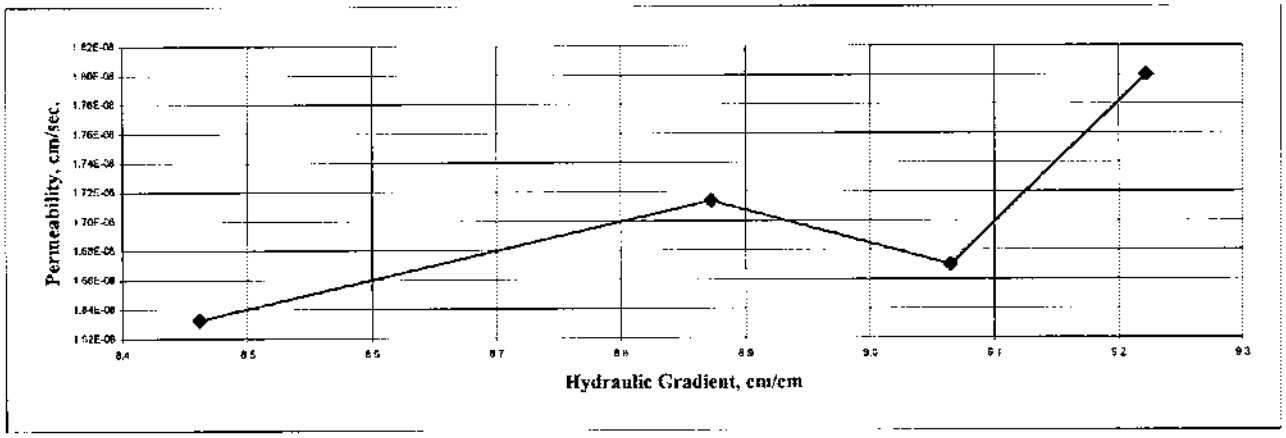
Permeability, cm/sec.: 1.70E-08 **Average Hydraulic Gradient: 8.9**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	6.45	Specimen Height, cm:	5.72
Specimen Diameter, cm:	5.08	Specimen Diameter, cm:	5.08
Dry Unit Weight, pcf:	76.0	Dry Unit Weight, pcf:	87.5
Moisture Content, %	35.1	Moisture Content, %	33.9
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	January 11, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

SLURRY MIX DESIGN PARAMETERS

Sample Identification	Mix No.	Slump (in.)	Wet Unit Weight (pcf)
OA-A-PW	4	5.70	111.2

Test Method: ASTM C 143 and API 13B

PROJECT NUMBER:	07-167	June 22, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING ENGINEERS

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Mix #4-OA w/Attapolgite/PW Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Slurry Sample
Remarks: OGW Water permeant

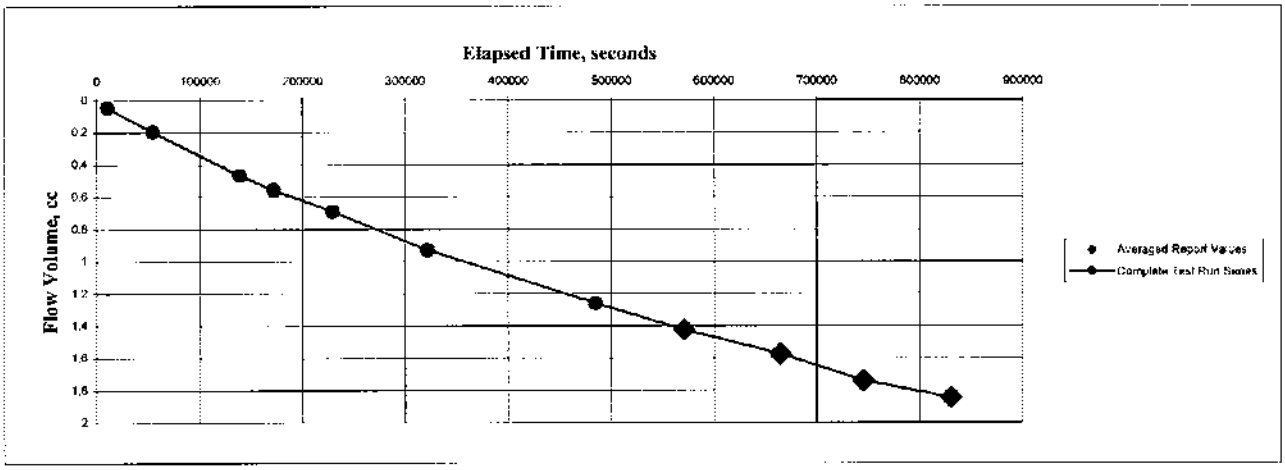
TEST RESULTS

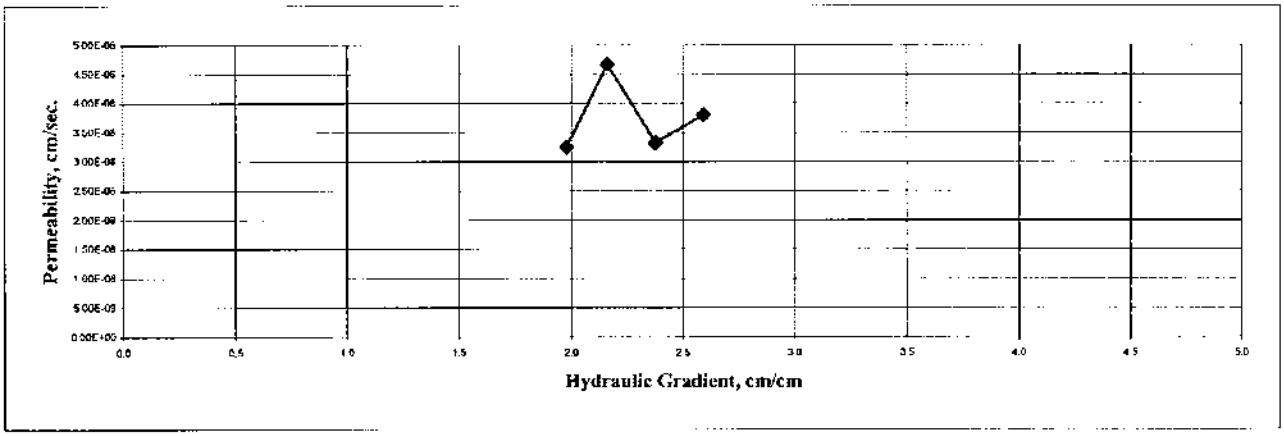
Permeability, cm/sec.: 3.76E-08 **Average Hydraulic Gradient: 2.3**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	5.05	Specimen Height, cm:	4.88
Specimen Diameter, cm:	5.08	Specimen Diameter, cm:	5.08
Dry Unit Weight, pcf:	101.1	Dry Unit Weight, pcf:	112.6
Moisture Content, %	26.3	Moisture Content, %	23.8
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	October 20, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Mix #2-OA w/Bentonite/PW Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Slurry Sample
Remarks: DI Water permeant

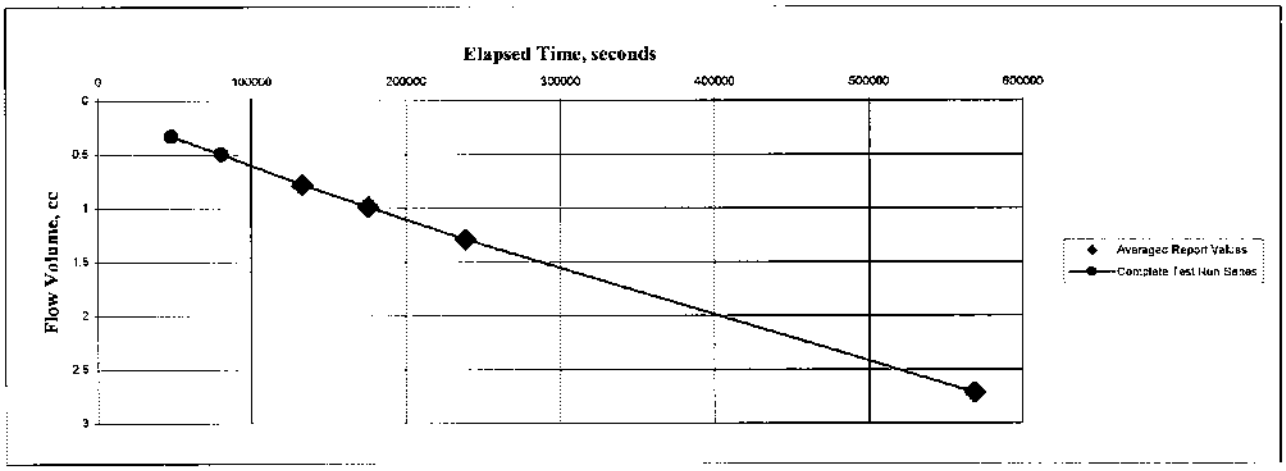
TEST RESULTS

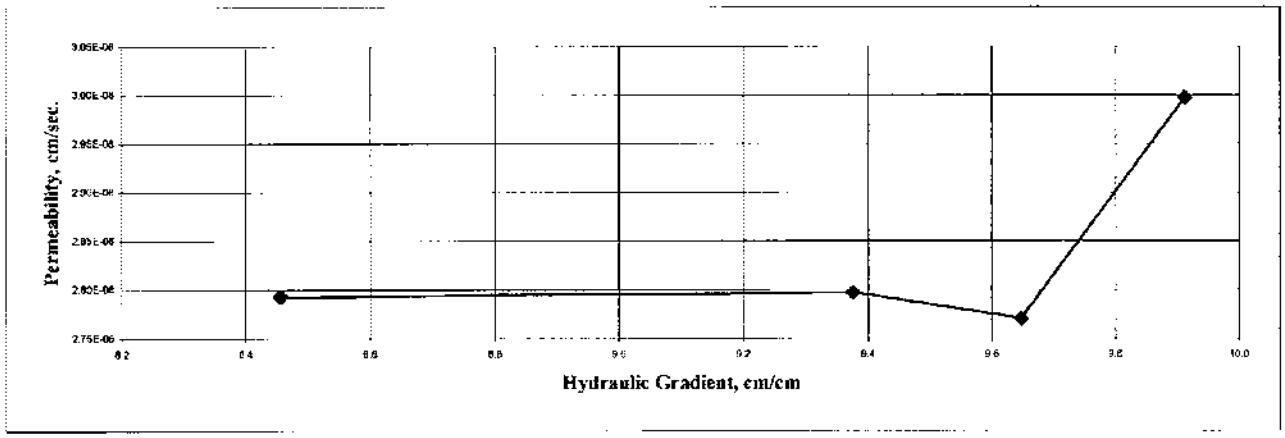
Permeability, cm/sec.: 2.84E-08 **Average Hydraulic Gradient: 9.3**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	6.27	Specimen Height, cm:	6.25
Specimen Diameter, cm:	5.08	Specimen Diameter, cm:	5.08
Dry Unit Weight, pcf:	102.7	Dry Unit Weight, pcf:	103.2
Moisture Content, %	24.9	Moisture Content, %	24.0
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	October 20, 2008

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

SLURRY MIX DESIGN PARAMETERS

Sample Identification	Mix No.	Slump (in.)	Wet Unit Weight (pcf)
OA-A-PW	4	5.70	111.2

Test Method: ASTM C 143 and API 13B

PROJECT NUMBER:	07-167	June 22, 2007	Arkema Portland Harbor Site Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

MOISTURE CONTENT & UNIT WEIGHT TEST RESULTS

Sample Identification	Depth, ft.	Wet Unit Weight, lb/ft.^{3}	Dry Unit Weight, lb/ft.^{3}	Moisture Content, %
OA-A-PW				39.7

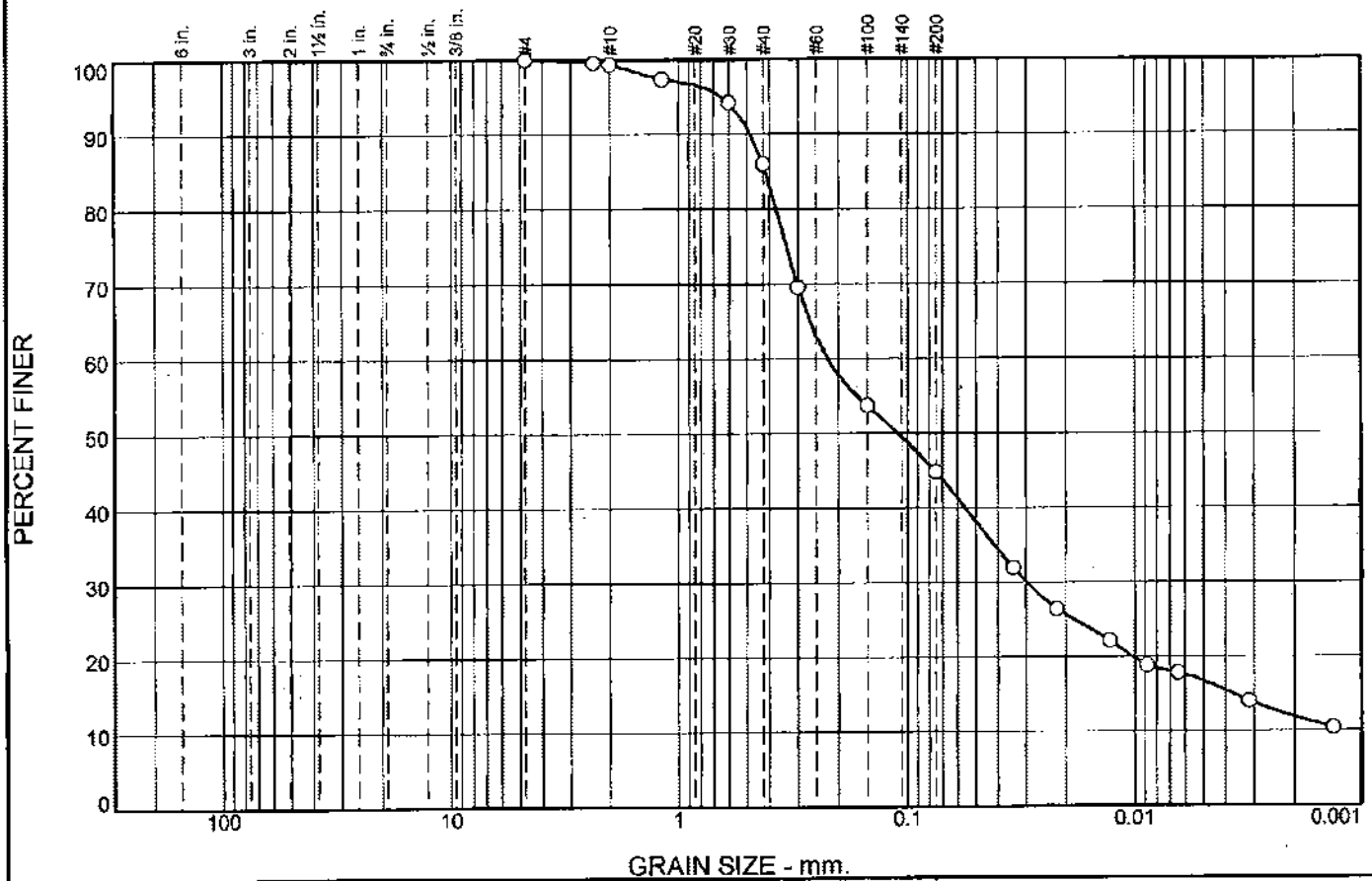
Test Method: ASTM D2216, ASTM D2937

PROJECT NUMBER:	07-167	October 20, 2007	Arkema Portland Harbor Site Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.7	13.3	41.1	28.1	16.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#8	99.6		
#10	99.3		
#16	97.3		
#30	94.2		
#40	86.0		
#50	69.6		
#100	53.8		
#200	44.9		
0.0341 mm.	32.0		
0.0219 mm.	26.5		
0.0128 mm.	22.2		
0.0088 mm.	18.9		
0.0064 mm.	17.9		
0.0032 mm.	14.0		
0.0013 mm.	10.4		

* (no specification provided)

Soil Description

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 0.4146 D_{60}= 0.2228 D_{50}= 0.1096
D_{30}= 0.0297 D_{15}= 0.0037 D_{10}=
C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Sample No.: Mix #4 **Source of Sample:** Mix #4, Slurry Backfill **Date:**
Location: OA w/Attapolgite/PW **Elev./Depth:**

SIERRA TESTING LABS, INC.
El Dorado Hills, CA

Client: ERM
Project: Arkema Portland Harbor Site
Portland, OR
Project No: 07-167 **Figure**

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Mix #4-OA w/ Attapulgite/PW Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Slurry Sample
Remarks: DI Water permeant

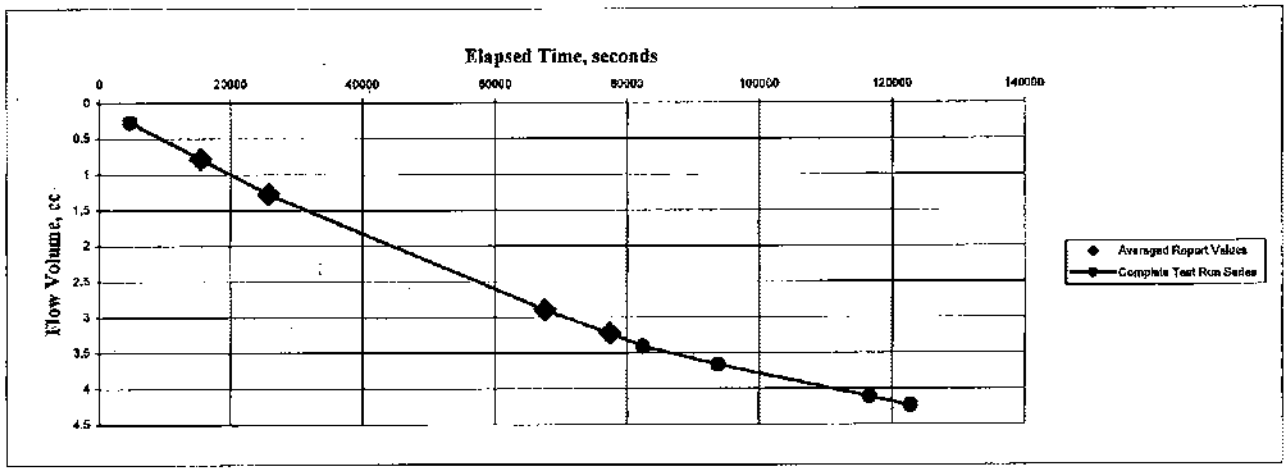
TEST RESULTS

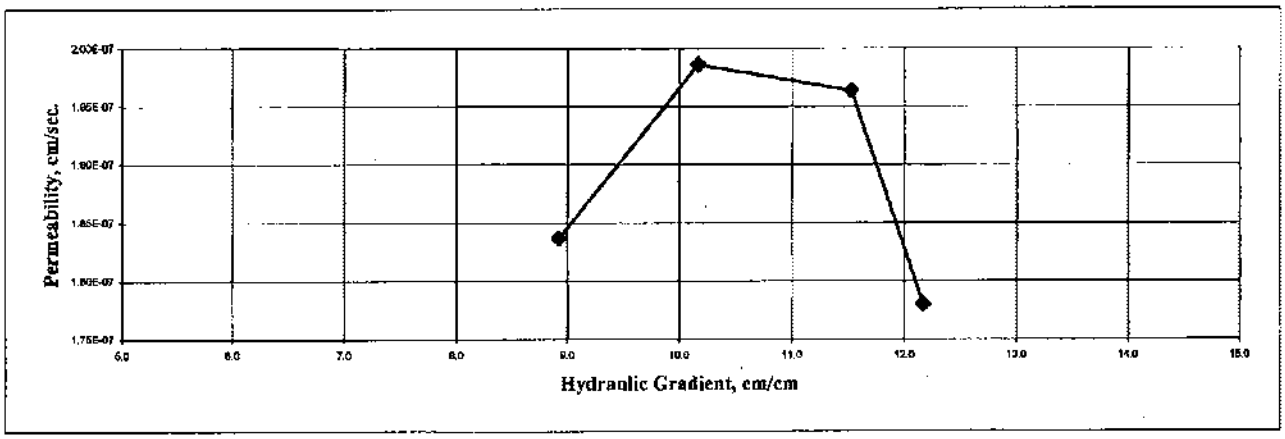
Permeability, cm/sec.: 1.89E-07 **Average Hydraulic Gradient: 10.7**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	5.31	Specimen Height, cm:	5.21
Specimen Diameter, cm:	5.08	Specimen Diameter, cm:	5.08
Dry Unit Weight, pcf:	100.7	Dry Unit Weight, pcf:	104.7
Moisture Content, %	27.0	Moisture Content, %	24.4
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	October 20, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Mix #4-OA w/Attapolgite/PW Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Slurry Sample
Remarks: OGW Water permeant

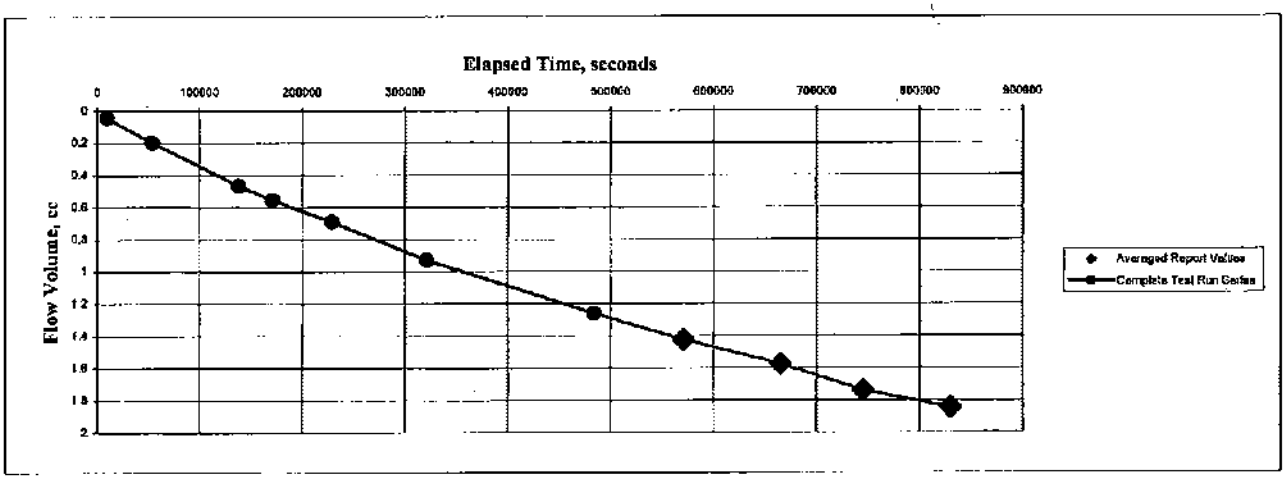
TEST RESULTS

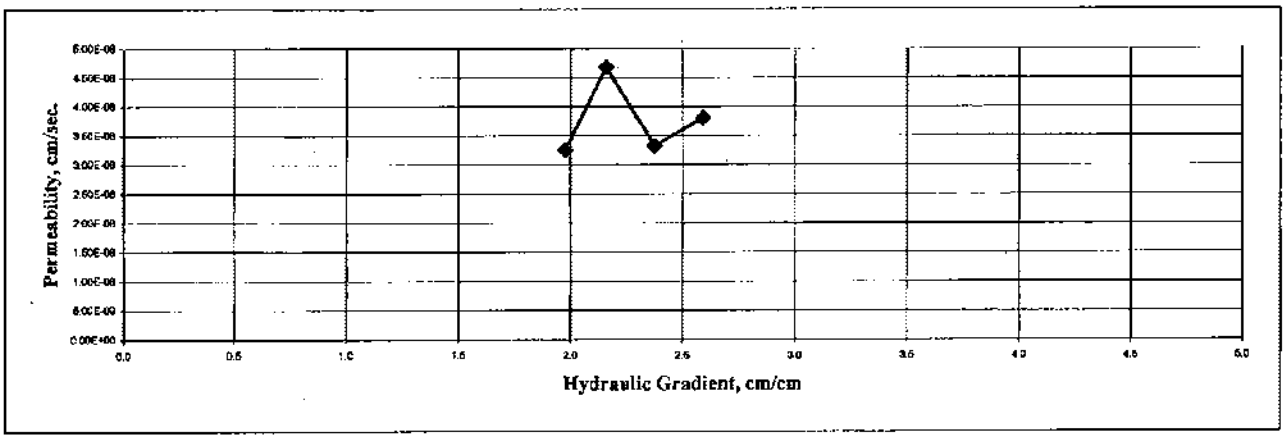
Permeability, cm/sec.: 3.76E-08 **Average Hydraulic Gradient: 2.3**

Effective Cell Pressure, psi: #VALUE!

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	5.05	Specimen Height, cm:	4.88
Specimen Diameter, cm:	5.08	Specimen Diameter, cm:	5.08
Dry Unit Weight, pcf:	101.1	Dry Unit Weight, pcf:	112.6
Moisture Content, %	26.3	Moisture Content, %	23.8
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	October 20, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

SLURRY MIX DESIGN PARAMETERS

Sample Identification	Mix No.	Slump (in.)	Wet Unit Weight (pcf)
CA-B-PW	1	5.50	109.5

Test Method: ASTM C 143 and API 13B

PROJECT NUMBER:	07-167	June 22, 2007	Arkema Portland Harbor Site Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

MOISTURE CONTENT & UNIT WEIGHT TEST RESULTS

Sample Identification	Depth, ft.	Wet Unit Weight, lb/ft.^{3}	Dry Unit Weight, lb/ft.^{3}	Moisture Content, %
CA-B-PW				43.7

Test Method: ASTM D2216, ASTM D2937

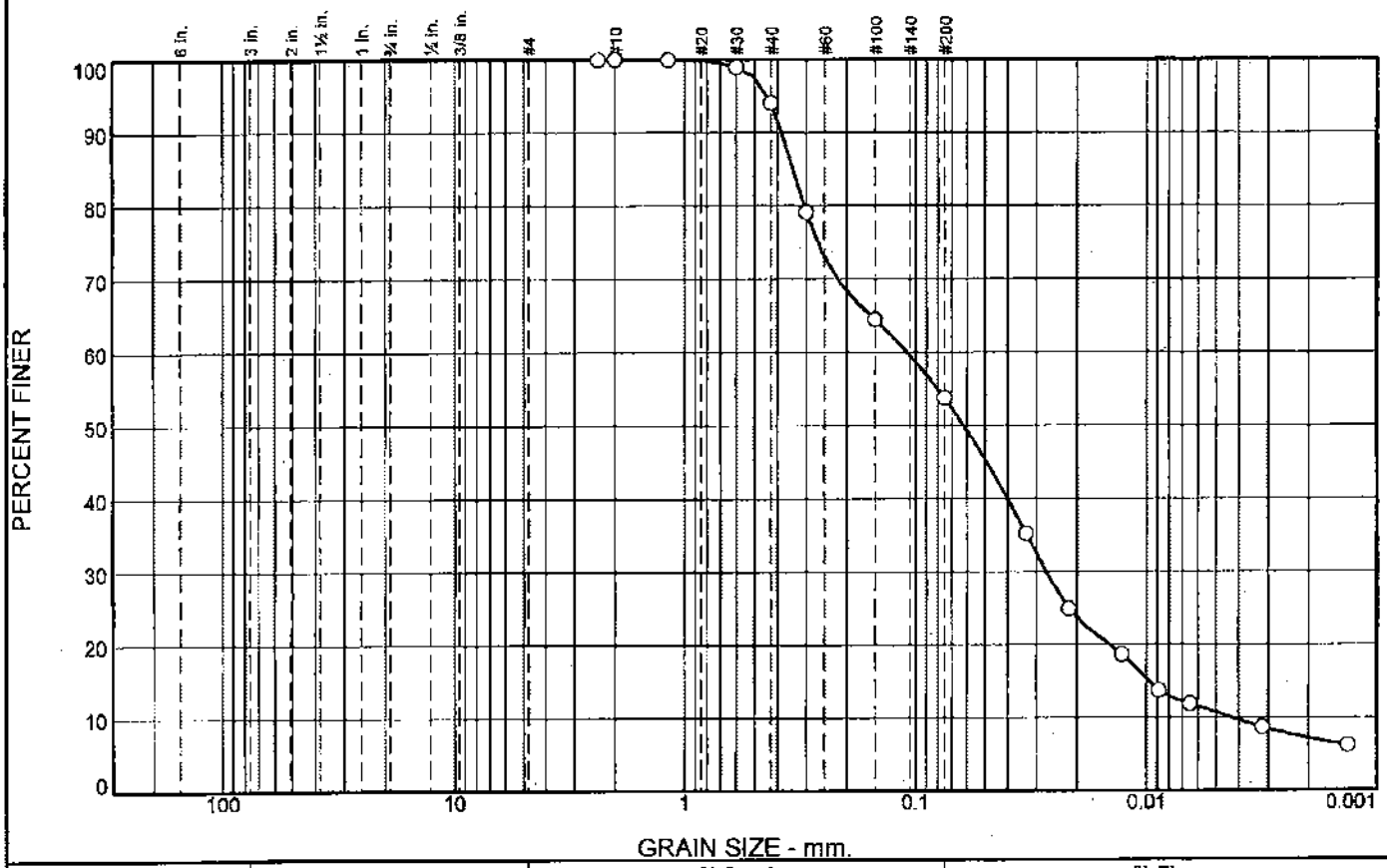
PROJECT NUMBER: 07-167 October 18, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	5.9	40.3	43.1	10.7

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#8	100.0		
#10	100.0		
#16	100.0		
#30	99.0		
#40	94.1		
#50	79.1		
#100	64.5		
#200	53.8		
0.0332 mm.	35.3		
0.0217 mm.	25.0		
0.0128 mm.	18.7		
0.0088 mm.	13.7		
0.0065 mm.	11.9		
0.0032 mm.	8.7		
0.0013 mm.	6.2		

* (no specification provided)

Soil Description

Slurry Backfill Sample

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 0.3420 D_{60}= 0.1084 D_{50}= 0.0618
D_{30}= 0.0271 D_{15}= 0.0098 D_{10}= 0.0043
C_u= 25.25 C_c= 1.58

Classification

USCS= AASHTO=

Remarks

Specific gravity assumed to be 2.70.

Sample No.: Mix #1 **Source of Sample:** Mix #1, Slurry Backfill **Date:** 10/19/07
Location: CA w/Bentonite/PW **Elev./Depth:**

SIERRA TESTING LABS, INC.
El Dorado Hills, CA

Client: ERM
Project: Arkema Portland Harbor Site
Portland, OR
Project No: 07-167 **Figure**

Tested By: MPW **Checked By:** CW

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Mix #1-CA w/Bentonite/PW Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Slurry Sample
Remarks: DI Water permeant

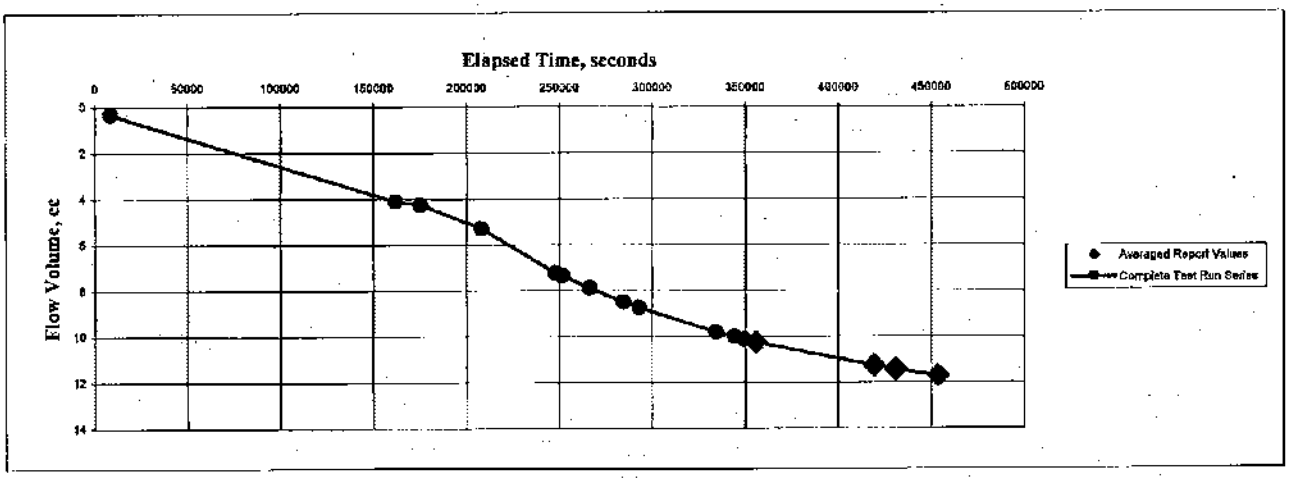
TEST RESULTS

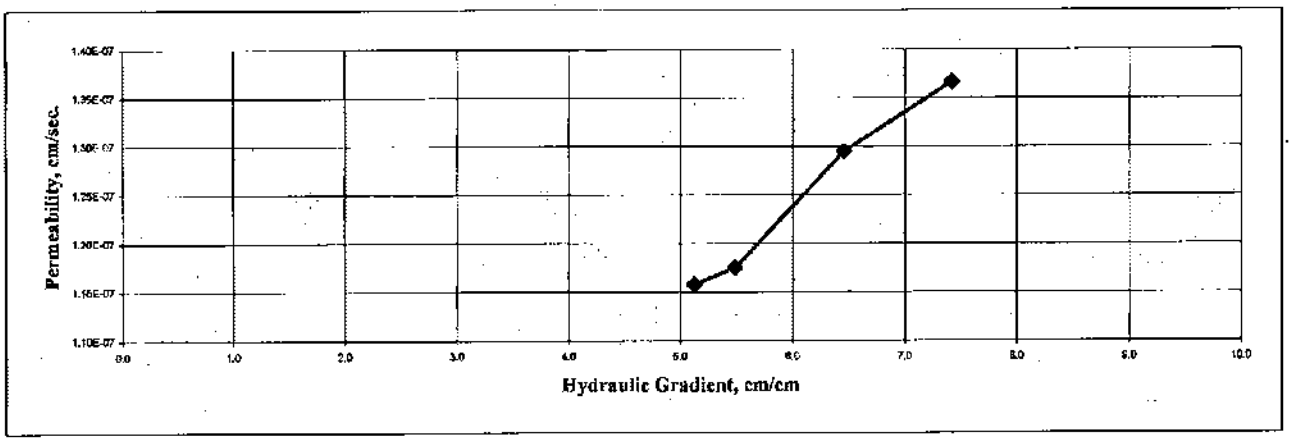
Permeability, cm/sec.: 1.25E-07 **Average Hydraulic Gradient: 6.1**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	4.19	Specimen Height, cm:	4.01
Specimen Diameter, cm:	5.08	Specimen Diameter, cm:	5.08
Dry Unit Weight, pcf:	93.9	Dry Unit Weight, pcf:	102.1
Moisture Content, %	31.1	Moisture Content, %	27.3
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	October 19, 2007	Arkema Portland Harbor Site Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Mix #1-CA w/Bentonite/PW Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Slurry Sample
Remarks: CGW permeant

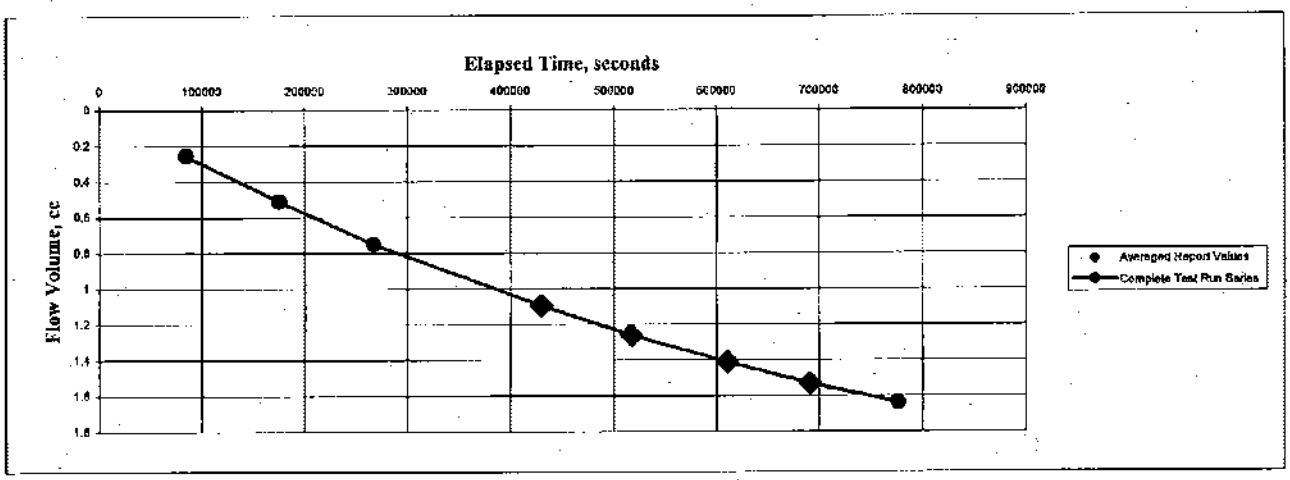
TEST RESULTS

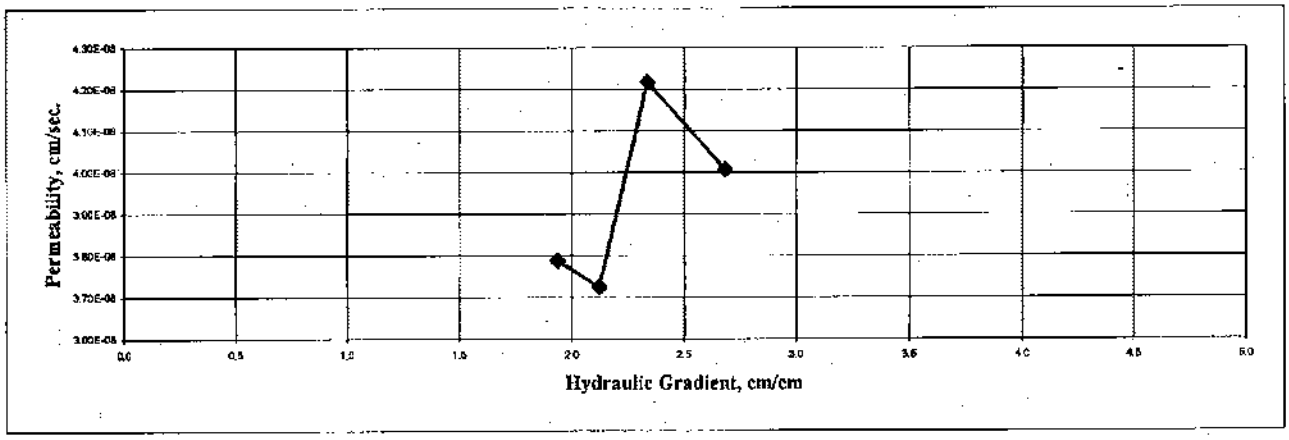
Permeability, cm/sec.: 3.93E-08 **Average Hydraulic Gradient: 2.3**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	4.95	Specimen Height, cm:	4.90
Specimen Diameter, cm:	5.08	Specimen Diameter, cm:	5.08
Dry Unit Weight, pcf:	98.3	Dry Unit Weight, pcf:	103.4
Moisture Content, %	29.6	Moisture Content, %	27.0
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	October 20, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

SLURRY MIX DESIGN PARAMETERS

Sample Identification	Mix No.	Slump (in.)	Wet Unit Weight (pcf)
CA-A-PW	3	5.90	109.1

Test Method: ASTM C 143 and API 13B

PROJECT NUMBER:	07-167	June 22, 2007	Arkema Portland Harbor Site Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

MOISTURE CONTENT & UNIT WEIGHT TEST RESULTS

Sample Identification	Depth, ft.	Wet Unit Weight, lb/ft.^{3}	Dry Unit Weight, lb/ft.^{3}	Moisture Content, %
CA-A-PW				47.8

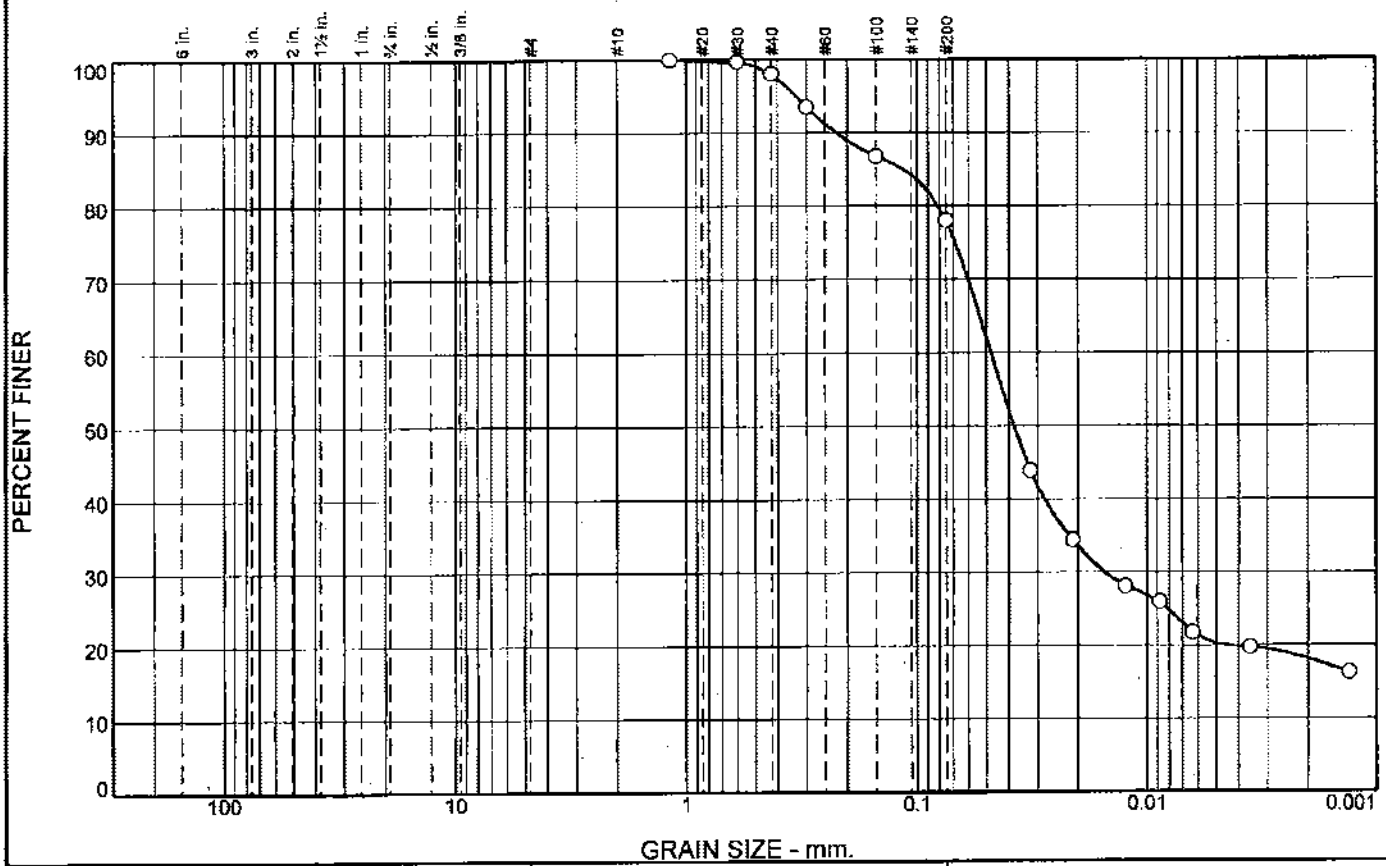
Test Method: ASTM D2216, ASTM D2937

PROJECT NUMBER:	07-167	October 20, 2007	Arkema Portland Harbor Site Porland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	1.9	20.1	57.7	20.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#16	100.0		
#30	99.7		
#40	98.1		
#50	93.6		
#100	86.8		
#200	78.0		
0.0323 mm.	43.9		
0.0210 mm.	34.4		
0.0124 mm.	28.1		
0.0088 mm.	26.0		
0.0063 mm.	21.8		
0.0036 mm.	19.8		
0.0013 mm.	16.3		

* (no specification provided)

Soil Description

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 0.1137 D_{60}= 0.0477 D_{50}= 0.0380
D_{30}= 0.0153 D_{15}= D_{10}=
C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Specific Gravity assumed to be 2.70.

Sample No.: Mix #3 **Source of Sample:** Mix #3, Slurry Backfill **Date:** 10/20/07
Location: CA w/Attapolgite/PW **Elev./Depth:**

SIERRA TESTING LABS, INC.
El Dorado Hills, CA

Client: ERM
Project: Arkema Portland Harbor Site
Portland, OR
Project No: 07-167 **Figure**

Tested By: MPW/JL **Checked By:** CMW

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Mix #3-CA w/Attapolgite/PW Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Slurry Sample
Remarks: DI Water permeant

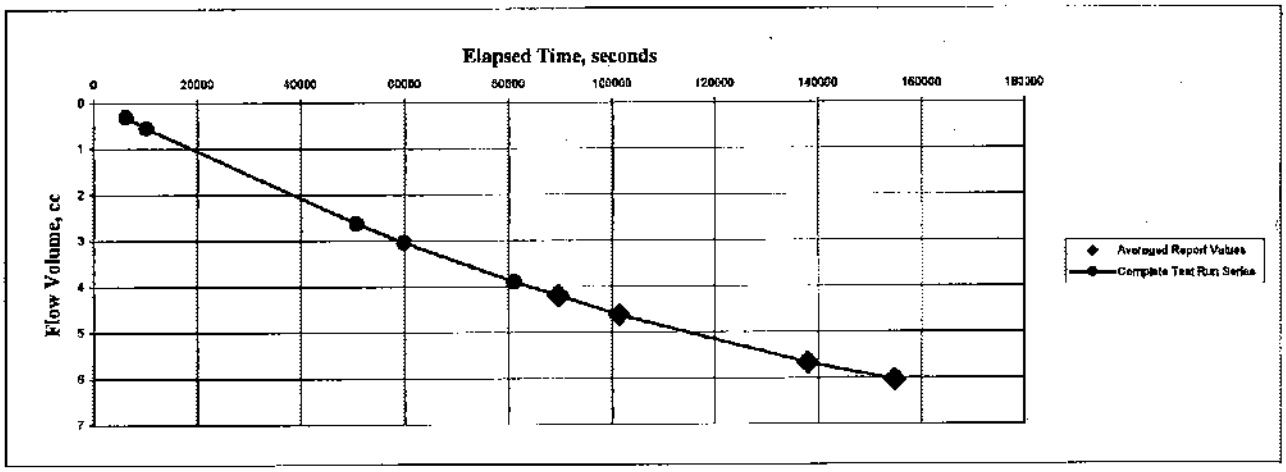
TEST RESULTS

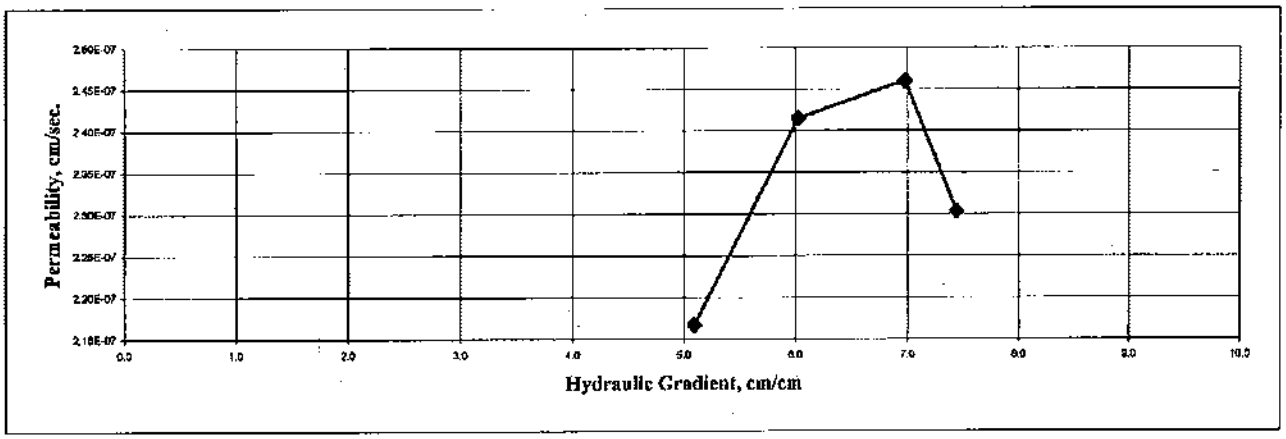
Permeability, cm/sec.: 2.34E-07 **Average Hydraulic Gradient: 6.4**

Effective Cell Pressure, psi: 10

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	5.13	Specimen Height, cm:	5.13
Specimen Diameter, cm:	5.08	Specimen Diameter, cm:	5.08
Dry Unit Weight, pcf:	96.5	Dry Unit Weight, pcf:	96.5
Moisture Content, %	31.9	Moisture Content, %	28.4
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

PROJECT NUMBER:	07-167	October 20, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

HYDRAULIC CONDUCTIVITY TEST REPORT

SAMPLE DATA

Sample Identification: Mix #3-CA w/Attapolgite/PW Sample Depth, ft.: N/A
Visual Description: N/A Sample Type: Slurry Sample
Remarks: CGW Water permeant

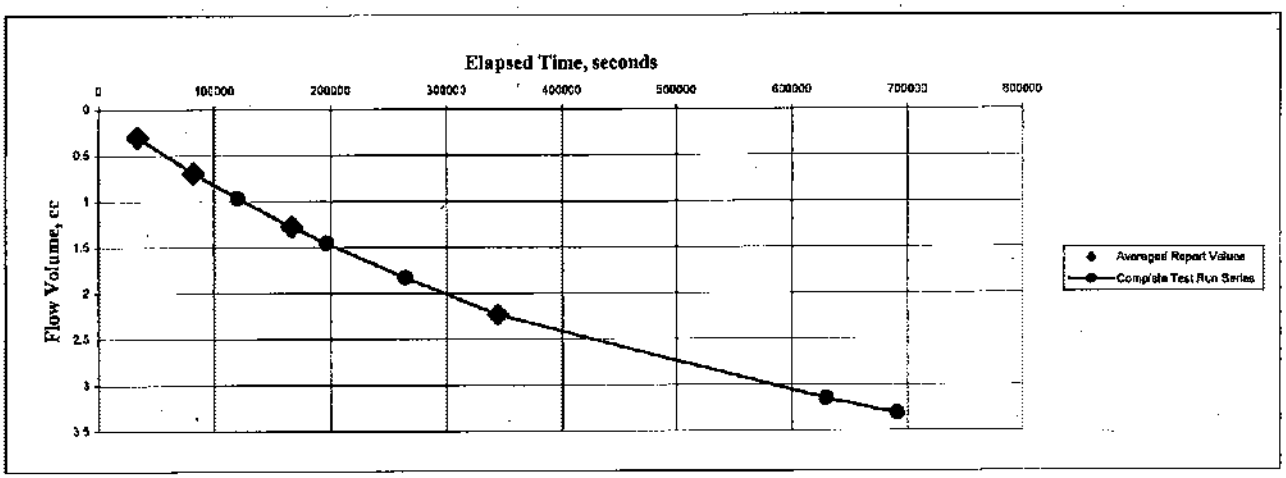
TEST RESULTS

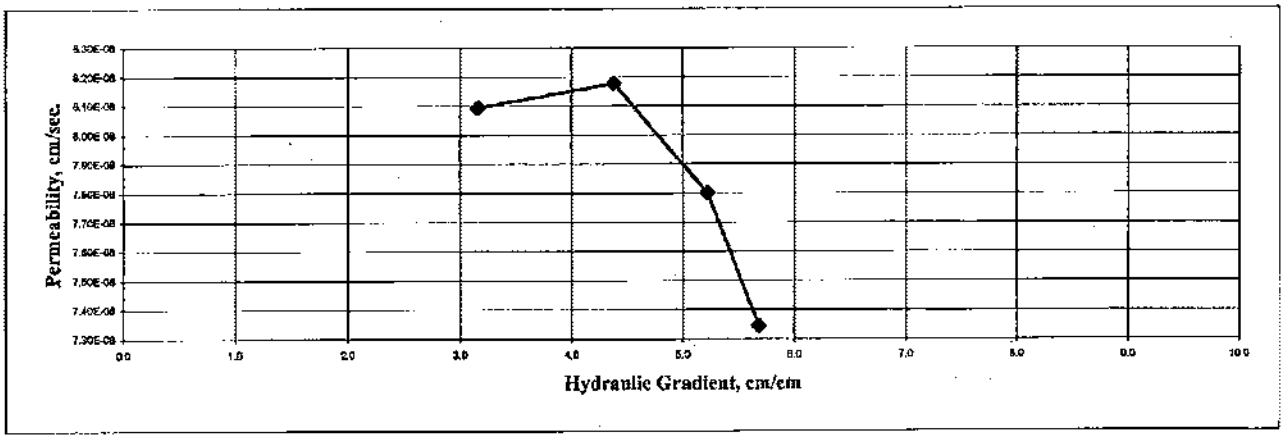
Permeability, cm/sec.: 7.85E-08 **Average Hydraulic Gradient: 4.6**

Effective Cell Pressure, psi: 20

TEST SAMPLE DATA

Before Test		After Test	
Specimen Height, cm:	5.00	Specimen Height, cm:	4.98
Specimen Diameter, cm:	5.08	Specimen Diameter, cm:	5.08
Dry Unit Weight, pcf:	96.2	Dry Unit Weight, pcf:	98.7
Moisture Content, %	30.4	Moisture Content, %	28.2
Specific Gravity, Assumed			
Percent Saturation:			





Test Method: ASTM D5084 Method C

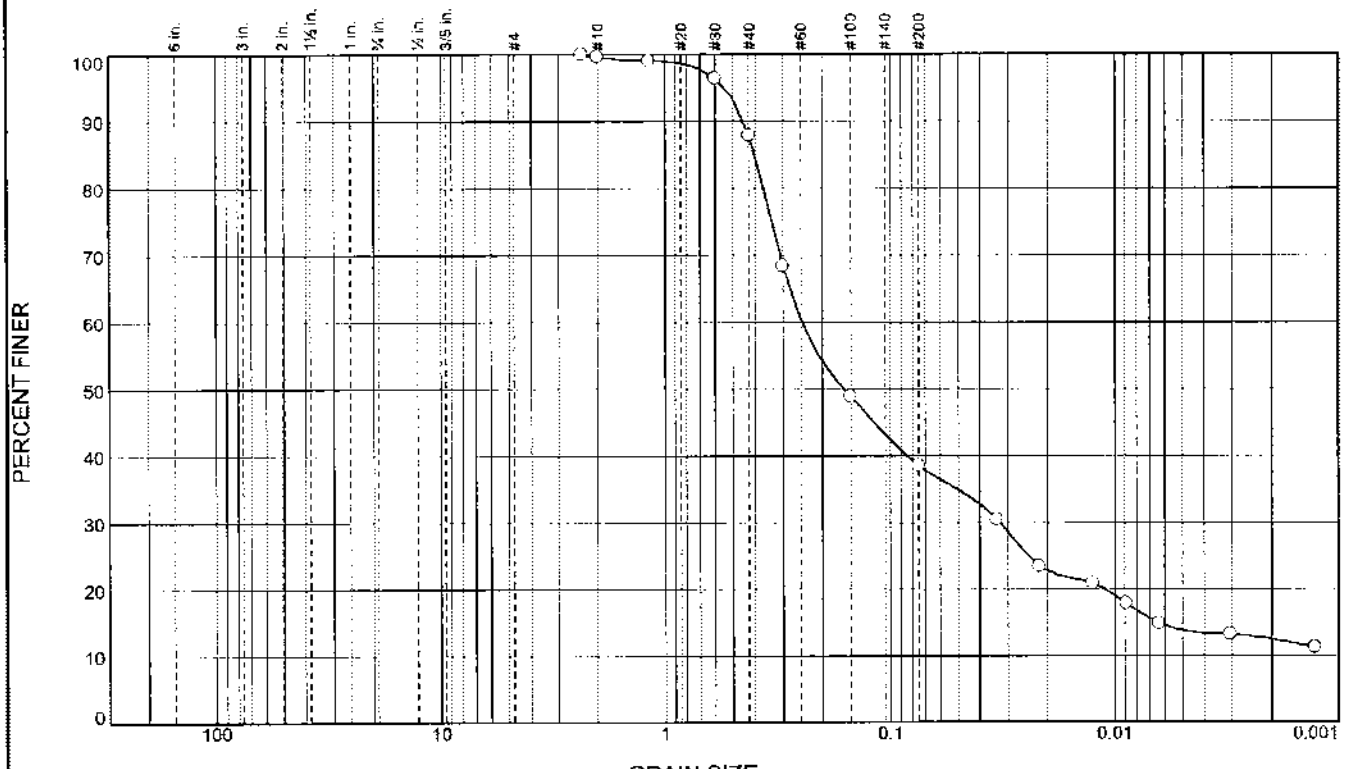
PROJECT NUMBER:	07-167	October 20, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3607

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.4	11.7	49.3	24.8	13.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#8	100.0		
#10	99.6		
#16	99.0		
#30	96.4		
#40	87.9		
#50	68.4		
#100	48.9		
#200	38.6		
0.0335 mm.	30.5		
0.0217 mm.	23.4		
0.0125 mm.	20.9		
0.0089 mm.	17.9		
0.0064 mm.	14.9		
0.0030 mm.	13.3		
0.0013 mm.	11.3		

* (no specification provided)

Soil Description

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 0.4007 D_{60}= 0.2469 D_{50}= 0.1604
D_{30}= 0.0326 D_{15}= 0.0065 D_{10}=
C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Sample No.: Mix #2 **Source of Sample:** Mix #2, Slurry Backfill **Date:** 10/20/07
Location: OA w/Bentoniote/PW **Elev./Depth:**

SIERRA TESTING LABS, INC.
El Dorado Hills, CA

Client: ERM
Project: Arkema Portland Harbor Site
Portland, OR
Project No: 07-167 **Figure**

Tested By: MPW **Checked By:** CMW

MOISTURE CONTENT & UNIT WEIGHT TEST RESULTS

Sample Identification	Depth, ft.	Wet Unit Weight, lb/ft.^{3}	Dry Unit Weight, lb/ft.^{3}	Moisture Content, %
OA-B/PW				31.7

Test Method: ASTM D2216, ASTM D2937

PROJECT NUMBER: 07-167 October 20, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

MOISTURE CONTENT & UNIT WEIGHT TEST RESULTS

Sample Identification	Depth, ft.	Wet Unit Weight, lb/ft.^{3}	Dry Unit Weight, lb/ft.^{3}	Moisture Content, %
DA-B-PW				43.4

Test Method: ASTM D2216, ASTM D2937

PROJECT NUMBER:	07-167	November 24, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

SPECIFIC GRAVITY, pH & CONDUCTIVITY

Sample Location	Sample I.D.	Specific Gravity	pH	Conductivity, (uS)
Site Potable Water	PW	1.003	7.02	40.0
Site Groundwater	CGW	1.048	7.37	Beyond Scale
Site Groundwater	CGW	-	-	19450.0
Site Groundwater	OGW	1.017	3.75	11780.0

Notes

1 part CGW mixed with 5 parts distilled water inorder for instrument to obtain a reading

Conductivity - Range 10-19990 uS, Resolution 10 uS, Accuracy +/- 0.5%

pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: Multi Meter (Extech 341450)

PROJECT NUMBER: 07-167 June 12, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

SWELL INDEX OF CLAY COMPONENTS OF GEOSYNTHETIC CLAY LINERS

Swell Index, mL /2 g
6.0

Test Method: ASTM D5890-06

SAMPLE IDENTIFICATION: Atapulgite Clay
SAMPLE DESCRIPTION: - #100 Atapulgite Clay

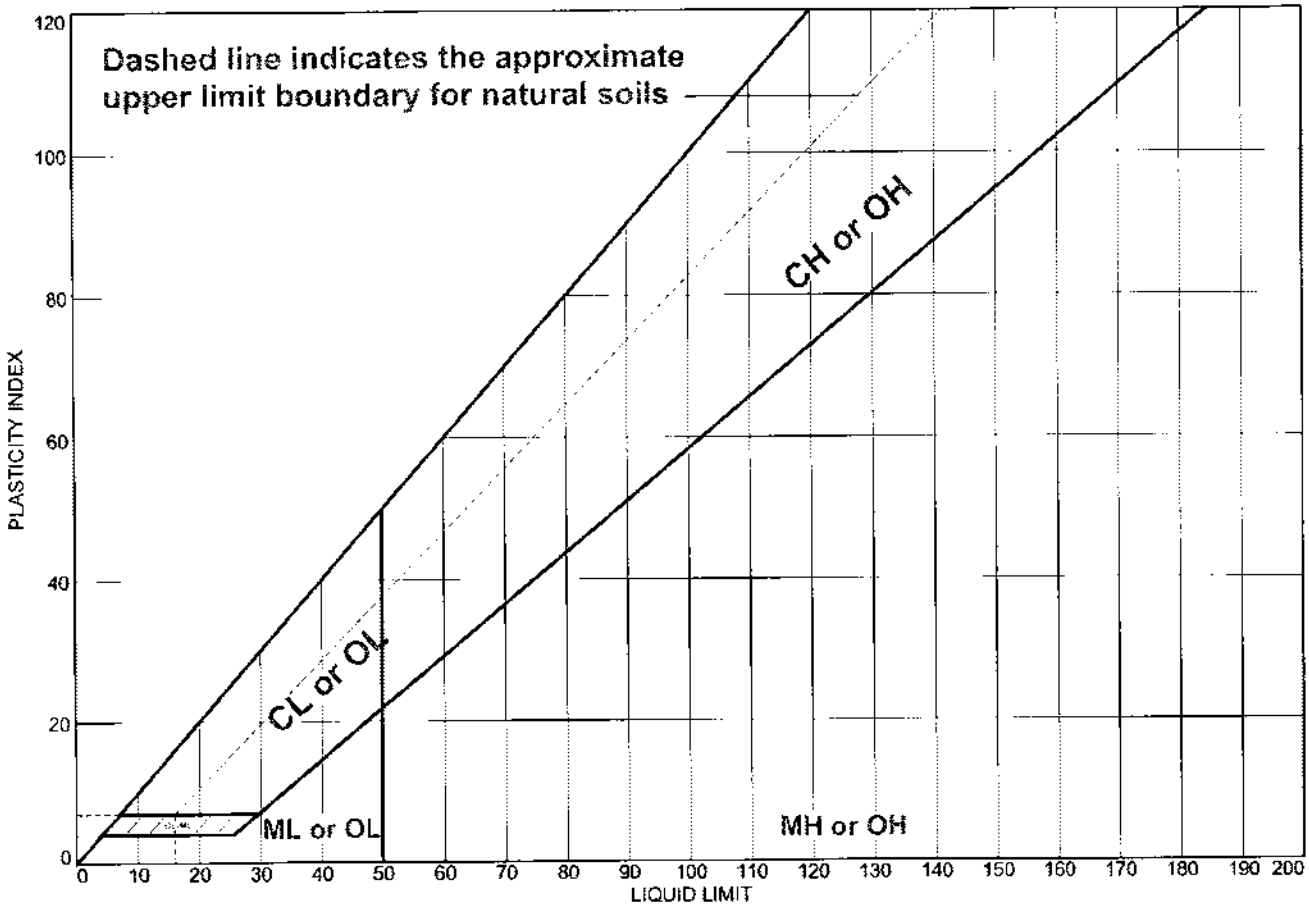
LABORATORY NO. :

PROJECT NUMBER:	07-167	June 12, 2007	Arkema Portland Harbor Site Portland Oregon	

SILHRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Bentonite w/OGW	283	39	244			

Project No. 07-167 **Client:** ERM

Project: Arkema Portland Harbor Site

Portland, OR

●**Location:** Bentonite w/OGW **Sample Number:** 6/12/07

Remarks:

●Section 14

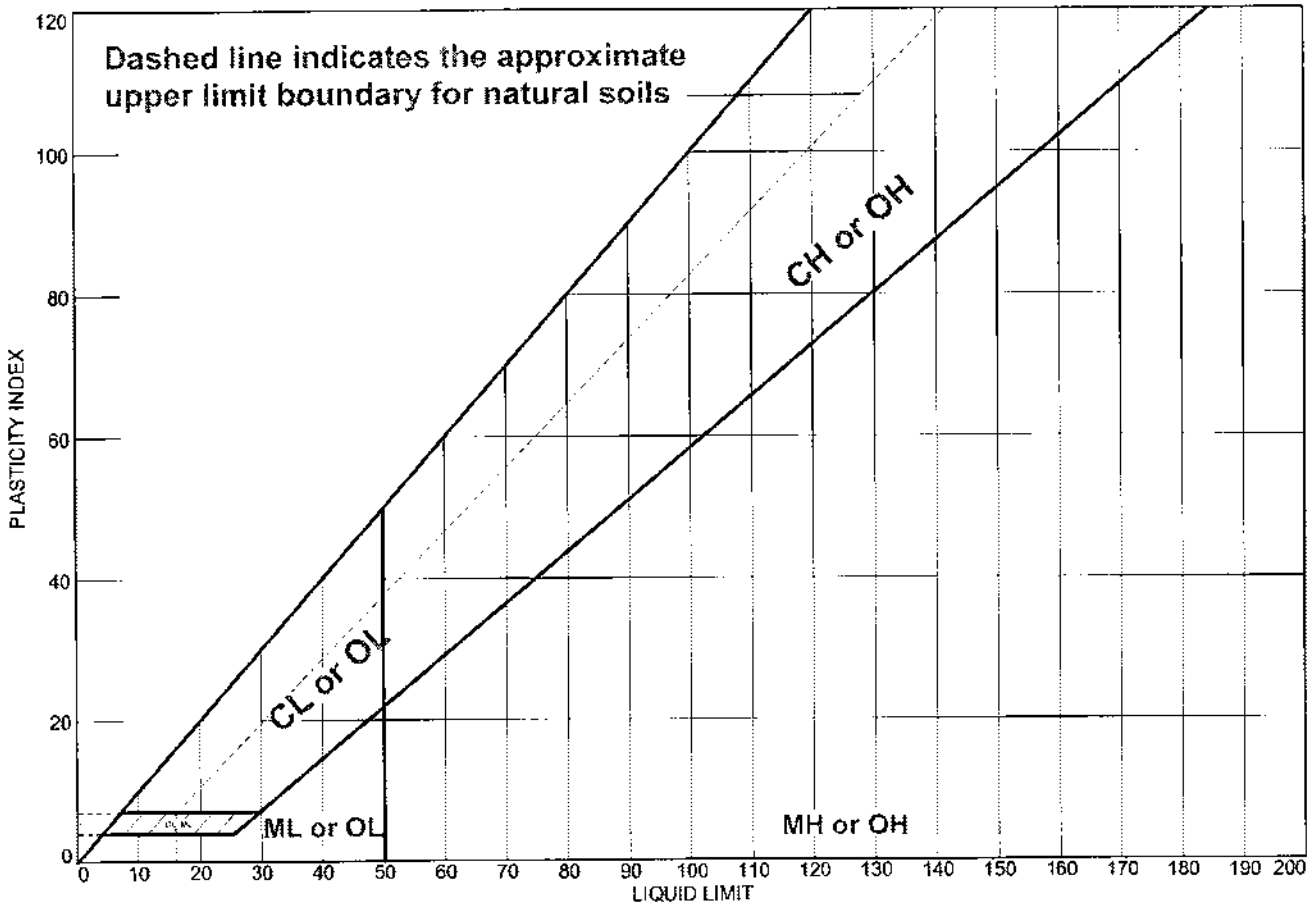
SIERRA TESTING LABS, INC.

El Dorado Hills, CA

Figure

Tested By: MG **Checked By:** CMW

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Attapulgite w/DI Water	243	94	149			

Project No. 07-167 **Client:** ERM

Project: Arkema Portland Harbor Site

Portland, OR

●**Location:** Attapulgite w/DI Water **Sample Number:** 6/12/07

Remarks:

●Section 14

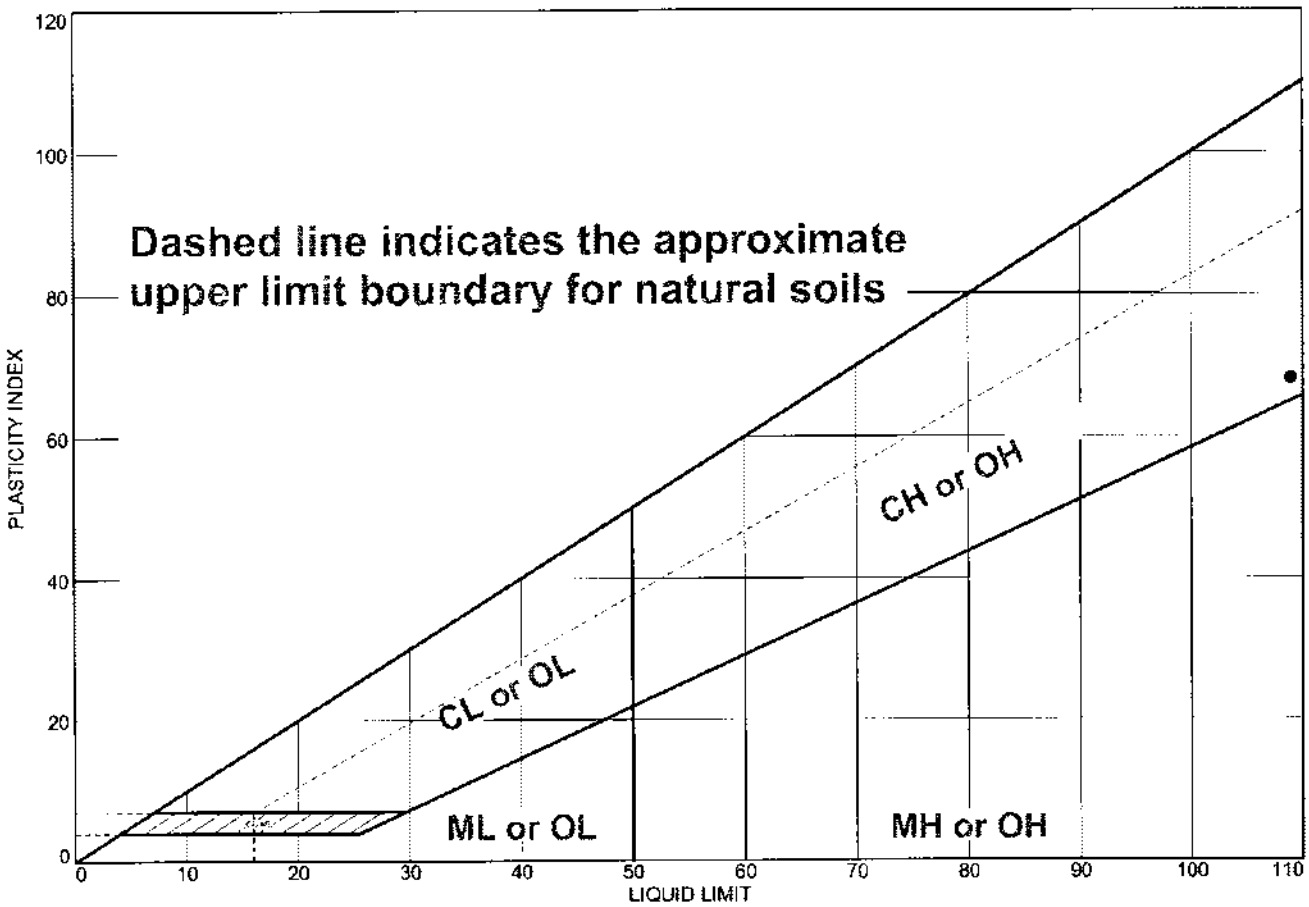
SIERRA TESTING LABS, INC.

El Dorado Hills, CA

Figure

Tested By: MG **Checked By:** CMW

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Bentonite w/CGW	109	41	68			

Project No. 07-167 **Client:** ERM

Project: Arkema Portland Harbor Site

Portland, OR

●**Location:** Bentonite w/CGW **Sample Number:** 6/12/07

Remarks:

●Section 14

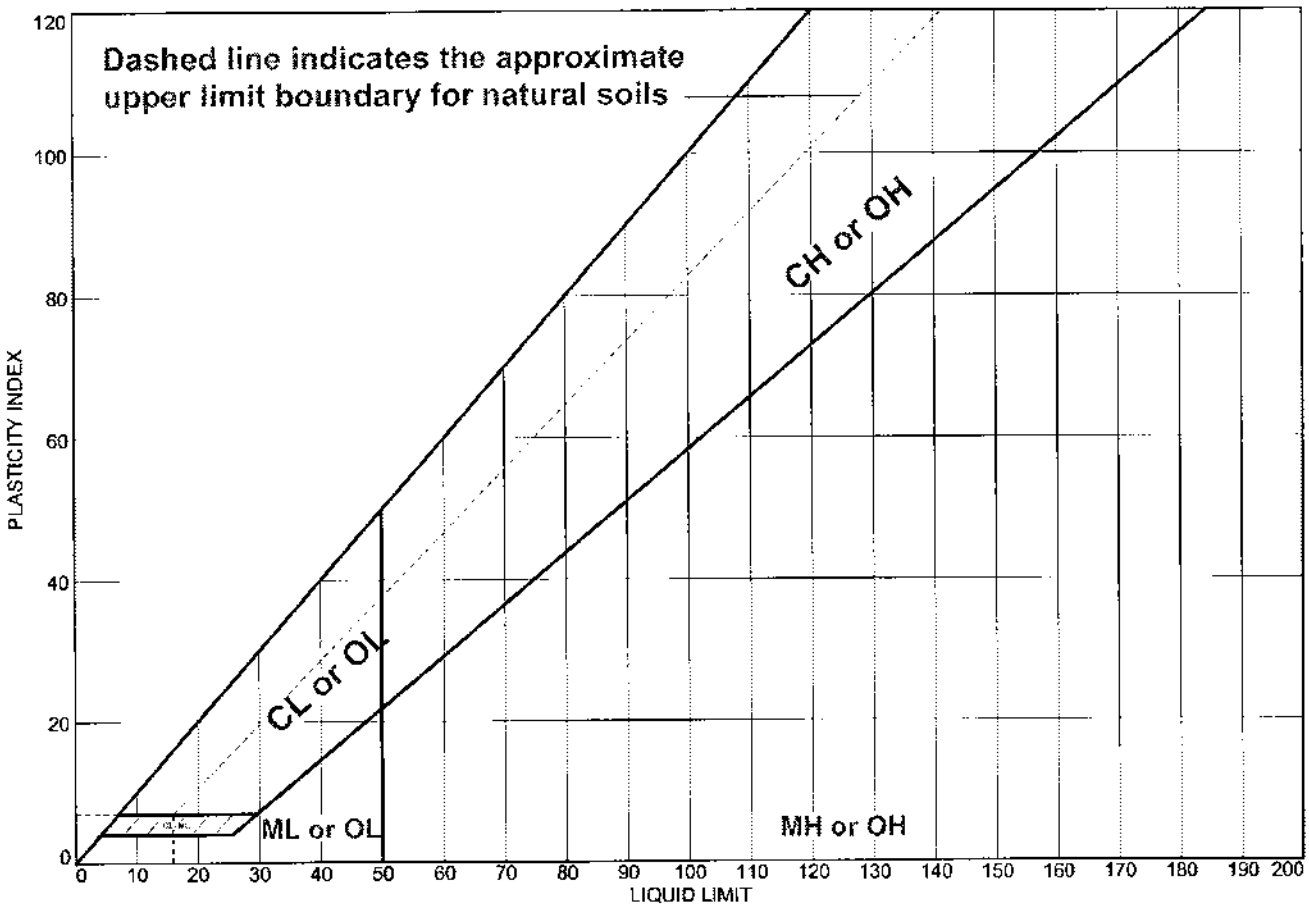
SIERRA TESTING LABS, INC.

El Dorado Hills, CA

Figure

Tested By: MG **Checked By:** CMW

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Attapulgite w/OGW	242	87	155			

Project No. 07-167 **Client:** ERM

Project: Arkema Portland Harbor Site

Portland, OR

●**Location:** Attapulgite w/OGW **Sample Number:** 6/12/07

Remarks:

●Section 14

SIERRA TESTING LABS, INC.

El Dorado Hills, CA

Figure

Tested By: AM **Checked By:** CMW

MOISTURE CONTENT & UNIT WEIGHT TEST RESULTS

Sample Identification	Depth, ft.	Wet Unit Weight, lb/ft.^{3}	Dry Unit Weight, lb/ft.^{3}	Moisture Content, %
Bentonite				12.4
Attapulgite				6.2
Clay Cement				N/A

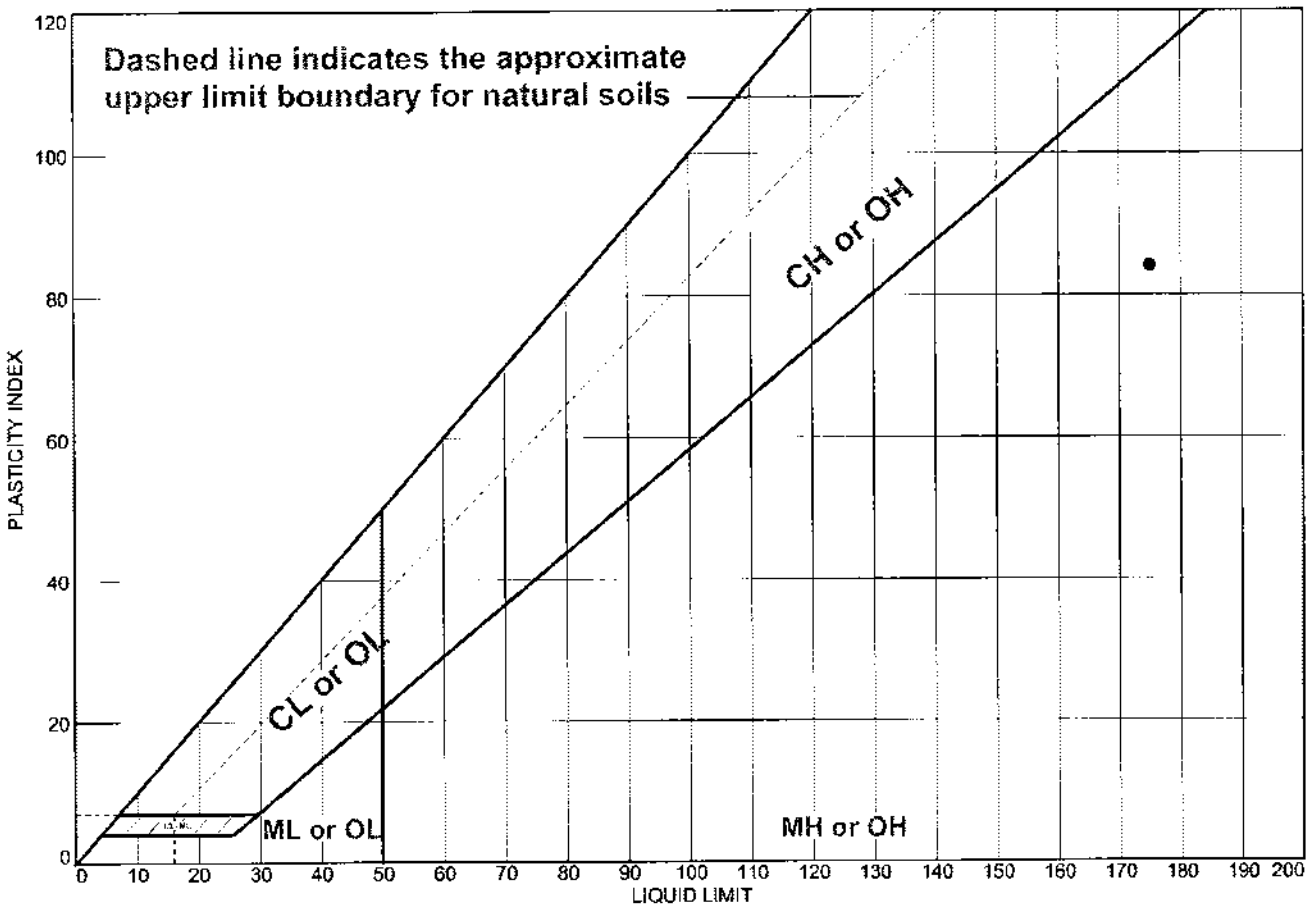
Test Method: ASTM D2216, ASTM D2937

PROJECT NUMBER:	07-167	June 12, 2007	Arkema Portland Harbor Site

SIERRA TESTING LABORATORIES, INC
GEOTECHNICAL AND MATERIALS TESTING SPECIALISTS

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Attapulgite w/CGW	175	91	84			

Project No. 07-167 **Client:** ERM

Project: Arkema Portland Harbor Site

Portland, OR

●**Location:** Attapulgite w/CGW **Sample Number:** 6/12/07

Remarks:

●Section 14

SIERRA TESTING LABS, INC.

El Dorado Hills, CA

Figure

Tested By: AM **Checked By:** CMW

MOISTURE CONTENT & pH VALUES

Sample Identification	Depth, ft.	Moisture Content, %	pH, Using Distilled Water	pH, Using Calcium Chloride
OA Soil, ST2, B120	28-34	31.8	4.95	3.00
OA Soil, S-1B2, B120	34-35	56.8	5.47	3.24
OA Soil, IT2, B120	41-44	31.3	9.97	7.03
OA Soil, DB2, B121	67-72	28.1	6.80	6.05

Notes

pH - Range 0.00 to 14.00, Resolution 0.01pH, Accuracy +/- 0.02pH

Test Method: ASTM D2216, pH Meter (Extech 341450-P)

PROJECT NUMBER: 07-167 June 12, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

MOISTURE CONTENT & pH VALUES

Sample Identification	Depth, ft.	Moisture Content, %	pH, Using Distilled Water	pH, Using Calcium Chloride
OA Soil, ST2, B120	28-34	31.8	4.95	3.00
OA Soil, S-lB2, B120	34-35	56.8	5.47	3.24
OA Soil, IT2, B120	41-44	31.3	9.97	7.03
OA Soil, DB2, B121	67-72	28.1	6.80	6.05

Test Method: ASTM D2216, pH Meter (Extech 341450-P)

PROJECT NUMBER: 07-167 June 12, 2007

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

Arkema Portland Harbor Site
Portland, Oregon

MOISTURE CONTENT & UNIT WEIGHT TEST RESULTS

Sample Identification	Depth, ft.	Wet Unit Weight, lb/ft.^{3}	Dry Unit Weight, lb/ft.^{3}	Moisture Content, %
OA Soil, ST2, B120	28-34	114.7	87.0	31.8
OA Soil, S-IB2, B120	34-35	104.1	66.2	57.4
OA Soil, IT2, B120	41-44	112.1	83.9	33.7
OA Soil, DB2, B121	67-72	123.1	94.0	31.0

Test Method: ASTM D2216, ASTM D2937

PROJECT NUMBER: 07-167 June 12, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC.
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

MOISTURE CONTENT TEST RESULTS

Sample Identification	Depth, ft.	Wet Unit Weight, lb/ft.^{3}	Dry Unit Weight, lb/ft.^{3}	Moisture Content, %
OA Soil, Full Depth	Composite			9.0
CA Soil, Full Depth	Composite			8.9

Test Method: ASTM D2216

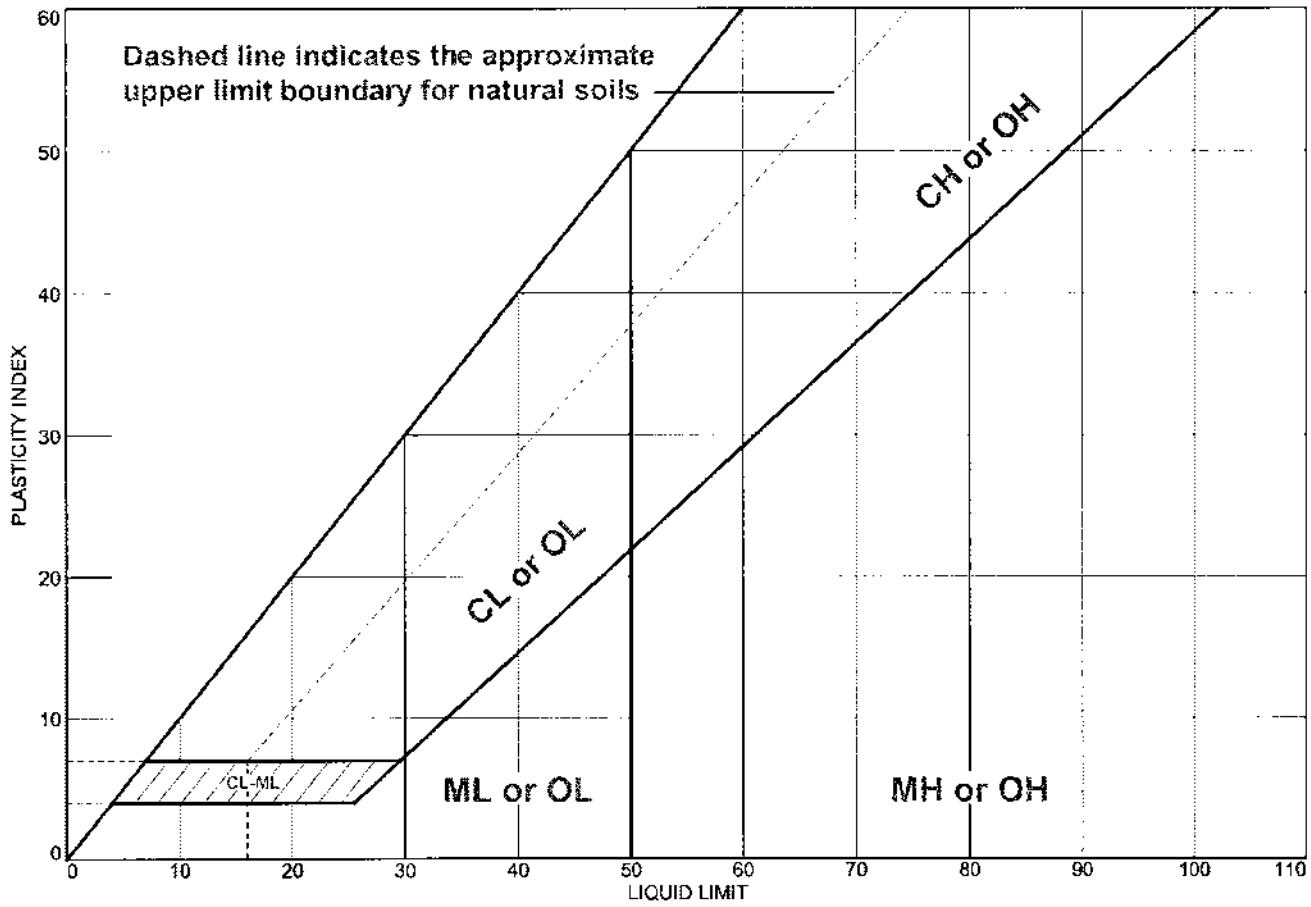
PROJECT NUMBER:	07-167	June 22, 2007

Arkema Portland Harbor Site
Portland, Oregon

SIERRA TESTING LABORATORIES, INC
GEOTECHNICAL AND MATERIALS TESTING SERVICES

5040 Robert J. Mathews Blvd., El Dorado Hills, CA 95762
Phone: (916) 939-3460 FAX: (916) 939-3507

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	sandy silt	NV	NP	NP	93.8	52.5	ML
■	silty sand	21	NP	NP	81.8	45.6	SM

Project No. 07-167 **Client:** ERM

Project: Arkema Portland Harbor Site

Portland, OR

●**Location:** CA Soil Full Depth Composite, B121 **Sample Number:** 6/12/07

■**Location:** OA Soil Full Depth Composite, B120 **Sample Number:** 6/12/07

Remarks:

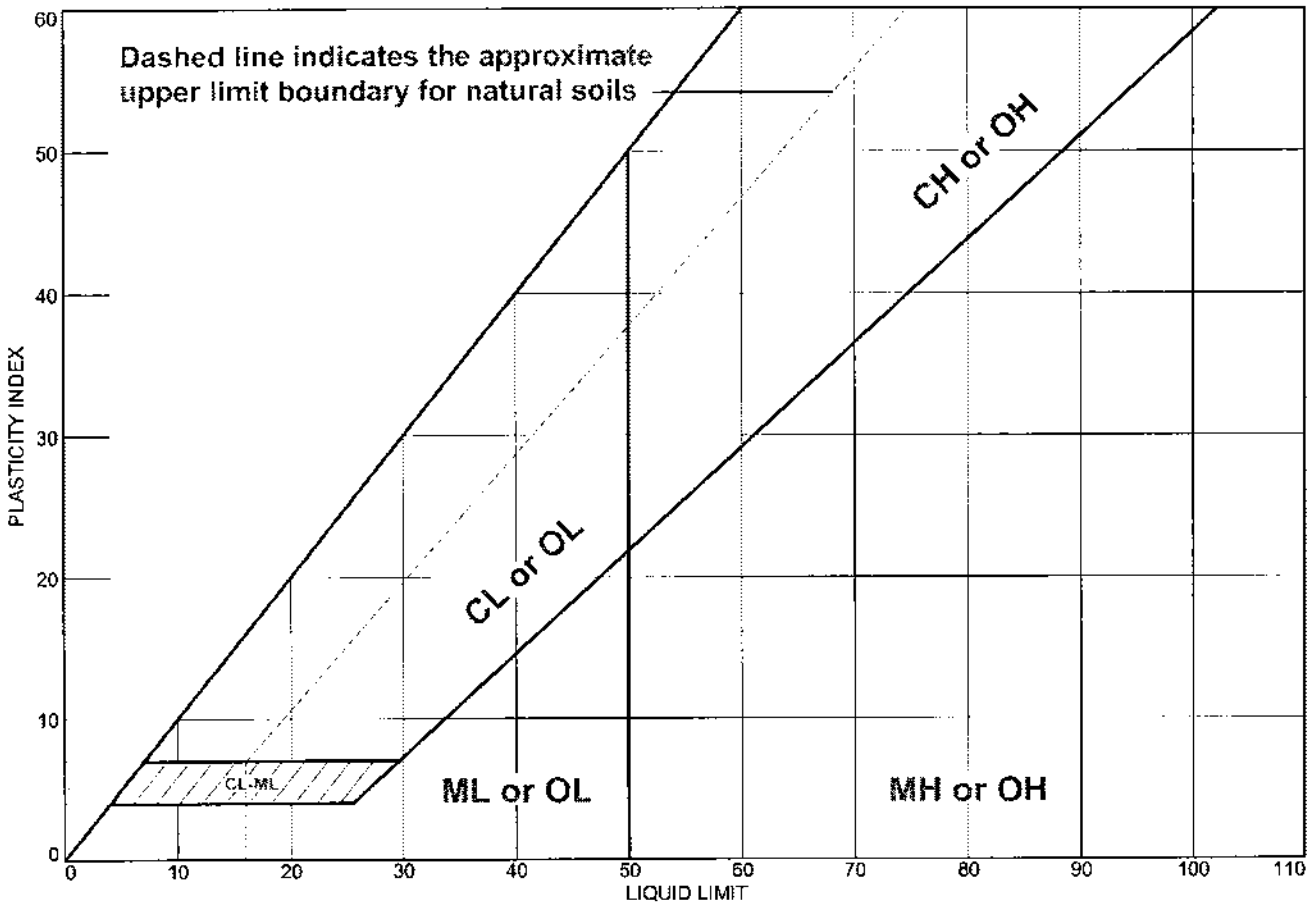
SIERRA TESTING LABS, INC.

El Dorado Hills, CA

Figure

Tested By: ☐ MS ☐ MG **Checked By:** MN

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	sandy silt	NV	NP	NP	99.8	61.9	ML
■	silt	NV	NP	NP	99.7	97.3	ML
▲	poorly graded sand with silt	NV	NP	NP	96.9	9.2	SP-SM
◆	silty sand	NV	NP	NP	92.7	16.6	SM

Project No. 07-167 **Client:** ERM

Project: Arkema Portland Harbor Site
Portland, OR

●**Location:** OA Soil DB2 B121 **Depth:** 67-72.0 **Sample Number:** 6/12/07
■**Location:** OA Soils S-IB2 B120 **Depth:** 34-35.0 **Sample Number:** 6/12/07
▲**Location:** OA Soil IT2 B120 **Depth:** 41-44.0 **Sample Number:** 6/12/07
◆**Location:** OA Soil ST2 B120 **Depth:** 28-34.0 **Sample Number:** 6/12/07

Remarks:

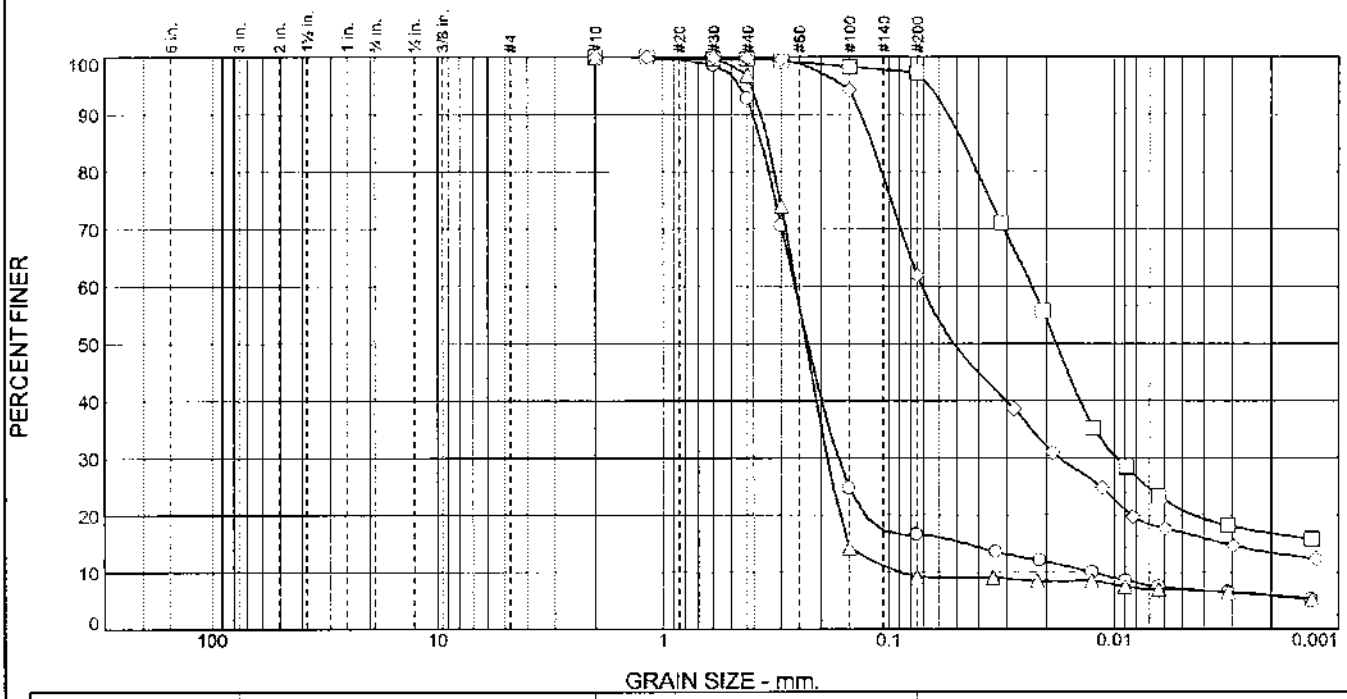
SIERRA TESTING LABS, INC.

El Dorado Hills, CA

Figure

Tested By: ○ AM □ MG △ MS ◇ MS **Checked By:** CMW

Particle Size Distribution Report



	% +3"	% Gravel	% Sand Coarse	% Sand Fine	% Fines Silt	% Fines Clay
○	0.0	0.0	7.3	76.1	10.7	5.9
□	0.0	0.0	0.3	2.4	80.5	16.8
△	0.0	0.0	3.1	87.7	3.2	6.0
◇	0.0	0.0	0.2	37.9	48.5	13.4

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	NV	NP	0.3670	0.2620	0.2296	0.1685	0.0457	0.0126	8.60	20.79
□	NV	NP	0.0469	0.0231	0.0181	0.0098				
△	NV	NP	0.3428	0.2584	0.2334	0.1883	0.1521	0.0892	1.54	2.90
◇	NV	NP	0.1192	0.0716	0.0518	0.0176	0.0032			

Material Description	USCS	AASHTO
○ silty sand	SM	A-2-4(0)
□ silt	ML	A-4(0)
△ poorly graded sand with silt	SP-SM	A-3
◇ sandy silt	ML	A-4(0)

Project No. 07-167 **Client:** ERM

Project: Arkema Portland Harbor Site

○ **Location:** OA Soil ST2 B120 **Depth:** 28-34.0 **Sample Number:** 6/12/07

□ **Location:** OA Soils S-IB2 B120 **Depth:** 34-35.0 **Sample Number:** 6/12/07

△ **Location:** OA Soil IT2 B120 **Depth:** 41-44.0 **Sample Number:** 6/12/07

◇ **Location:** OA Soil DB2 B121 **Depth:** 67-72.0 **Sample Number:** 6/12/07

Remarks:

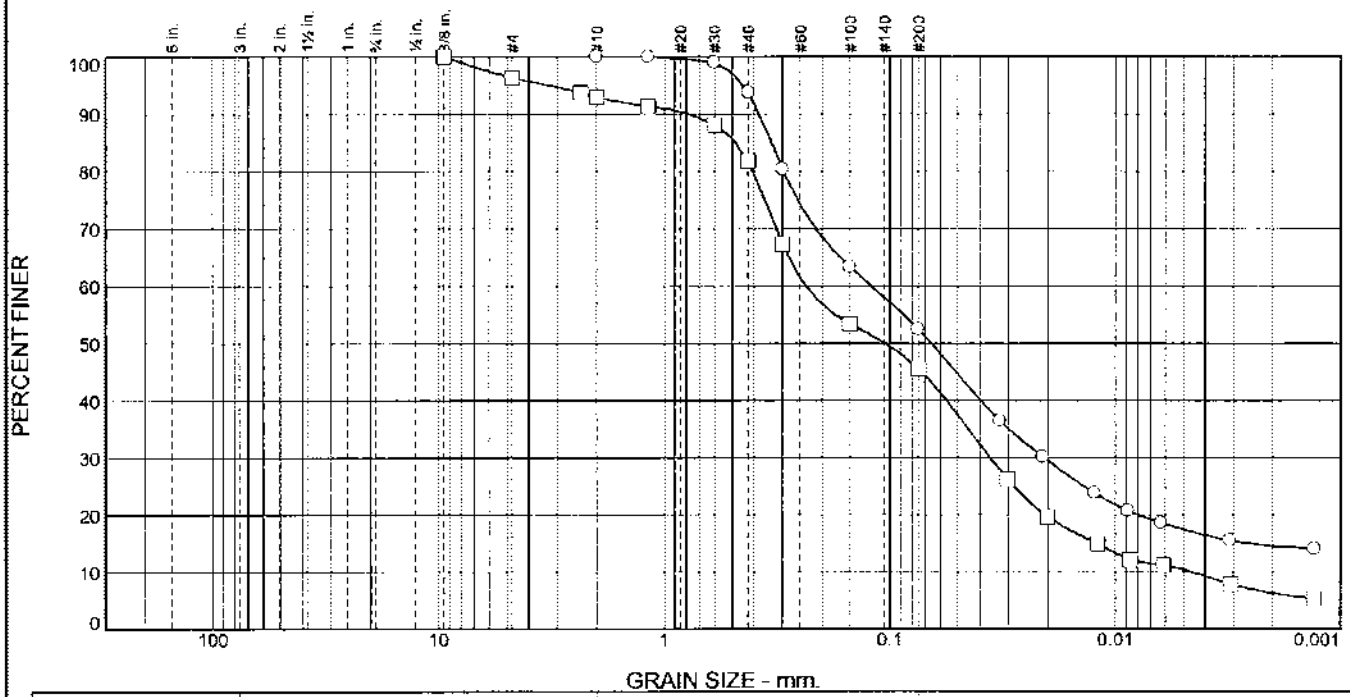
SIERRA TESTING LABS, INC.

El Dorado Hills, CA

Figure

Tested By: ○ PD □ PD/MG △ PD/MG ◇ PD/AM **Checked By:** MN

Particle Size Distribution Report



	% +3"	% Gravel	% Sand		% Fines	
			Coarse	Fine	Silt	Clay
○	0.0	0.0	6.2	41.3	37.9	14.6
□	0.0	7.1	11.1	36.2	39.3	6.3

	LL	PL	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○	NV	NP	0.3360	0.1210	0.0657	0.0208	0.0025			
□	21	NP	0.4799	0.2361	0.1053	0.0361	0.0121	0.0046	1.21	51.66

	Material Description	USCS	AASHTO
○	sandy silt	ML	A-4(0)
□	silty sand	SM	A-4(0)

Project No. 07-167 **Client:** ERM

Project: Arkema Portland Harbor Site

○ **Location:** CA Soil Full Depth Composite, B121 **Sample Number:** 6/12/07

□ **Location:** OA Soil Full Depth Composite, B120 **Sample Number:** 6/12/07

Remarks:

SIERRA TESTING LABS, INC.

El Dorado Hills, CA

Figure

Tested By: PD/MG **Checked By:** MN

Appendix D
Analytical Testing Laboratory Reports

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

April 26, 2007

Brendan Robinson
ERM - Portland
101 SW Main St. Suite 804
Portland, OR 97204

RE: Arkema-2007-STL/Legacy

Enclosed are the results of analyses for samples received by the laboratory on 04/06/07 16:50.
The following list is a summary of the Work Orders contained in this report, generated on 04/26/07 17:18.

If you have any questions concerning this report, please feel free to contact me.

Work Order	Project	ProjectNumber
PQD0258	Arkema-2007-STL/Legacy	63836.02

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Laboratory ID	Matrix	Date Sampled	Date Received
MWA-67si-040607	PQD0258-01	Water	04/06/07 09:35	04/06/07 16:50
MWA-30-040607	PQD0258-02	Water	04/06/07 10:21	04/06/07 16:50
B-120 35-37	PQD0258-03	Soil	04/05/07 12:00	04/06/07 16:50
B-121 27-29	PQD0258-04	Soil	04/05/07 12:00	04/06/07 16:50
B-120 34-35	PQD0258-05	Soil	04/05/07 12:00	04/06/07 16:50
B-120 41-44	PQD0258-06	Soil	04/05/07 12:00	04/06/07 16:50
B-120 46-50	PQD0258-07	Soil	04/05/07 12:00	04/06/07 16:50
B-121 29-31	PQD0258-08	Soil	04/05/07 12:00	04/06/07 16:50
B-121 32-39	PQD0258-09	Soil	04/05/07 12:00	04/06/07 16:50
B-121 62-65	PQD0258-10	Soil	04/05/07 12:00	04/06/07 16:50
MWA-67si-040607	PQD0258-11	Other wet	04/06/07 09:35	04/06/07 16:50
MWA-30-040607	PQD0258-12	Other wet	04/06/07 10:21	04/06/07 16:50

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Analytical Case Narrative

TestAmerica - Portland, OR

PQD0258

1.0 DESCRIPTION OF CASE
Two water and eight soil samples were received on April 6th, 2007 at a temperature of 4.8 and 5.9 °C for the two coolers received.

2.0 PREPARATIONS AND ANALYSIS
The two water samples PQD0258-1 and 2, (MWA-67si-040607 and MWA-30-040607 respectively) were requested for specific gravity by method SM2710F. This method is designed for oil samples not water samples. To enable reporting, these two samples were logged in twice, once as our sample numbers PQD0258-1 and 2 and again as PQD0258-11 and 12. These are the same samples, we simply had to log them in as "water" (samples 1 & 2) matrix for other tests and again as "other wet" (samples 11 & 12) matrix to report the specific gravity

No additional anomalies, discrepancies, or issues were associated with sample preparation, analysis and quality control other than those already qualified in the data and described in the Notes and Definitions page at the end of this report.

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Oil and Grease Analysis per EPA Method 1664

TestAmerica - Portland, OR

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
PQD0258-01 (MWA-67si-040607)		**Water**			**Sampled: 04/06/07 09:35**					
Oil & Grease	EPA 1664	ND	-----	4.85	mg/l	1x	7040470	04/11/07 14:45	04/12/07 09:17	
PQD0258-02 (MWA-30-040607)		**Water**			**Sampled: 04/06/07 10:21**					
Oil & Grease	EPA 1664	ND	-----	4.85	mg/l	1x	7040470	04/11/07 14:45	04/12/07 09:17	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Conventional Chemistry Parameters per APHA/EPA Methods

TestAmerica - Portland, OR

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
PQD0258-01 (MWA-67si-040607)		**Water**			**Sampled: 04/06/07 09:35**					
Total Dissolved Solids	EPA 160.1	**9150**	-----	10.0	mg/l	1x	7040392	04/10/07 09:25	04/10/07 15:50	
Total Organic Carbon	EPA 9060	**67.0**	-----	1.00	"	"	7040807	04/18/07 22:54	04/19/07 03:30	
Total Suspended Solids	EPA 160.2	ND	-----	10.0	"	"	7040416	04/10/07 11:35	04/10/07 16:25	
PQD0258-02 (MWA-30-040607)		**Water**			**Sampled: 04/06/07 10:21**					
Total Dissolved Solids	EPA 160.1	**66000**	-----	10.0	mg/l	1x	7040392	04/10/07 09:25	04/10/07 15:50	
Total Organic Carbon	EPA 9060	**12.6**	-----	1.00	"	"	7040807	04/18/07 22:54	04/19/07 03:30	
Total Suspended Solids	EPA 160.2	ND	-----	10.0	"	"	7040416	04/10/07 11:35	04/10/07 16:25	
PQD0258-03 (B-120 35-37)		**Soil**			**Sampled: 04/05/07 12:00**					
pH	150.1/9040A	**5.06**	-----		pH Units	1x	7040338	04/09/07 09:56	04/09/07 10:15	
PQD0258-04 (B-121 27-29)		**Soil**			**Sampled: 04/05/07 12:00**					
pH	150.1/9040A	**8.19**	-----		pH Units	1x	7040338	04/09/07 09:56	04/09/07 10:15	
PQD0258-05 (B-120 34-35)		**Soil**			**Sampled: 04/05/07 12:00**					
pH	150.1/9040A	**4.76**	-----		pH Units	1x	7040662	04/16/07 12:32	04/16/07 13:30	
PQD0258-06 (B-120 41-44)		**Soil**			**Sampled: 04/05/07 12:00**					
pH	150.1/9040A	**10.2**	-----		pH Units	1x	7040662	04/16/07 12:32	04/16/07 13:30	**A-01**
PQD0258-07 (B-120 46-50)		**Soil**			**Sampled: 04/05/07 12:00**					
pH	150.1/9040A	**8.18**	-----		pH Units	1x	7040662	04/16/07 12:32	04/16/07 13:30	
PQD0258-08 (B-121 29-31)		**Soil**			**Sampled: 04/05/07 12:00**					
pH	150.1/9040A	**8.81**	-----		pH Units	1x	7040662	04/16/07 12:32	04/16/07 13:30	
PQD0258-09 (B-121 32-39)		**Soil**			**Sampled: 04/05/07 12:00**					
pH	150.1/9040A	**7.57**	-----		pH Units	1x	7040662	04/16/07 12:32	04/16/07 13:30	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Conventional Chemistry Parameters per APHA/EPA Methods

TestAmerica - Portland, OR

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
PQD0258-10 (B-121 62-65)		**Soil**			**Sampled: 04/05/07 12:00**					
pH	150.1/9040A	**7.29**	-----		pH Units	1x	7040662	04/16/07 12:32	04/16/07 13:30	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Physical Parameters per APHA/ASTM/EPA Methods

TestAmerica - Portland, OR

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
PQD0258-03 (B-120 35-37)		**Soil**			**Sampled: 04/05/07 12:00**					
Salinity	SM 2520 B	**0.300**	-----	0.100	N/A	1x	7040711	04/17/07 10:45	04/17/07 13:04	
PQD0258-04 (B-121 27-29)		**Soil**			**Sampled: 04/05/07 12:00**					
Salinity	SM 2520 B	**2.49**	-----	0.0996	N/A	1x	7040711	04/17/07 10:45	04/17/07 13:04	
PQD0258-05 (B-120 34-35)		**Soil**			**Sampled: 04/05/07 12:00**					
Salinity	SM 2520 B	**0.797**	-----	0.0996	N/A	1x	7040711	04/17/07 10:45	04/17/07 13:04	
PQD0258-06 (B-120 41-44)		**Soil**			**Sampled: 04/05/07 12:00**					
Salinity	SM 2520 B	**1.48**	-----	0.0986	N/A	1x	7040711	04/17/07 10:45	04/17/07 13:04	
PQD0258-07 (B-120 46-50)		**Soil**			**Sampled: 04/05/07 12:00**					
Salinity	SM 2520 B	**0.589**	-----	0.0982	N/A	1x	7040711	04/17/07 10:45	04/17/07 13:04	
PQD0258-08 (B-121 29-31)		**Soil**			**Sampled: 04/05/07 12:00**					
Salinity	SM 2520 B	**138**	-----	0.0986	N/A	1x	7040711	04/17/07 10:45	04/17/07 13:04	
PQD0258-09 (B-121 32-39)		**Soil**			**Sampled: 04/05/07 12:00**					
Salinity	SM 2520 B	**2.89**	-----	0.0996	N/A	1x	7040711	04/17/07 10:45	04/17/07 13:04	
PQD0258-10 (B-121 62-65)		**Soil**			**Sampled: 04/05/07 12:00**					
Salinity	SM 2520 B	**292**	-----	0.0996	N/A	1x	7040711	04/17/07 10:45	04/17/07 13:04	
PQD0258-11 (MWA-67si-040607)		**Other wet**			**Sampled: 04/06/07 09:35**					
Specific Gravity	SM 2710F	**1.01**	-----	0.00100	N/A	1x	7040677	04/16/07 17:37	04/16/07 17:45	
PQD0258-12 (MWA-30-040607)		**Other wet**			**Sampled: 04/06/07 10:21**					
Specific Gravity	SM 2710F	**1.05**	-----	0.00100	N/A	1x	7040677	04/16/07 17:37	04/16/07 17:45	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Percent Dry Weight (Solids) per Standard Methods

TestAmerica - Portland, OR

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
PQD0258-03 (B-120 35-37)		**Soil**			**Sampled: 04/05/07 12:00**					
% Solids	NCA SOP	**73.7**	-----	0.00	% by Weight	1x	7040321	04/07/07 08:53	04/07/07 08:53	
PQD0258-04 (B-121 27-29)		**Soil**			**Sampled: 04/05/07 12:00**					
% Solids	NCA SOP	**75.4**	-----	0.00	% by Weight	1x	7040321	04/07/07 08:53	04/07/07 08:53	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

General Chemistry Parameters

TestAmerica - Nashville, TN

Analyte	Method	Result	MDL*	MRL	Units	Dil	Batch	Prepared	Analyzed	Notes
PQD0258-01 (MWA-67si-040607)		**Water**			**Sampled: 04/06/07 09:35**					
Total Organic Halides	SW846 9020B	**39.8**	-----	0.0100	mg/L	1x	7040914	04/09/07 10:09	04/21/07 00:45	
PQD0258-02 (MWA-30-040607)		**Water**			**Sampled: 04/06/07 10:21**					
Total Organic Halides	SW846 9020B	**9.36**	-----	0.0100	mg/L	1x	7040914	04/09/07 10:09	04/21/07 00:45	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Oil and Grease Analysis per EPA Method 1664 - Laboratory Quality Control Results

TestAmerica - Portland, OR

QC Batch: 7040470 **Water Preparation Method: O&G prep CE**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (7040470-BLK1)									**Extracted: 04/11/07 11:50**					
Oil & Grease	EPA 1664	ND	---	5.00	mg/l	1x	--	--	--	--	--	--	04/12/07 09:17	
LCS (7040470-BS1)									**Extracted: 04/11/07 11:50**					
Oil & Grease	EPA 1664	39.0	---		mg/l	1x	--	40.2	97.0%	(78-114)	--	--	04/12/07 09:17	
Matrix Spike (7040470-MS1)				**QC Source: PQD0206-01**					**Extracted: 04/11/07 11:50**					
Oil & Grease	EPA 1664	33.5	---		mg/l	1x	0.396	40.2	82.3%	(78-114)	--	--	04/12/07 09:17	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Conventional Chemistry Parameters per APHA/EPA Methods - Laboratory Quality Control Results

TestAmerica - Portland, OR

QC Batch: 7040338 **Soil Preparation Method: General Preparation**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (7040338-DUP1)								Extracted: 04/09/07 09:56						
pH	150.1/9040A	6.62	---		pH Units	1x		--	--	--		(25)	04/09/07 10:15	R2

QC Batch: 7040392 **Water Preparation Method: General Preparation**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (7040392-BLK1)								Extracted: 04/10/07 09:25						
Total Dissolved Solids	EPA 160.1	ND	---	10.0	mg/l	1x	--	--	--	--	--	--	04/10/07 15:50	
LCS (7040392-BS1)								Extracted: 04/10/07 09:25						
Total Dissolved Solids	EPA 160.1	102	---	10.0	mg/l	1x	--	100	102%	(80-120)	--	--	04/10/07 15:50	
Duplicate (7040392-DUP1)				QC Source: PQD0258-01				Extracted: 04/10/07 09:25						
Total Dissolved Solids	EPA 160.1	9150	---	10.0	mg/l	1x	9150	--	--	--	0.00%	(20)	04/10/07 15:50	

QC Batch: 7040416 **Water Preparation Method: General Preparation**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (7040416-BLK1)								Extracted: 04/10/07 11:35						
Total Suspended Solids	EPA 160.2	ND	---	10.0	mg/l	1x	--	--	--	--	--	--	04/10/07 16:25	
LCS (7040416-BS1)								Extracted: 04/10/07 11:35						
Total Suspended Solids	EPA 160.2	49.0	---	10.0	mg/l	1x	--	50.0	98.0%	(80-120)	--	--	04/10/07 16:25	
Duplicate (7040416-DUP1)				QC Source: PQD0258-01				Extracted: 04/10/07 11:35						
Total Suspended Solids	EPA 160.2	ND	---	10.0	mg/l	1x	ND	--	--	--	0.00%	(20)	04/10/07 16:25	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Conventional Chemistry Parameters per APHA/EPA Methods - Laboratory Quality Control Results

TestAmerica - Portland, OR

QC Batch: 7040662 **Soil Preparation Method: General Preparation**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (7040662-DUP1)					QC Source: PQD0258-05				Extracted: 04/16/07 12:32					
pH	150.1/9040A	4.76	---		pH Units	1x	4.76	--	--	--	0.00%	(25)	04/16/07 13:30	

QC Batch: 7040807 **Water Preparation Method: General Preparation**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (7040807-BLK1)									Extracted: 04/18/07 22:54					
Total Organic Carbon	EPA 9060	ND	---	1.00	mg/l	1x	--	--	--	--	--	--	04/19/07 03:30	
LCS (7040807-BS1)									Extracted: 04/18/07 22:54					
Total Organic Carbon	EPA 9060	21.7	---	1.00	mg/l	1x	--	20.0	108%	(85-115)	--	--	04/19/07 03:30	
Duplicate (7040807-DUP1)					QC Source: PQD0258-01				Extracted: 04/18/07 22:54					
Total Organic Carbon	EPA 9060	65.9	---	1.00	mg/l	1x	67.0	--	--	--	1.66%	(20)	04/19/07 03:30	
Matrix Spike (7040807-MS1)					QC Source: PQD0258-01				Extracted: 04/18/07 22:54					
Total Organic Carbon	EPA 9060	91.6	---	1.01	mg/l	1x	67.0	25.3	97.2%	(75-125)	--	--	04/19/07 03:30	
Matrix Spike Dup (7040807-MSD1)					QC Source: PQD0258-01				Extracted: 04/18/07 22:54					
Total Organic Carbon	EPA 9060	92.1	---	1.01	mg/l	1x	67.0	25.3	99.2%	(75-125)	0.544%	(20)	04/19/07 03:30	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Physical Parameters per APHA/ASTM/EPA Methods - Laboratory Quality Control Results

TestAmerica - Portland, OR

QC Batch: 7040677 **Other wet Preparation Method: Oil Qual.**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (7040677-DUP1)					**QC Source: PQD0258-11**				**Extracted: 04/16/07 17:16**					
Specific Gravity	SM 2710F	1.01	---	0.00100	N/A	1x	1.01	--	--	--	0.00%	(10)	04/16/07 17:45	

QC Batch: 7040711 **Soil Preparation Method: General Preparation**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (7040711-BLK1)									**Extracted: 04/17/07 10:45**					
Salinity	SM 2520 B	ND	---	0.100	N/A	1x	--	--	--	--	--	--	04/17/07 13:04	
LCS (7040711-BS1)									**Extracted: 04/17/07 10:45**					
Salinity	SM 2520 B	340	---	0.100	N/A	1x	--	350	97.1%	(80-120)	--	--	04/17/07 13:04	
Duplicate (7040711-DUP1)					**QC Source: PQD0258-03**				**Extracted: 04/17/07 10:45**					
Salinity	SM 2520 B	0.295	---	0.0982	N/A	1x	0.300	--	--	--	1.68%	(20)	04/17/07 13:04	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Percent Dry Weight (Solids) per Standard Methods - Laboratory Quality Control Results

TestAmerica - Portland, OR

QC Batch: 7040321 **Soil Preparation Method: Dry Weight**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Duplicate (7040321-DUP1)					**QC Source: PQD0007-09**				**Extracted: 04/07/07 08:53**					
% Solids	NCA SOP	80.0	---	0.00	% by Weight	1x	80.0	--	--	--	0.00%	(20)	04/07/07 08:53	
Duplicate (7040321-DUP2)					**QC Source: PQD0251-01**				**Extracted: 04/07/07 08:53**					
% Solids	NCA SOP	78.7	---	0.00	% by Weight	1x	78.1	--	--	--	0.765%	(20)	04/07/07 08:53	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

General Chemistry Parameters - Laboratory Quality Control Results

TestAmerica - Nashville, TN

QC Batch: 7040914 **Water Preparation Method: NO PREP**

Analyte	Method	Result	MDL*	MRL	Units	Dil	Source Result	Spike Amt	% REC	(Limits)	% RPD	(Limits)	Analyzed	Notes
Blank (7040914-BLK1)								**Extracted: 04/09/07 10:09**						
Total Organic Halides	SW846 9020B	ND	---	0.0100	mg/L	1x	--	--	--	--	--	--	04/21/07 00:45	
LCS (7040914-BS1)								**Extracted: 04/09/07 10:09**						
Total Organic Halides	SW846 9020B	269	---		ug/L	1x	--	250	108%	(90-110)	--	--	04/21/07 00:45	
Duplicate (7040914-DUP1)				**QC Source: NQD0368-02**				**Extracted: 04/09/07 10:09**						
Total Organic Halides	SW846 9020B	0.0219	---	0.0100	mg/L	1x	ND	--	--	--		(37)	04/21/07 00:45	
Matrix Spike (7040914-MS1)				**QC Source: NQD0368-05**				**Extracted: 04/09/07 10:09**						
Total Organic Halides	SW846 9020B	117	---		ug/L	1x	7.36	100	110%	(69-134)	--	--	04/21/07 00:45	
Matrix Spike Dup (7040914-MSD1)				**QC Source: NQD0368-05**				**Extracted: 04/09/07 10:09**						MNR3
Total Organic Halides	SW846 9020B	0.00	---	TIC	ug/L	1x	7.36	100	-7%	(69-134)		(37)	04/21/07 00:45	

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

TestAmerica
ANALYTICAL TESTING CORPORATION

PORTLAND, OR 9405 S.W. NIMBUS AVENUE
BEAVERTON, OR 97008-7132
ph: (503) 906.9200 fax: (503) 906.9210

ERM - Portland	Project Name:	**Arkema-2007-STL/Legacy**	
101 SW Main St. Suite 804	Project Number:	63836.02	Report Created:
Portland, OR 97204	Project Manager:	Brendan Robinson	04/26/07 17:18

Notes and Definitions

Report Specific Notes:

A-01	-	Outside of calibration
MNR3	-	Insufficient sample received to meet method QC requirements.
R2	-	The RPD exceeded the acceptance limit.

Laboratory Reporting Conventions:

DET	-	Analyte DETECTED at or above the Reporting Limit. Qualitative Analyses only.
ND	-	Analyte NOT DETECTED at or above the reporting limit (MDL or MRL, as appropriate).
NR/NA	-	Not Reported / Not Available
dry	-	Sample results reported on a Dry Weight Basis. Results and Reporting Limits have been corrected for Percent Dry Weight.
wet	-	Sample results and reporting limits reported on a Wet Weight Basis (as received). Results with neither 'wet' nor 'dry' are reported on a Wet Weight Basis.
RPD	-	RELATIVE PERCENT DIFFERENCE (RPDs calculated using Results, not Percent Recoveries).
MRL	-	METHOD REPORTING LIMIT. Reporting Level at, or above, the lowest level standard of the Calibration Table.
MDL*	-	METHOD DETECTION LIMIT. Reporting Level at, or above, the statistically derived limit based on 40CFR, Part 136, Appendix B. *MDLs are listed on the report only if the data has been evaluated below the MRL. Results between the MDL and MRL are reported as Estimated Results.
Dil	-	Dilutions are calculated based on deviations from the standard dilution performed for an analysis, and may not represent the dilution found on the analytical raw data.
Reporting Limits	-	Reporting limits (MDLs and MRLs) are adjusted based on variations in sample preparation amounts, analytical dilutions and percent solids, where applicable.
Electronic Signature	-	Electronic Signature added in accordance with TestAmerica's *Electronic Reporting and Electronic Signatures Policy*. Application of electronic signature indicates that the report has been reviewed and approved for release by the laboratory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

TestAmerica - Portland, OR

Darrell Auvil, Project Manager

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report shall not be reproduced except in full, without the written approval of the laboratory.

PQD0258

ERM

CHAIN OF CUSTODY RECORD

NO: 2049

6650 S.W. REDWOOD LANE, SUITE 300 • PORTLAND, OR 97224 • (503) 542-8007 • FAX (503) 542-8017

63336.02 | Soil and Slurry Compatibility Study

Brendan Robinson

Test America

SAMPLE ID	DATE	TIME						# OF CONTAINERS	SOIL	WATER	GAS	Specific Gravity	Total Suspended Solids	Total Dissolved Solids	Oil and Grease	Total Organic Carbon	Total Organic Halides	pH	Salt Content			
MWA-6151-040607	4/6/07	0935		X	Bladder Pump	Assoc	Y	2750 ml	6		X		X	X	X	X	X	X				
MWA-30-040607	4/6/07	1021		X	"	"	Y	2750 ml	6		X		X	X	X	X	X	X				
B-120 35-37	4/5/07			X	Split Spoon	—	Y	8oz	2	X									X	X		
B-121 27-29	4/2/07			X	split spoon	—	Y	8oz	2	X									X	X		

RELINQUISHED BY (SIGNATURE)	DATE	TIME	RECEIVED BY	DATE	TIME
	4/4/07	1600		4/6	16:00
RELINQUISHED BY (SIGNATURE)	DATE	TIME	RECEIVED BY	DATE	TIME
				lab	16:40
RELINQUISHED BY (SIGNATURE)	DATE	TIME	RECEIVED BY	DATE	TIME

FIELD REMARKS

REMARKS ON SAMPLE RECEIPT

- [ ] BOTTLE INTACT
- [ ] CUSTODY SEALS
- [ ] CHILLED
- [ ] PRESERVED
- [ ] SEALS INTACT
- [ ] SEE REMARKS

ERM REMARKS

SEND REPORT TO: Brendan Robinson

WHITE - LABORATORY COPY CANARY - FIELD COPY PINK - DATABASE MANAGER GOLD - PROJECT FILE

4.8

TAT: _____ Cooler ID: _____

TEST AMERICA SAMPLE RECEIPT CHECKLIST

Received By: (applies to temp at receipt)
Date: 4/6/07
Time: 16:00
Initials: [illegible]

Logged-in By:
Date: 4/6
Initials: SM

Unpacked/Labeled By:
Date: 4/6
Initials: SM

Work Order No. PQD0258
Client: ERM
Project: Atofina

Container Type:
____ Cooler
____ Box
____ None/Other _____

COC Seals:
____ Ship. Container
____ On Bottles
X None
_____ Name
_____ Date

Packing Material _____:
____ Bubble Bags
____ Styrofoam
____ Foam Packs
X None/Other Other _____

Refrigerant:
____ Gel Ice Pack _____
X Loose Ice
____ None/Other _____

Received Via: Bill# _____
____ Fed Ex
____ Client
____ UPS
X TA Courier
____ DHL
____ Mid Valley
____ Senvoy
____ TDP
____ GS
____ Other _____

Cooler Temperature (*IR*): 4.8 5.9 °C/Plastic Glass (circle one) (Frozen filters, Tedlars and aqueous Metals exempt)

Temperature Blank? _____ °C or NA

Trip Blank? Y or N or NA

Sample Containers:		ID			ID
Intact?	Y or N	_____	Metals Preserved?	Y or N or NA	_____
Provided by NCA?	Y or N	_____	Client QAPP Preserved?	Y or N or NA	_____
Correct Type?	Y or N	_____	Adequate Volume? (for tests requested)	Y or N	_____
#Containers match COC?	Y or N	(NOD)	Water VOAs: Headspace?	Y or N or NA	_____
IDs/time/date match COC?	Y or N	_____	Comments:		
Hold Times in hold?	Y or N	_____			

PROJECT MANAGEMENT

Is the Chain of Custody complete? Y or N If N, circle the items that were incomplete

Comments,Problems _____

Total access set up? Y or N
Has client been contacted regarding non-conformances? Y or N If Y, ____/____ Date Time

PM Initials: _____ Date: _____ Time: _____

(rev 3, 09/12/05)

PADO258

ERM

CHAIN OF CUSTODY RECORD

NO: 2049

6650 S.W. REDWOOD LANE, SUITE 300 • PORTLAND, OR 97224 • (503) 542-8007 • FAX (503) 542-8017

Page 1 of 1

PROJECT # 65336.02 | PROJECT NAME: Soil and Slurry Compatibility Study

SAMPLER (PRINT NAME): Brendan Robinson | (SIGNATURE)

RECEIVING LABORATORY: Test America

SAMPLE ID	DATE	TIME	[illegible]	[illegible]	SAMPLING METHOD	[illegible]	[illegible]	MATRIX VOLUME	# OF CONTAINERS	SOIL	WATER	GAS	Specific Gravity	Total Suspended Solids	Total Dissolved Solids	Oil and Grease	Total Organic Carbon	Total Organic Halides	pH	Salt Content			
MWA-6/SI-040607	4/6/07	0935		X	Bladder Pump	Acson	Y	2750 ml	6		X		X	X	X	X	X	X					
MWA-30-040607	4/6/07	1021		X	"	"	Y	2750 ml	6		X		X	X	X	X	X	X					
B-120 35-37	4/5/07			X	Split Spoon	—	Y	8 oz	2	X									X	X			
B-121 27-31	4/2/07			X	Split Spoon	—	Y	8 oz	2	X									X	X			
B-120 34-35	4/2/07						Y	8 oz	1	X									X	X			
B-120 41-44	4/2/07						Y	8 oz	1	X									X	X			
B-120 46-50	4/2/07						Y	8 oz	1	X									X	X			
B-121 29-31	4/2/07						Y	8 oz	1	X									X	X			
B-121 32-39	4/2/07						Y	8 oz	1	X									X	X			
B-121 62-65	4/2/07						Y	8 oz	1	X									X	X			

RELINQUISHED BY (SIGNATURE)	DATE	TIME	RECEIVED BY	DATE	TIME
[signature]	4/6/07	1600	[signature]	4/6	16:00
RELINQUISHED BY (SIGNATURE)	DATE	TIME	RECEIVED BY	DATE	TIME
				lab	16:40
RELINQUISHED BY (SIGNATURE)	DATE	TIME	RECEIVED BY	DATE	TIME

FIELD REMARKS

Revised COC
4/10/07 Date
Initial

REMARKS ON SAMPLE RECEIPT

☐ BOTTLE INTACT ☐ CUSTODY SEALS ☐ CHILLED
☐ PRESERVED ☐ SEALS INTACT ☐ SEE REMARKS

ERM REMARKS

SEND REPORT TO: Brendan Robinson

WHITE - LABORATORY COPY CANARY - FIELD COPY PINK - DATABASE MANAGER GOLD - PROJECT FILE

4.8.5

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix D
Groundwater Treatability Study Report

TO BE INSERTED

Appendix E
Cost Estimates for Groundwater Barrier Wall Alternatives

Table E-1

Cost Comparison for Groundwater Barrier Wall Alternatives
Summary of Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

Location >	River Side High Bank GWBW Route						Full Enclosure GWBW Route						River Side Low Bank GWBW Route					
Technology >	Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile	
Depth >	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt
Direct IRM Costs	$ 6,200,000	$ 6,300,000	$ 6,400,000	$ 6,500,000	$ 10,000,000	$ 10,300,000	$ 11,400,000	$ 11,600,000	$ 11,800,000	$ 12,200,000	$ 19,300,000	$ 20,500,000	$ 7,000,000	$ 7,300,000	$ 7,300,000	$ 7,700,000	$ 10,200,000	$ 11,300,000
Indirect IRM Construction Costs	$ 2,700,000	$ 2,800,000	$ 2,800,000	$ 2,900,000	$ 4,300,000	$ 4,500,000	$ 4,900,000	$ 5,000,000	$ 5,100,000	$ 5,300,000	$ 8,200,000	$ 8,700,000	$ 3,100,000	$ 3,200,000	$ 3,200,000	$ 3,400,000	$ 4,400,000	$ 4,900,000
Total Estimated Construction Cost	$ 8,900,000	$ 9,100,000	$ 9,200,000	$ 9,400,000	$ 14,300,000	$ 14,800,000	$ 16,300,000	$ 16,600,000	$ 16,900,000	$ 17,500,000	$ 27,500,000	$ 29,200,000	$ 10,100,000	$ 10,500,000	$ 10,500,000	$ 11,100,000	$ 14,600,000	$ 16,200,000
Annual IMR Costs	$ 31,000	$ 31,000	$ 31,000	$ 31,000	$ 31,000	$ 31,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 126,000	$ 126,000	$ 126,000	$ 126,000	$ 126,000	$ 126,000
IMR, Present Value	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 600,000	$ 600,000	$ 600,000	$ 600,000	$ 600,000	$ 600,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000
IRM Closure Costs	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000
Present Value	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Estimated Cost, Present Value	$ 9,300,000	$ 9,500,000	$ 9,600,000	$ 9,800,000	$ 14,700,000	$ 15,200,000	$ 16,900,000	$ 17,200,000	$ 17,500,000	$ 18,100,000	$ 28,100,000	$ 29,800,000	$ 11,600,000	$ 12,000,000	$ 12,000,000	$ 12,600,000	$ 16,100,000	$ 17,700,000

Notes:

GWBW groundwater barrier wall
FFS focused feasibility study
IMR inspection, monitoring, and reporting
IRM interim remedial measure
T.D. total depth

Table E-2

Cost Comparison for Groundwater Barrier Wall Alternatives
Itemized Breakdown of Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

			Estimated Cost																			
		Location >	River Side High Bank GWBW Route						Full Enclosure GWBW Route						River Side Low Bank GWBW Route					
		Technology >	Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile	
		Depth >	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt
	Item No.	Description																		
Direct Construction Costs	1	GWBW Mobilization/Demobilization	$ 120,000	$ 120,000	$ 80,000	$ 100,000	$ 80,000	$ 100,000	$ 120,000	$ 120,000	$ 80,000	$ 100,000	$ 80,000	$ 100,000	$ 120,000	$ 120,000	$ 80,000	$ 100,000	$ 80,000	$ 100,000
	2	GWBW Support Mobilization/Demobilization	$ 83,000	$ 84,000	$ 86,000	$ 87,000	$ 136,000	$ 140,000	$ 154,000	$ 158,000	$ 162,000	$ 166,000	$ 266,000	$ 281,000	$ 90,000	$ 94,000	$ 95,000	$ 100,000	$ 132,000	$ 147,000
	3	Temporary Facilities and Controls	$ 207,000	$ 209,000	$ 215,000	$ 219,000	$ 339,000	$ 350,000	$ 386,000	$ 396,000	$ 404,000	$ 416,000	$ 664,000	$ 702,000	$ 449,000	$ 468,000	$ 473,000	$ 499,000	$ 662,000	$ 735,000
	4	Demolish Surface Slabs	$ 329,000	$ 329,000	$ 329,000	$ 329,000	$ 329,000	$ 329,000	$ 592,000	$ 592,000	$ 592,000	$ 592,000	$ 592,000	$ 592,000	$ 172,000	$ 172,000	$ 172,000	$ 172,000	$ 172,000	$ 172,000
	5	Demolish Dock Piers	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 90,000	$ 90,000	$ 90,000	$ 90,000	$ 90,000	$ 90,000
	6	Decon Demolition Debris	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 118,000	$ 118,000	$ 118,000	$ 118,000	$ 118,000	$ 118,000	$ 34,000	$ 34,000	$ 34,000	$ 34,000	$ 34,000	$ 34,000
	7	T&D Demolition Debris (Assume Non-Haz)	$ 667,000	$ 667,000	$ 667,000	$ 667,000	$ 667,000	$ 667,000	$ 1,198,000	$ 1,198,000	$ 1,198,000	$ 1,198,000	$ 1,198,000	$ 1,198,000	$ 348,000	$ 348,000	$ 348,000	$ 348,000	$ 348,000	$ 348,000
	8	Excavate GWBW Clearance Trench	$ 418,000	$ 418,000	$ 418,000	$ 418,000	$ 418,000	$ 418,000	$ 751,000	$ 751,000	$ 751,000	$ 751,000	$ 751,000	$ 751,000	$ 206,000	$ 206,000	$ 206,000	$ 206,000	$ 206,000	$ 206,000
	9	T&D GWBW Clearance Trench Excavation Spoil (Assume Non-Haz)	$ 838,000	$ 838,000	$ 838,000	$ 838,000	$ 838,000	$ 838,000	$ 1,506,000	$ 1,506,000	$ 1,506,000	$ 1,506,000	$ 1,506,000	$ 1,506,000	$ 357,000	$ 357,000	$ 357,000	$ 357,000	$ 357,000	$ 357,000
	10	Screen GWBW Clearance Trench Spoil and Use to Backfill Trench	$ 527,000	$ 527,000	$ 527,000	$ 527,000	$ 527,000	$ 527,000	$ 947,000	$ 947,000	$ 947,000	$ 947,000	$ 947,000	$ 947,000	$ 264,000	$ 264,000	$ 264,000	$ 264,000	$ 264,000	$ 264,000
	11	Backfill GWBW Clearance Trench with Imported Soil	$ 124,000	$ 124,000	$ 124,000	$ 124,000	$ 124,000	$ 124,000	$ 223,000	$ 223,000	$ 223,000	$ 223,000	$ 223,000	$ 223,000	$ 53,000	$ 53,000	$ 53,000	$ 53,000	$ 53,000	$ 53,000
	12	Import Soil for GWBW Work Platforms	$ 31,000	$ 31,000	$ 131,000	$ 138,000	$ 31,000	$ 31,000	$ 56,000	$ 56,000	$ 267,000	$ 288,000	$ 56,000	$ 56,000	$ 221,000	$ 221,000	$ 234,000	$ 237,000	$ 221,000	$ 221,000
	13	Construct Fill for GWBW Bench and Ramps	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 187,000	$ 187,000	$ 187,000	$ 187,000	$ 187,000	$ 187,000
	14	Construct GWBW Pilot Trench	$ 3,000	$ 3,000	$ -	$ -	$ -	$ -	$ 6,000	$ 6,000	$ -	$ -	$ -	$ -	$ 4,000	$ 4,000	$ -	$ -	$ -	$ -
	15	Construct GWBW	$ 965,000	$ 1,023,000	$ 724,000	$ 768,000	$ 3,619,000	$ 3,838,000	$ 2,025,000	$ 2,228,000	$ 1,519,000	$ 1,671,000	$ 7,594,000	$ 8,355,000	$ 777,000	$ 971,000	$ 971,000	$ 1,214,000	$ 2,913,000	$ 3,643,000
	16	Excavate GWBW Work Platform	$ 10,000	$ 10,000	$ 44,000	$ 46,000	$ 10,000	$ 10,000	$ 19,000	$ 19,000	$ 89,000	$ 96,000	$ 19,000	$ 19,000	$ 74,000	$ 74,000	$ 78,000	$ 79,000	$ 74,000	$ 74,000
	17	T&D GWBW Work Platform Spoil (Assume Non-Haz)	$ 87,000	$ 87,000	$ 370,000	$ 387,000	$ 87,000	$ 87,000	$ 156,000	$ 156,000	$ 750,000	$ 809,000	$ 156,000	$ 156,000	$ 187,000	$ 187,000	$ 223,000	$ 232,000	$ 187,000	$ 187,000
	18	Excavate GWBW Bench and Ramp Fill	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 62,000	$ 62,000	$ 62,000	$ 62,000	$ 62,000	$ 62,000
	19	T&D GWBW Bench and Ramp Excavation Spoil (Assume Non-Haz)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 263,000	$ 263,000	$ 263,000	$ 263,000	$ 263,000	$ 263,000
	20	Construct GWBW Cap	$ 33,000	$ 33,000	$ 33,000	$ 33,000	$ 33,000	$ 33,000	$ 59,000	$ 59,000	$ 59,000	$ 59,000	$ 59,000	$ 59,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000
	21	Excavate River Bank Riprap to Stockpile	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 140,000	$ 140,000	$ 140,000	$ 140,000	$ 140,000	$ 140,000
	22	Place River Bank FML Cushion Soil	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 78,000	$ 78,000	$ 78,000	$ 78,000	$ 78,000	$ 78,000
	23	Excavate River Bank FML Anchor Trench	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000
	24	T&D River Bank FML Anchor Trench Spoil	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 44,000	$ 44,000	$ 44,000	$ 44,000	$ 44,000	$ 44,000
	25	Place River Bank FML	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 115,000	$ 115,000	$ 115,000	$ 115,000	$ 115,000	$ 115,000
	26	Place River Bank FML Cushion Geotextile	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 92,000	$ 92,000	$ 92,000	$ 92,000	$ 92,000	$ 92,000
	27	Backfill FML Anchor Trench with Imported Fill	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 21,000	$ 21,000	$ 21,000	$ 21,000	$ 21,000	$ 21,000
	28	Place River Bank Riprap from Stockpile	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 280,000	$ 280,000	$ 280,000	$ 280,000	$ 280,000	$ 280,000
	29	Place Imported Riprap	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 206,000	$ 206,000	$ 206,000	$ 206,000	$ 206,000	$ 206,000
	30	Re-connect Dock Piers	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 135,000	$ 135,000	$ 135,000	$ 135,000	$ 135,000	$ 135,000
	31	Construct GWBW Piezometers	$ 32,000	$ 32,000	$ 32,000	$ 32,000	$ 32,000	$ 32,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 32,000	$ 32,000	$ 32,000	$ 32,000	$ 32,000	$ 32,000
	32	Bid and Scope Contingencies	$ 1,589,000	$ 1,610,000	$ 1,639,000	$ 1,673,000	$ 2,568,000	$ 2,657,000	$ 2,930,000	$ 3,006,000	$ 3,052,000	$ 3,149,000	$ 5,000,000	$ 5,292,000	$ 1,801,000	$ 1,877,000	$ 1,882,000	$ 1,990,000	$ 2,623,000	$ 2,916,000
	33	Subtotal:	$ 6,129,000	$ 6,211,000	$ 6,323,000	$ 6,452,000	$ 9,904,000	$ 10,247,000	$ 11,302,000	$ 11,595,000	$ 11,773,000	$ 12,145,000	$ 19,285,000	$ 20,411,000	$ 6,947,000	$ 7,240,000	$ 7,260,000	$ 7,675,000	$ 10,116,000	$ 11,247,000
		Round To:	$ 6,200,000	$ 6,300,000	$ 6,400,000	$ 6,500,000	$ 10,000,000	$ 10,300,000	$ 11,400,000	$ 11,600,000	$ 11,800,000	$ 12,200,000	$ 19,300,000	$ 20,500,000	$ 7,000,000	$ 7,300,000	$ 7,300,000	$ 7,700,000	$ 10,200,000	$ 11,300,000
Indirect Construction Costs	34	Final Design Investigation	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000
	35	Final Design Engineering	$ 248,000	$ 252,000	$ 256,000	$ 260,000	$ 400,000	$ 412,000	$ 456,000	$ 464,000	$ 472,000	$ 488,000	$ 772,000	$ 820,000	$ 280,000	$ 292,000	$ 292,000	$ 308,000	$ 408,000	$ 452,000
	36	HASP and HASP Implementation	$ 186,000	$ 189,000	$ 192,000	$ 195,000	$ 300,000	$ 309,000	$ 342,000	$ 348,000	$ 354,000	$ 366,000	$ 579,000	$ 615,000	$ 210,000	$ 219,000	$ 219,000	$ 231,000	$ 306,000	$ 339,000
	37	Bidding and Contracting	$ 62,000	$ 63,000	$ 64,000	$ 65,000	$ 100,000	$ 103,000	$ 114,000	$ 116,000	$ 118,000	$ 122,000	$ 193,000	$ 205,000	$ 70,000	$ 73,000	$ 73,000	$ 77,000	$ 102,000	$ 113,000
	38	Construction Management	$ 1,860,000	$ 1,890,000	$ 1,920,000	$ 1,950,000	$ 3,000,000	$ 3,090,000	$ 3,420,000	$ 3,480,000	$ 3,540,000	$ 3,660,000	$ 5,790,000	$ 6,150,000	$ 2,100,000	$ 2,190,000	$ 2,190,000	$ 2,310,000	$ 3,060,000	$ 3,390,000
	39	CQA Plan and Implementation	$ 186,000	$ 189,000	$ 192,000	$ 195,000	$ 300,000	$ 309,000	$ 342,000	$ 348,000	$ 354,000	$ 366,000	$ 579,000	$ 615,000	$ 210,000	$ 219,000	$ 219,000	$ 231,000	$ 306,000	$ 339,000
	40	Construction Phase Engineering	$ 62,000	$ 63,000	$ 64,000	$ 65,000	$ 100,000	$ 103,000	$ 114,000	$ 116,000	$ 118,000	$ 122,000	$ 193,000	$ 205,000	$ 70,000	$ 73,000	$ 73,000	$ 77,000	$ 102,000	$ 113,000
	41	GWBW IRM Completion Report	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000
	42	Subtotal:	$ 2,694,000	$ 2,736,000	$ 2,778,000	$ 2,820,000	$ 4,290,000	$ 4,416,000	$ 4,878,000	$ 4,962,000	$ 5,046,000	$ 5,214,000	$ 8,196,000	$ 8,700,000	$ 3,030,000	$ 3,156,000	$ 3,156,000	$ 3,324,000	$ 4,374,000	$ 4,836,000
		Round To:	$ 2,700,000	$ 2,800,000	$ 2,800,000	$ 2,900,000	$ 4,300,000	$ 4,500,000	$ 4,900,000	$ 5,000,000	$ 5,100,000	$ 5,300,000	$ 8,200,000	$ 8,700,000	$ 3,100,000	$ 3,200,000	$ 3,200,000	$ 3,400,000	$ 4,400,000	$ 4,900,000
	43	Total Estimated Construction Cost	$ 8,900,000	$ 9,100,000	$ 9,200,000	$ 9,400,000	$ 14,300,000	$ 14,800,000	$ 16,300,000	$ 16,600,000	$ 16,900,000	$ 17,500,000	$ 27,500,000	$ 29,200,000	$ 10,100,000	$ 10,500,000	$ 10,500,000	$ 11,100,000	$ 14,600,000	$ 16,200,000

Table E-2

Cost Comparison for Groundwater Barrier Wall Alternatives
Itemized Breakdown of Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

			Estimated Cost																	
		Location >	River Side High Bank GWBW Route						Full Enclosure GWBW Route						River Side Low Bank GWBW Route					
		Technology >	Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile	
		Depth >	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt
	No.	Item Description																		
IMR Costs	44	Ground Water Level Monitoring	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000
	45	Repair Mobilization/Demobilization	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000
	46	Repair GWBW Cap	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000
	47	Repair River Bank Cap	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 23,000	$ 23,000	$ 23,000	$ 23,000	$ 23,000	$ 23,000
	48	Repair River Bank Riprap	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 23,000	$ 23,000	$ 23,000	$ 23,000	$ 23,000	$ 23,000
	49	Repair Contingencies	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 22,000	$ 22,000	$ 22,000	$ 22,000	$ 22,000	$ 22,000
	50	Repair Engineering, CM, and Field Services	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 23,000	$ 23,000	$ 23,000	$ 23,000	$ 23,000	$ 23,000
	51	Replace Piezometer	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000	$ 1,000
	52	Ground Water Sampling and Analysis	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000	$ 16,000
	53	Annual Inspection and Report	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000
	54	Subtotal:	$ 31,000	$ 31,000	$ 31,000	$ 31,000	$ 31,000	$ 31,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 126,000	$ 126,000	$ 126,000	$ 126,000	$ 126,000	$ 126,000
		Round To:	$ 31,000	$ 31,000	$ 31,000	$ 31,000	$ 31,000	$ 31,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 126,000	$ 126,000	$ 126,000	$ 126,000	$ 126,000	$ 126,000
	55	Effective Discount Rate, APR	7.5%																	
	56	IMR Planning Period, YR	30																	
	57	Present Value	$ 366,000	$ 366,000	$ 366,000	$ 366,000	$ 366,000	$ 366,000	$ 531,000	$ 531,000	$ 531,000	$ 531,000	$ 531,000	$ 531,000	$ 1,488,000	$ 1,488,000	$ 1,488,000	$ 1,488,000	$ 1,488,000	$ 1,488,000
		Round To:	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 600,000	$ 600,000	$ 600,000	$ 600,000	$ 600,000	$ 600,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000
IRM Closure Costs	58	P&A Piezometers	$ 32,000	$ 32,000	$ 32,000	$ 32,000	$ 32,000	$ 32,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 56,000	$ 32,000	$ 32,000	$ 32,000	$ 32,000	$ 32,000	$ 32,000
	59	GWBW Part of Closure Certification Report	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000
	60	Subtotal:	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000
		Round To:	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000	$ 42,000
	61	Effective Discount Rate, APR	7.5%																	
	62	IMR Planning Period, YR	30																	
	63	Present Value	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000
		Round To:	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	64	Total Estimated Cost, Present Value	$ 9,300,000	$ 9,500,000	$ 9,600,000	$ 9,800,000	$ 14,700,000	$ 15,200,000	$ 16,900,000	$ 17,200,000	$ 17,500,000	$ 18,100,000	$ 28,100,000	$ 29,800,000	$ 11,600,000	$ 12,000,000	$ 12,000,000	$ 12,600,000	$ 16,100,000	$ 17,700,000
		Round To:	$ 9,300,000	$ 9,500,000	$ 9,600,000	$ 9,800,000	$ 14,700,000	$ 15,200,000	$ 16,900,000	$ 17,200,000	$ 17,500,000	$ 18,100,000	$ 28,100,000	$ 29,800,000	$ 11,600,000	$ 12,000,000	$ 12,000,000	$ 12,600,000	$ 16,100,000	$ 17,700,000

Notes:

APR	annual percentage rate
BCY	bank cubic yards
CCY	compacted cubic yards
CM	construction management
CQA	construction quality assurance
CY	cubic yards
EA	each
F	future (value)
FFS	focused feasibility study
FML	flexible membrane liner
GWBW	groundwater barrier wall
HASP	health and safety plan
i	interest rate
IMR	inspection, monitoring and reporting
IRM	interim remedial measures
LF	linear feet
LS	lump sum
n	number of years (planning period)
Non-Haz	nonhazardous
P	present (value)
P&A	plug and abandon
SF	square feet
T&D	transport and dispose
T.D.	total depth
VSF	vertical square feet
YR	year

Table E-3

Cost Comparison for Groundwater Barrier Wall Alternatives
Estimated Quantities for Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

			Estimated Quantities																	
		Location >	River Side High Bank GWBW Route						Full Enclosure GWBW Route						River Side Low Bank GWBW Route					
		Technology >	Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile	
		Depth >	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt
	Item No.	Description	Estimate Units																	
Direct Construction Costs	1	GWBW Mobilization/Demobilization	LS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2	GWBW Support Mobilization/Demobilization	SUM																		
	3	Temporary Facilities and Controls	SUM																		
	4	Demolish Surface Slabs	CY	6,589	6,589	6,589	6,589	6,589	6,589	11,837	11,837	11,837	11,837	11,837	11,837	3,438	3,438	3,438	3,438	3,438	3,438
	5	Demolish Dock Piers	EA	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3
	6	Decon Demolition Debris	CY	6,589	6,589	6,589	6,589	6,589	6,589	11,837	11,837	11,837	11,837	11,837	11,837	3,438	3,438	3,438	3,438	3,438	3,438
	7	T&D Demolition Debris (Assume Non-Haz)	TON	26,685	26,685	26,685	26,685	26,685	26,685	47,938	47,938	47,938	47,938	47,938	47,938	13,924	13,924	13,924	13,924	13,924	13,924
	8	Excavate GWBW Clearance Trench	BCY	83,599	83,599	83,599	83,599	83,599	83,599	150,182	150,182	150,182	150,182	150,182	150,182	41,205	41,205	41,205	41,205	41,205	41,205
	9	T&D GWBW Clearance Trench Excavation Spoil (Assume Non-Haz)	TON	33,537	33,537	33,537	33,537	33,537	33,537	60,248	60,248	60,248	60,248	60,248	60,248	14,283	14,283	14,283	14,283	14,283	14,283
	10	Screen GWBW Clearance Trench Spoil and Use to Backfill Trench	CCY	75,319	75,319	75,319	75,319	75,319	75,319	135,306	135,306	135,306	135,306	135,306	135,306	37,678	37,678	37,678	37,678	37,678	37,678
	11	Backfill GWBW Clearance Trench with Imported Soil	CCY	8,281	8,281	8,281	8,281	8,281	8,281	14,876	14,876	14,876	14,876	14,876	14,876	3,527	3,527	3,527	3,527	3,527	3,527
	12	Import Soil for GWBW Work Platforms	BCY	2,063	2,063	8,765	9,171	2,063	2,063	3,707	3,707	17,770	19,179	3,707	3,707	14,756	14,756	15,605	15,831	14,756	14,756
	13	Construct Fill for GWBW Bench and Ramps	CCY	0	0	0	0	0	0	0	0	0	0	0	0	12,454	12,454	12,454	12,454	12,454	12,454
	14	Construct GWBW Pilot Trench	CCY	275	275	0	0	0	0	494	494	0	0	0	0	295	295	0	0	0	0
	15	Construct GWBW	VSF	120,627	127,930	120,627	127,930	120,627	127,930	253,141	278,502	253,141	278,502	253,141	278,502	80,906	101,182	80,906	101,182	80,906	101,182
	16	Excavate GWBW Work Platform	BCY	2,063	2,063	8,765	9,171	2,063	2,063	3,707	3,707	17,770	19,179	3,707	3,707	14,756	14,756	15,605	15,831	14,756	14,756
	17	T&D GWBW Work Platform Spoil (Assume Non-Haz)	TON	3,482	3,482	14,791	15,475	3,482	3,482	6,255	6,255	29,987	32,365	6,255	6,255	7,470	7,470	8,903	9,284	7,470	7,470
	18	Excavate GWBW Bench and Ramp Fill	BCY	0	0	0	0	0	0	0	0	0	0	0	0	6,227	6,227	6,227	6,227	6,227	6,227
	19	T&D GWBW Bench and Ramp Excavation Spoil (Assume Non-Haz)	TON	0	0	0	0	0	0	0	0	0	0	0	0	10,508	10,508	10,508	10,508	10,508	10,508
	20	Construct GWBW Cap	CCY	1,651	1,651	1,651	1,651	1,651	1,651	2,965	2,965	2,965	2,965	2,965	2,965	1,771	1,771	1,771	1,771	1,771	1,771
	21	Excavate River Bank Riprap to Stockpile	CY	0	0	0	0	0	0	0	0	0	0	0	0	9,317	9,317	9,317	9,317	9,317	9,317
	22	Place River Bank FML Cushion Soil	CCY	0	0	0	0	0	0	0	0	0	0	0	0	3,106	3,106	3,106	3,106	3,106	3,106
	23	Excavate River Bank FML Anchor Trench	BCY	0	0	0	0	0	0	0	0	0	0	0	0	1,043	1,043	1,043	1,043	1,043	1,043
	24	T&D River Bank FML Anchor Trench Spoil	TON	0	0	0	0	0	0	0	0	0	0	0	0	1,759	1,759	1,759	1,759	1,759	1,759
	25	Place River Bank FML	SF	0	0	0	0	0	0	0	0	0	0	0	0	114,763	114,763	114,763	114,763	114,763	114,763
	26	Place River Bank FML Cushion Geotextile	SF	0	0	0	0	0	0	0	0	0	0	0	0	114,763	114,763	114,763	114,763	114,763	114,763
	27	Backfill FML Anchor Trench with Imported Fill	CCY	0	0	0	0	0	0	0	0	0	0	0	0	1,043	1,043	1,043	1,043	1,043	1,043
	28	Place River Bank Riprap from Stockpile	CY	0	0	0	0	0	0	0	0	0	0	0	0	9,317	9,317	9,317	9,317	9,317	9,317
	29	Place Imported Riprap	CY	0	0	0	0	0	0	0	0	0	0	0	0	3,435	3,435	3,435	3,435	3,435	3,435
	30	Re-connect Dock Piers	EA	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3
	31	Construct GWBW Piezometers	EA	8	8	8	8	8	8	14	14	14	14	14	14	8	8	8	8	8	8
	32	Bid and Scope Contingencies	SUM																		
	33																				
Indirect Construction Costs	34	Final Design Investigation	LS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	35	Final Design Engineering	SUM																		
	36	HASP and HASP Implementation	SUM																		
	37	Bidding and Contracting	SUM																		
	38	Construction Management	SUM																		
	39	CQA Plan and Implementation	SUM																		
	40	Construction Phase Engineering	SUM																		
	41	GWBW IRM Completion Report	LS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	42																				
	43	Total Estimated Construction Cost																			

Table E-3

Cost Comparison for Groundwater Barrier Wall Alternatives
Estimated Quantities for Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

			Estimated Quantities																	
		Location >	River Side High Bank GWBW Route						Full Enclosure GWBW Route						River Side Low Bank GWBW Route					
		Technology >	Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile	
		Depth >	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt
	Item No.	Description / Estimate Units																		
IMR Costs	44	Ground Water Level Monitoring / EVENT/YR	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	45	Repair Mobilization/Demobilization / SUM																		
	46	Repair GWBW Cap / CY/YR	30	30	30	30	30	30	60	60	60	60	60	60	40	40	40	40	40	40
	47	Repair River Bank Cap / SF/YR	0	0	0	0	0	0	0	0	0	0	0	0	2,300	2,300	2,300	2,300	2,300	2,300
	48	Repair River Bank Riprap / CY/YR	0	0	0	0	0	0	0	0	0	0	0	0	190	190	190	190	190	190
	49	Repair Contingencies / SUM																		
	50	Repair Engineering, CM, and Field Services / SUM																		
	51	Replace Piezometer / EA/YR	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	52	Ground Water Sampling and Analysis / EVENT/YR	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	53	Annual Inspection and Report / EA/YR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	54																			
	55	Effective Discount Rate / APR	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
	56	IMR Planning Period / YR	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
	57	Present Value / SUM																		
IRM Closure Costs	58	P&A Piezometers / EA	8	8	8	8	8	8	14	14	14	14	14	14	8	8	8	8	8	8
	59	GWBW Part of Closure Certification Report / LS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	60																			
	61	Net Effective Discount Rate / APR	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
	62	IMR Planning Period / YR	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
	63	Present Value / SUM																		
	64	Total Estimated Cost, Present Value																		

Notes:

APR	annual percentage rate	CY	cubic yards	GWBW	groundwater barrier wall	LF	linear feet	P&A	plug and abandon
BCY	bank cubic yards	EA	each	HASP	health and safety plan	LS	lump sum	SF	square feet
CCY	compacted cubic yards	F	future (value)	i	interest rate	n	number of years (planning period)	T&D	transport and dispose
CM	construction management	FFS	focused feasibility study	IMR	inspection, monitoring and reporting	Non-Haz	non-hazardous	T.D.	total depth
CQA	construction quality assurance	FML	flexible membrane liner	IRM	interim remedial measures	P	present (value)	VSF	vertical square feet
YR	year								

Table E-4

Cost Comparison for Groundwater Barrier Wall Alternatives
Quantity Calculations for Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

			Location >	River Side High Bank GWBW Route						Full Enclosure GWBW Route						River Side Low Bank GWBW Route					
			Technology >	Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile	
			Depth >	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt
	Items		Estimate																		
	Class	Component	Units																		
GWBW Length and Area	Acid Plant Part	Through Bank Fill	LF	837	837	837	837	837	837	774	774	774	774	774	774	315	315	315	315	315	315
			VSF	48,842	48,842	48,842	48,842	48,842	48,842	44,827	44,827	44,827	44,827	44,827	44,827	11,029	11,029	11,029	11,029	11,029	11,029
		Not Through Bank Fill	LF	93	93	93	93	93	93	86	86	86	86	86	86	735	735	735	735	735	735
			VSF	5,427	5,427	5,427	5,427	5,427	5,427	4,981	4,981	4,981	4,981	4,981	4,981	25,734	25,734	25,734	25,734	25,734	25,734
		Subtotal	LF	930	930	930	930	930	930	860	860	860	860	860	860	1,050	1,050	1,050	1,050	1,050	1,050
			VSF	54,269	54,269	54,269	54,269	54,269	54,269	49,807	49,807	49,807	49,807	49,807	49,807	36,763	36,763	36,763	36,763	36,763	36,763
	Non-Acid Plant Part	Through Bank Fill	LF	834	834	834	834	834	834	2,228	2,228	2,228	2,228	2,228	2,228	283	283	283	283	283	283
			VSF	59,722	66,295	59,722	66,295	59,722	66,295	183,000	205,826	183,000	205,826	183,000	205,826	11,803	17,886	11,803	17,886	11,803	17,886
		Not Through Bank Fill	LF	93	93	93	93	93	93	248	248	248	248	248	248	659	659	659	659	659	659
			VSF	6,636	7,366	6,636	7,366	6,636	7,366	20,333	22,870	20,333	22,870	20,333	22,870	27,541	41,733	27,541	41,733	27,541	41,733
		Subtotal	LF	927	927	927	927	927	927	2,476	2,476	2,476	2,476	2,476	2,476	942	942	942	942	942	942
			VSF	66,358	73,661	66,358	73,661	66,358	73,661	203,333	228,695	203,333	228,695	203,333	228,695	39,344	59,619	39,344	59,619	39,344	59,619
	All Parts		LF	1,857	1,857	1,857	1,857	1,857	1,857	3,336	3,336	3,336	3,336	3,336	3,336	1,992	1,992	1,992	1,992	1,992	1,992
			VSF	120,627	127,930	120,627	127,930	120,627	127,930	253,141	278,502	253,141	278,502	253,141	278,502	76,106	96,382	76,106	96,382	76,106	96,382
	Bank Fill Part of GWBW Route Surface Clearing	Top Width	FT W	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
		Length	LF	1,671	1,671	1,671	1,671	1,671	1,671	3,002	3,002	3,002	3,002	3,002	3,002	598	598	598	598	598	598
		% Cover	SF/SF	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	10%	10%	10%	10%	10%	10%
		Avg. Thk.	VF	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Debris V	BCY	6,438	6,438	6,438	6,438	6,438	6,438	11,565	11,565	11,565	11,565	11,565	11,565	2,302	2,302	2,302	2,302	2,302	2,302
		Debris Unit Wt.	PCF	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
		Waste	TON	26,072	26,072	26,072	26,072	26,072	26,072	46,837	46,837	46,837	46,837	46,837	46,837	9,323	9,323	9,323	9,323	9,323	9,323
	Bank Fill Part of GWBW Subsurface Debris Clearance	Bottom Width	FT W	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Avg. Depth	VF	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
		Side Slope	H:V	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Side Slope	FT W	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
		Top Width	FT W	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
		Exc. X-sec. A	VSF	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325	1,325
		Length	LF	1,671	1,671	1,671	1,671	1,671	1,671	3,002	3,002	3,002	3,002	3,002	3,002	598	598	598	598	598	598
		Spoil V	BCY	82,018	82,018	82,018	82,018	82,018	82,018	147,340	147,340	147,340	147,340	147,340	147,340	29,327	29,327	29,327	29,327	29,327	29,327
		% Debris	BCY/BCY	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
		Debris V	BCY	8,202	8,202	8,202	8,202	8,202	8,202	14,734	14,734	14,734	14,734	14,734	14,734	2,933	2,933	2,933	2,933	2,933	2,933
		Debris Unit Wt.	PCF	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
		Waste	TON	33,217	33,217	33,217	33,217	33,217	33,217	59,673	59,673	59,673	59,673	59,673	59,673	11,877	11,877	11,877	11,877	11,877	11,877
		Exc. Backfill	CCY	73,816	73,816	73,816	73,816	73,816	73,816	132,606	132,606	132,606	132,606	132,606	132,606	26,394	26,394	26,394	26,394	26,394	26,394
		Import Backfill	CCY	8,202	8,202	8,202	8,202	8,202	8,202	14,734	14,734	14,734	14,734	14,734	14,734	2,933	2,933	2,933	2,933	2,933	2,933
	Non-Bank Fill Part GWBW Route Surface Clearing	Top Width	FT W	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
		Length	LF	186	186	186	186	186	186	334	334	334	334	334	334	1,394	1,394	1,394	1,394	1,394	1,394
		% Cover	SF/SF	20%	20%	20%	20%	20%	20%	30%	30%	30%	30%	30%	30%	0%	0%	0%	0%	0%	0%
		Avg. Thk.	VF	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Debris V	BCY	151	151	151	151	151	151	272	272	272	272	272	272	1,136	1,136	1,136	1,136	1,136	1,136
		Debris Unit Wt.	PCF	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
		Waste	TON	613	613	613	613	613	613	1,101	1,101	1,101	1,101	1,101	1,101	4,602	4,602	4,602	4,602	4,602	4,602
	Non-Bank Fill GWBW Subsurface Debris Clearance	Bottom Width	FT W	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Avg. Depth	VF	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
		Side Slope	H:V	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		SS Reach	FT W	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
		Top Width	FT W	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
		Exc X-A	VSF	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230
		Length	LF	186	186	186	186	186	186	334	334	334	334	334	334	1,394	1,394	1,394	1,394	1,394	1,394
		Spoil V	BCY	1,582	1,582	1,582	1,582	1,582	1,582	2,842	2,842	2,842	2,842	2,842	2,842	11,878	11,878	11,878	11,878	11,878	11,878
		% Debris	BCY/BCY	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
		Debris V	BCY	79	79	79	79	79	79	142	142	142	142	142	142	594	594	594	594	594	594
		Debris Unit Wt.	PCF	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
		Waste	TON	320	320	320	320	320	320	575	575	575	575	575	575	2,405	2,405	2,405	2,405	2,405	2,405
		Exc. Backfill	CCY	1,503	1,503	1,503	1,503	1,503	1,503	2,700	2,700	2,700	2,700	2,700	2,700	11,284	11,284	11,284	11,284	11,284	11,284
		Import Backfill	CCY	79	79	79	79	79	79	142	142	142	142	142	142	594	594	594	594	594	594

Table E-4

Cost Comparison for Groundwater Barrier Wall Alternatives
Quantity Calculations for Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

		Location >	River Side High Bank GWBW Route						Full Enclosure GWBW Route						River Side Low Bank GWBW Route					
		Technology >	Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile	
		Depth >	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.
Excavation Work Platform	Width	FT W	20	20	20	20	20	20	20	20	20	20	20	20	40	40	40	40	40	40
	Avg. Thk.	VF	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	5.0	5.0	5.0	5.0	5.0	5.0
	Length	LF	1,857	1,857	1,857	1,857	1,857	1,857	3,336	3,336	3,336	3,336	3,336	3,336	1,992	1,992	1,992	1,992	1,992	1,992
	Import Fill	CCY	2,063	2,063	2,063	2,063	2,063	2,063	3,707	3,707	3,707	3,707	3,707	3,707	14,756	14,756	14,756	14,756	14,756	14,756
	% Aff	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	30%	30%	30%	30%	30%	30%
	Affected V	BCY	2,063	2,063	2,063	2,063	2,063	2,063	3,707	3,707	3,707	3,707	3,707	3,707	4,427	4,427	4,427	4,427	4,427	4,427
	Affected UW	PCF	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125
	Waste	TON	3,482	3,482	3,482	3,482	3,482	3,482	6,255	6,255	6,255	6,255	6,255	6,255	7,470	7,470	7,470	7,470	7,470	7,470
	Unaffected V	CY	0	0	0	0	0	0	0	0	0	0	0	0	10,329	10,329	10,329	10,329	10,329	10,329
Slurry Mix Work Platform	Width	FT W	0	0	65	69	0	0	0	0	76	83	0	0	0	0	38	48	0	0
	Avg. Thk.	VF	0.0	0.0	1.5	1.5	0.0	0.0	0.0	0.0	1.5	1.5	0.0	0.0	0.0	0.0	1.5	1.5	0.0	0.0
	Length	LF	0	0	1,857	1,857	0	0	0	0	3,336	3,336	0	0	0	0	400	400	0	0
	Imp. Fill	CCY	0	0	6,701	7,107	0	0	0	0	14,063	15,472	0	0	0	0	849	1,075	0	0
	% Aff	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Affected V	BCY	0	0	6,701	7,107	0	0	0	0	14,063	15,472	0	0	0	0	849	1,075	0	0
	Affected UW	PCF	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125
	Waste	TON	0	0	11,309	11,993	0	0	0	0	23,732	26,110	0	0	0	0	1,433	1,814	0	0
	Unaffected V	CCY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Work Platform Bench and Ramps	Bench Width	FT W	0	0	0	0	0	0	0	0	0	0	0	0	40	40	40	40	40	40
	Bench Avg. Thk.	VF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30	30	30	30	30	30
	Bench Length	LF	0	0	0	0	0	0	0	0	0	0	0	0	150	150	150	150	150	150
	GWBW Through Bench Avg. D	VF	0	0	0	0	0	0	0	0	0	0	0	0	30	30	30	30	30	30
	GWBW Through Bench Avg. L	LF	0	0	0	0	0	0	0	0	0	0	0	0	160	160	160	160	160	160
	GWBW Through Bench A	VSF	0	0	0	0	0	0	0	0	0	0	0	0	4,800	4,800	4,800	4,800	4,800	4,800
	GWBW Total A Inc. Bench	VSF	120,627	127,930	120,627	127,930	120,627	127,930	253,141	278,502	253,141	278,502	253,141	278,502	80,906	101,182	80,906	101,182	80,906	101,182
	Bench Volume	CCY	0	0	0	0	0	0	0	0	0	0	0	0	6,667	6,667	6,667	6,667	6,667	6,667
	Ramp Width	FT W	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
	Ramp Avg. Thk.	VF	0	0	0	0	0	0	0	0	0	0	0	0	13	13	13	13	13	13
	Ramp Length	LF	0	0	0	0	0	0	0	0	0	0	0	0	208	208	208	208	208	208
	Number of Ramps	EA	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Ramp Volume	CCY	0	0	0	0	0	0	0	0	0	0	0	0	5,787	5,787	5,787	5,787	5,787	5,787
	Import Fill	CCY	0	0	0	0	0	0	0	0	0	0	0	0	12,454	12,454	12,454	12,454	12,454	12,454
	% Aff	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	50%	50%	50%	50%	50%	50%
	Affected V	BCY	0	0	0	0	0	0	0	0	0	0	0	0	6,227	6,227	6,227	6,227	6,227	6,227
	Affected UW	PCF	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125
	Waste	TON	0	0	0	0	0	0	0	0	0	0	0	0	10,508	10,508	10,508	10,508	10,508	10,508
	Unaffected V	CY	0	0	0	0	0	0	0	0	0	0	0	0	6,227	6,227	6,227	6,227	6,227	6,227
Pilot Trench Excavation	Width	FT W	2	2	0	0	0	0	2	2	0	0	0	0	2	2	0	0	0	0
	Avg Depth	VF	2	2	0	0	0	0	2	2	0	0	0	0	2	2	0	0	0	0
	Area	VSF	837	837	837	837	837	837	774	774	774	774	774	774	315	315	315	315	315	315
	Length	LF	1,857	1,857	1,857	1,857	1,857	1,857	3,336	3,336	3,336	3,336	3,336	3,336	1,992	1,992	1,992	1,992	1,992	1,992
	Spoil V	BCY	275	275	0	0	0	0	494	494	0	0	0	0	295	295	0	0	0	0
	% Aff	BCY/BCY	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Affected V	BCY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Affected Spoil	PCF	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
	Waste	TON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Exc. Backfill	CCY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Import Backfill	CCY	138	138	0	0	0	0	247	247	0	0	0	0	148	148	0	0	0	0

Table E-4

Cost Comparison for Groundwater Barrier Wall Alternatives
Quantity Calculations for Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

		Location >	River Side High Bank GWBW Route						Full Enclosure GWBW Route						River Side Low Bank GWBW Route					
		Technology >	Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile	
		Depth >	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.	Deep	T.D.
Trench Excavation	Width	FT W	0	0	3	3	0	0	0	0	3	3	0	0	0	0	3	3	0	0
	Avg Depth	VF	65	69	65	69	65	69	76	83	76	83	76	83	38	48	38	48	38	48
	Area	VSF	120,627	127,930	120,627	127,930	120,627	127,930	253,141	278,502	253,141	278,502	253,141	278,502	76,106	96,382	76,106	96,382	76,106	96,382
	Length	LF	1,857	1,857	1,857	1,857	1,857	1,857	3,336	3,336	3,336	3,336	3,336	3,336	1,992	1,992	1,992	1,992	1,992	1,992
	Spoil V	BCY	0	0	13,403	14,214	0	0	0	0	28,127	30,945	0	0	0	0	8,456	10,709	0	0
	% Aff	BCY/BCY	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Affected V	BCY	0	0	1,340	1,421	0	0	0	0	2,813	3,094	0	0	0	0	846	1,071	0	0
	Affected Spoil	PCF	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
	Waste	TON	0	0	2,714	2,878	0	0	0	0	5,696	6,266	0	0	0	0	1,712	2,169	0	0
	Exc. Backfill	CCY	0	0	12,063	12,793	0	0	0	0	25,314	27,850	0	0	0	0	7,611	9,638	0	0
	Import Backfill	CCY	0	0	1,340	1,421	0	0	0	0	2,813	3,094	0	0	0	0	846	1,071	0	0
Cap	Width	FT W	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	Thk.	VF	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Length	LF	1,857	1,857	1,857	1,857	1,857	1,857	3,336	3,336	3,336	3,336	3,336	3,336	1,992	1,992	1,992	1,992	1,992	1,992
	Volume	CCY	1,651	1,651	1,651	1,651	1,651	1,651	2,965	2,965	2,965	2,965	2,965	2,965	1,771	1,771	1,771	1,771	1,771	1,771
Construct River Bank Cap	Length	LF	0	0	0	0	0	0	0	0	0	0	0	0	1,500	1,500	1,500	1,500	1,500	1,500
	SS Rise	VF	0	0	0	0	0	0	0	0	0	0	0	0	25	25	25	25	25	25
	Side Slope	H:V	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0	2.0
	SS Reach	LF	0	0	0	0	0	0	0	0	0	0	0	0	50	50	50	50	50	50
	SS Area	SF	0	0	0	0	0	0	0	0	0	0	0	0	83,853	83,853	83,853	83,853	83,853	83,853
	Riprap Thk.	VF	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Riprap V	CY	0	0	0	0	0	0	0	0	0	0	0	0	9,317	9,317	9,317	9,317	9,317	9,317
	Cap Subgrade Fill	VF	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Cap Subgrade Fill	CCY	0	0	0	0	0	0	0	0	0	0	0	0	3,106	3,106	3,106	3,106	3,106	3,106
	Anchor Trench, TOB	LF	0	0	0	0	0	0	0	0	0	0	0	0	1,500	1,500	1,500	1,500	1,500	1,500
	Anchor Trench, TOS	LF	0	0	0	0	0	0	0	0	0	0	0	0	1,500	1,500	1,500	1,500	1,500	1,500
	Anchor Trench Offset, TOS/TOB	LF	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4
	Anchor Trench, Ends	LF	0	0	0	0	0	0	0	0	0	0	0	0	64	64	64	64	64	64
	Anchor Trench Depth	VF	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3
	Anchor Trench Width	FT W	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3
	Anchor Trench Exc. Spoil	BCY	0	0	0	0	0	0	0	0	0	0	0	0	1,043	1,043	1,043	1,043	1,043	1,043
	Anchor Trench Exc. Spoil	PCF	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125
	% Affected	%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Waste	TON	0	0	0	0	0	0	0	0	0	0	0	0	1,759	1,759	1,759	1,759	1,759	1,759
	FML	SF	0	0	0	0	0	0	0	0	0	0	0	0	114,763	114,763	114,763	114,763	114,763	114,763
	Cushion GT	SF	0	0	0	0	0	0	0	0	0	0	0	0	114,763	114,763	114,763	114,763	114,763	114,763
	Anchor Trench Imp. Backfill	CCY	0	0	0	0	0	0	0	0	0	0	0	0	1,043	1,043	1,043	1,043	1,043	1,043
	Riprap	CY	0	0	0	0	0	0	0	0	0	0	0	0	12,751	12,751	12,751	12,751	12,751	12,751
Construct GWBW Piezometers	GWBW Length	LF	1,857	1,857	1,857	1,857	1,857	1,857	3,336	3,336	3,336	3,336	3,336	3,336	1,992	1,992	1,992	1,992	1,992	1,992
	Max Interval	LF/EA	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
	Intervals	EA	4	4	4	4	4	4	7	7	7	7	7	7	4	4	4	4	4	4
	Ends	EA	2	2	2	2	2	2	0	0	0	0	0	0	2	2	2	2	2	2
	Piezometers	EA	8	8	8	8	8	8	14	14	14	14	14	14	8	8	8	8	8	8

Table E-5

Cost Comparison for Groundwater Barrier Wall Alternatives
Estimated Unit Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

			Estimated Unit Cost																	
		Location >	River Side High Bank GWBW Route						Full Enclosure GWBW Route						River Side Low Bank GWBW Route					
		Technology >	Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile	
		Depth >	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt
	Item No.	Description	Estimate Units																	
Direct Construction Costs	1	GWBW Mobilization/Demobilization	LS	$ 120,000	$ 120,000	$ 80,000	$ 100,000	$ 80,000	$ 100,000	$ 120,000	$ 120,000	$ 80,000	$ 100,000	$ 80,000	$ 100,000	$ 120,000	$ 120,000	$ 80,000	$ 100,000	$ 80,000	$ 100,000
	2	GWBW Support Mobilization/Demobilization	SUM	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	3	Temporary Facilities and Controls	SUM	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	10%	10%	10%	10%	10%	10%
	4	Demolish Surface Slabs	CY	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50
	5	Demolish Dock Piers	EA	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000
	6	Decon Demolition Debris	CY	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10
	7	T&D Demolition Debris (Assume Non-Haz)	TON	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25
	8	Excavate GWBW Clearance Trench	BCY	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5
	9	T&D GWBW Clearance Trench Excavation Spoil (Assume Non-Haz)	TON	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25
	10	Screen GWBW Clearance Trench Spoil and Use to Backfill Trench	CCY	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7	$ 7
	11	Backfill GWBW Clearance Trench with Imported Soil	CCY	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15
	12	Import Soil for GWBW Work Platforms	BCY	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15
	13	Construct Fill for GWBW Bench and Ramps	CCY	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15
	14	Construct GWBW Pilot Trench	CCY	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12
	15	Construct GWBW	VSF	$ 8	$ 8	$ 6	$ 6	$ 30	$ 30	$ 8	$ 8	$ 6	$ 6	$ 30	$ 30	$ 10	$ 10	$ 12	$ 12	$ 36	$ 36
	16	Excavate GWBW Work Platform	BCY	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5	$ 5
	17	T&D GWBW Work Platform Spoil (Assume Non-Haz)	TON	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25
	18	Excavate GWBW Bench and Ramp Fill	BCY	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10
	19	T&D GWBW Bench and Ramp Excavation Spoil (Assume Non-Haz)	TON	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25
	20	Construct GWBW Cap	CCY	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20
	21	Excavate River Bank Riprap to Stockpile	CY	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15	$ 15
	22	Place River Bank FML Cushion Soil	CCY	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25
	23	Excavate River Bank FML Anchor Trench	BCY	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10
	24	T&D River Bank FML Anchor Trench Spoil	TON	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25	$ 25
	25	Place River Bank FML	SF	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00	$ 1.00
	26	Place River Bank FML Cushion Geotextile	SF	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80	$ 0.80
	27	Backfill FML Anchor Trench with Imported Fill	CCY	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20
	28	Place River Bank Riprap from Stockpile	CY	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30	$ 30
	29	Place Imported Riprap	CY	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60
	30	Re-connect Dock Piers	EA	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000
	31	Construct GWBW Piezometers	EA	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000
	32	Bid and Scope Contingencies	SUM	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%
	33																				
Indirect Construction Costs	34	Final Design Investigation	LS	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000
	35	Final Design Engineering	SUM	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
	36	HASP and HASP Implementation	SUM	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
	37	Bidding and Contracting	SUM	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	38	Construction Management	SUM	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
	39	CQA Plan and Implementation	SUM	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
	40	Construction Phase Engineering	SUM	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
	41	GWBW IRM Completion Report	LS	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000
	42																				
	43	Total Estimated Construction Cost																			

Table E-5

Cost Comparison for Groundwater Barrier Wall Alternatives
Estimated Unit Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

			Estimated Unit Cost																	
		Location >	River Side High Bank GWBW Route						Full Enclosure GWBW Route						River Side Low Bank GWBW Route					
		Technology >	Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile		Vibrated Beam		Slurry Trench		Sheet Pile	
		Depth >	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt	Deep Zone Key	T.D. to Basalt
	Item No.	Description / Estimate Units																		
IMR Costs	44	Ground Water Level Monitoring / EVENT	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000
IMR Costs	45	Repair Mobilization/Demobilization / SUM	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
IMR Costs	46	Repair GWBW Cap / CCY	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80
IMR Costs	47	Repair River Bank Cap / SF	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10	$ 10
IMR Costs	48	Repair River Bank Riprap / CY	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120	$ 120
IMR Costs	49	Repair Contingencies / SUM	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
IMR Costs	50	Repair Engineering, CM, and Field Services / SUM	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
IMR Costs	51	Replace Piezometer / EA	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000
IMR Costs	52	Ground Water Sampling and Analysis / EVENT	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000
IMR Costs	53	Annual Inspection and Report / EA	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000
IMR Costs	54																			
IMR Costs	55	Effective Discount Rate / APR	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
IMR Costs	56	IMR Planning Period / YR	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
IMR Costs	57	Present Value / P|A i,n	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104	11.8104
IRM Closure Costs	58	P&A Piezometers / EA	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000
IRM Closure Costs	59	GWBW Part of Closure Certification Report / LS	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000
IRM Closure Costs	60																			
IRM Closure Costs	61	Net Effective Discount Rate / APR	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
IRM Closure Costs	62	IMR Planning Period / YR	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
IRM Closure Costs	63	Present Value / P|F i,n	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142	0.1142
	64	Total Estimated Cost, Present Value																		

Notes:

APR	annual percentage rate	CY	cubic yards	GWBW	groundwater barrier wall	LF	linear feet	P&A	plug and abandon	YR	year
BCY	bank cubic yards	EA	each	HASP	health and safety plan	LS	lump sum	SF	square feet		
CCY	compacted cubic yards	F	future (value)	i	interest rate	n	number of years (planning period)	T&D	transport and dispose		
CM	construction management	FFS	Focused Feasibility Study	IMR	inspection, monitoring and reporting	Non-Haz	nonhazardous	T.D.	total depth		
CQA	construction quality assurance	FML	flexible membrane liner	IRM	interim remedial measures	P	present (value)	VSF	vertical square feet		

Appendix F
Cost Estimates for Ex Situ Groundwater Treatment Alternatives

Table F-1

Cost Comparison for Ex Situ Groundwater Treatment Alternatives
Summary of Capital and O&M Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

Item	Capital	Annual Operation and Maintenance	Net Present Value
Engineering and Site Infrastructure			
Design and Permitting	$300,000	$0	$300,000
Site Preparation and Utilities	$80,000	$0	$80,000
Groundwater Recovery System	$990,000	$191,300	$3,250,000
Treatment System Components	$360,000	$75,000	$1,250,000
System Performance Monitoring	$0	$147,000	$1,740,000
Project Management and Technical Support	$458,000	$61,600	$1,190,000
Total	**$2,188,000**	**$474,900**	**$7,810,000**
Treatment Alternatives			
Hydroxide Precipitation with Anaerobic Biological Treatment	$1,205,000	$356,700	$5,420,000
Iron Co-Precipitation with Anaerobic Biological Treatment	$1,205,000	$356,700	$5,420,000
Alternate Process - Aerobic Biological Treatment	$1,710,000	$214,900	$4,250,000
Alternate Process - Anaerobic Biological Treatment	$2,170,000	$228,700	$4,880,000
Alternate Process - Air Stripping and Carbon Adsorption	$1,020,000	$219,700	$3,620,000

Notes:
Costs based on design flow rate of 150 gallons per minute.
Assumes discount rate of 7.5% over 30-year design life.

THIS PAGE INTENTIONALLY LEFT BLANK

Table F-2

Cost Comparison for Ex Situ Groundwater Treatment Alternatives
Estimated Equipment and Construction Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
Design and Permitting				
Design[1]	1	allowance	$150,000	$150,000
Vendor and Contractor Bid Packages[2]	1	allowance	$50,000	$50,000
Permitting[3]	1	allowance	$50,000	$50,000
Regulatory Agency Communication and Submittals[4]	1	allowance	$50,000	$50,000
Subtotal				**$300,000**
Site Preparation and Utilities				
Site Preparation[5]	1	allowance	$20,000	$20,000
Underground Utility Clearance[6]	1	allowance	$20,000	$20,000
Potable Water[7]	1	allowance	$20,000	$20,000
Electricity[7]	1	allowance	$20,000	$20,000
Subtotal				**$80,000**
Groundwater Recovery System				
Recovery Well Installation (Intermediate Zone)[8]	20	well	$15,000	$300,000
Submersible Pumps with VFD (2 HP)[9]	20	each	$4,000	$80,000
Level Transducers[10]	20	each	$1,500	$30,000
Pre-Cast Concrete Well House[11]	20	allowance/each	$4,000	$80,000
Piping and Components[12]	1	allowance	$100,000	$100,000
Flow Meters[13]	20	each	$3,500	$70,000
Electrical Wire, Conduit, and Equipment[14]	1	allowance	$25,000	$25,000
Electrical Controls & Programming[15]	1	allowance	$20,000	$20,000
Civil/Mechanical Contractor[16]	1	allowance	$150,000	$150,000
Electrical Contractor[17]	1	allowance	$35,000	$35,000
Well Pump Installation Contractor[18]	20	allowance/well	$5,000	$100,000
Subtotal				**$990,000**
Groundwater Treatment System				
Treatment System Components				
Piping and Components[19]	1	allowance	$20,000	$20,000
Electrical Wire, Conduit, and Equipment[20]	1	allowance	$10,000	$10,000
Electrical Controls & Programming[21]	1	allowance	$10,000	$10,000
Ground Water Treatment Building & Foundation[22]	1	allowance	$200,000	$200,000
Civil/Mechanical Contractor (excluding building construction)[23]	1	allowance	$100,000	$100,000
Electrical Contractor[24]	1	allowance	$20,000	$20,000
Subtotal				**$360,000**
Hydroxide Precipitation with Anaerobic Biological Treatment				
Hydroxide Precipitation Unit[25]	1	each	$450,000	$450,000
Dewatering Bin[26]	1	each	$15,000	$15,000
Solids Handling Equipment[27]	1	allowance	$100,000	$100,000
Organic Substrate and Nutrient Feed System[28]	1	allowance	$10,000	$10,000
FBR (sand)[31]	1	each	$500,000	$500,000
Liquid Phase GAC[33]	2	each	$15,000	$30,000
Ancillary Equipment	1	allowance	$100,000	$100,000
Subtotal				**$1,205,000**
Iron Co-Precipitation with Anaerobic Biological Treatment				
Iron Co-Precipitation Unit[25]	1	each	$450,000	$450,000
Dewatering Bin[26]	1	each	$15,000	$15,000
Solids Handling Equipment[27]	1	allowance	$100,000	$100,000
Organic Substrate and Nutrient Feed System[28]	1	allowance	$10,000	$10,000
FBR (sand)[31]	1	each	$500,000	$500,000
Liquid Phase GAC[33]	2	each	$15,000	$30,000
Ancillary Equipment	1	allowance	$100,000	$100,000
Subtotal				**$1,205,000**

Table F-2

Cost Comparison for Ex Situ Groundwater Treatment Alternatives
Estimated Equipment and Construction Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
Alternate Process - Aerobic Biological Treatment				
EHC Reactor[29]	1	each	$800,000	$800,000
Solids Handling Equipment[27]	1	allowance	$100,000	$100,000
Oxygenation Column and PBR Reactor - AQUAMEND® [30]	1	each	$760,000	$760,000
Ancillary Equipment	1	allowance	$50,000	$50,000
Subtotal				**$1,710,000**
Alternate Process - Anaerobic Biological Treatment				
EHC Reactor[29]	1	each	$800,000	$800,000
Solids Handling Equipment[27]	1	allowance	$100,000	$100,000
PBR Reactor - AQUAMEND® [30]	2	each	$610,000	$1,220,000
Ancillary Equipment	1	allowance	$50,000	$50,000
Subtotal				**$2,170,000**
Alternate Process - Air Stripping and Carbon Adsorption				
EHC Reactor[29]	1	each	$800,000	$800,000
Solids Handling Equipment[27]	1	allowance	$100,000	$100,000
Air Stripper Unit[32]	1	each	$40,000	$40,000
Liquid Phase GAC[33]	2	each	$15,000	$30,000
Ancillary Equipment	1	allowance	$50,000	$50,000
Subtotal				**$1,020,000**
Project Management and Technical Support				
Project Management (8% of Equipment/Const. Cost)[34]	1	allowance	$256,000	$256,000
Technical Support (5% of Equipment/Const. Cost)[35]	1	allowance	$160,000	$160,000
Expenses (10% of Project Management/Tech. Support)[36]	1	allowance	$42,000	$42,000
Subtotal				**$458,000**

Table F-3

Cost Comparison for Ex Situ Groundwater Treatment Alternatives
Notes for Estimated Equipment and Construction Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

1	Design includes completing the remedial system design, drawings, and specifications.
2	Bid and specification packages to be prepared for the various equipment and contractors to construct the groundwater remediation system.
3	Permitting includes NPDES, UIC, and/or POTW for treated water discharge, and preparing the equipment building permit application (Contractor with assistance from ERM).
4	Regulatory agency submittals may include various responses to ODEQ comments, submitting various scheduling and planning letters to ODEQ, and meeting with ODEQ to discuss the project.
5	Assume construction on existing paved areas. Building foundation costs included in civil construction costs.
6	Underground utility clearance includes working with Arkema to locate and mark the locations of underground utilities in the proposed trenching areas, and retaining a specialty contractor to perform non-intrusive/intrusive methods to clear work areas if necessary.
7	An allowance has been included to provide potable water, sewer, and electric service to the ground water treatment building. Electrical includes installing a main disconnect switch at the building.
8	Recovery well configuration to be determined from additional hydrogeological characterization.
9	Submersible pumps consist of 2 HP electric submersible pumps for environmental remediation application equipped with variable frequency drives.
10	Level/pressure transducers are In-Situ Inc. Model PXD-261 with Teflon cable.
11	Assume pre-cast concrete rings with FRP lid will be used to house the recovery wells.
12	Piping and components includes influent piping, elbows, couplings, valves, pressure/temperature gauges, and conduit between chemical precipitation reactor and recovery wells. This is an allowance based on unit costs from a combination of vendors and reference documents.
13	Flow meters will be magnetic flow meters with direct read of instantaneous flow rate and total volume, and equipped with a transmitter.
14	Electrical wire, conduit, and equipment includes electrical wire, conduit for electrical wire, separate conduit for level control wire, step-down transformers, disconnects, and lighting for each well. This is an allowance based on unit costs from a combination of vendors and reference documents.
15	Electrical controls and programming including the fabrication and PLC programming of an electrical control panel for controlling the flow rate from each recovery well and logging/reporting the flow and ground water elevation data.
16	Civil/mechanical contractor costs include trenching, HDPE piping installation, backfilling materials, managing excavated trench materials not used to backfill the trenches on site, restoration, and setting the pre-cast concrete well houses.
17	Electrical contractor costs include conduit/wire installation, electrical equipment installation, and connecting electrical power to the equipment and submersible pumps.
18	Well installation contractor costs include submersible pump and level transducer installation, down-well ground water piping from the pump and connecting it to aboveground piping, and securing the pump.
19	Piping and components includes plastic piping from influent tanks, reactor units and carbon vessels, transfer pumps, valves, pressure/temperature gauges, flow meters, instrumentation and sampling equipment.
20	Electrical wire, conduit, and equipment includes electrical wire, conduit for electrical wire, step-down transformers, and disconnects for connecting electrical power and control wires to equipment.
21	Electrical controls and programming including the fabrication and PLC programming of a master electrical control panel for connecting each of the electrical controls for individual equipment that have their own control panel so that alarm conditions in one piece of equipment can shut down other pieces of equipment as necessary.
22	Ground water treatment building is a 60-ft by 60-ft, 25-ft high steel building with concrete foundation/floor also serving as a secondary containment dike. Includes building/foundation/floor design and construction (allowance for foundation/floor construction).
23	Civil/mechanical contractor costs include setting equipment and installing all interconnecting piping.
24	Electrical contractor costs include installing conduit and wire to bring electrical power and control wires to the various equipment, connecting the electrical power, and installing required electrical equipment (disconnects, transformers, etc.).

25	Chemical Precipitation Unit includes a turnkey system, comprised of reactor and pH adjustment tanks, clarifier, solids holding tank, transfer pumps, and chemical feed pumps with gravity flow discharge to the biological reactor system. Includes design package, procurement, installation, and operator training. Pricing provided by Unipure Corporation and Siemens Corporation.
26	Dewatering bin includes manufacture of 20 cy bin. Pricing provided by Baker Tank.
27	Solids handling equipment includes biological reactor influent solids filters, biomass separation system, and effluent solids filters. System is common to all treatment options. Pricing from Siemens Corporation.
28	Substrate and nutrient feed system includes tanks, pumps, and controls for additives to biological reactors. Feed system is common to all treatment options.
29	EHC® Reactor includes a reactor vessel filled with 20% EHC - 80% sand by mass. Pricing provided by Adventus Group.
30	PBR includes a reactor vessel filled with AQUAMEND® biocarrier. Pricing provided by Adventus Group.
31	FBR includes reactor vessel filled with sand. Pricing provided by Adventus Group.
32	Air stripper is low-profile, skid-mounted air strippers capable of handling flow rates from 10 to 250 gpm and equipped with 4 trays, 15-HP blower, transfer pump for treated effluent, low air pressure switch, high level sump switch and level controls for transfer pump, high air pressure switch for sump, electrical control panel with additional contacts to external controls for other equipment. Pricing provided by QED.
33	Liquid phase carbon includes a CR5000 Modular System, filled with granular activated carbon. Pricing provided by Calgon Carbon.
34	Project management costs include staff and contractor coordination, managing the project budget and schedule, contracting/procurement, and project team communication.
35	Technical support costs include engineering support and technical evaluations that may be needed to address unexpected conditions that may be encountered during construction.
36	Expenses for project management and technical support include miscellaneous office and field expenses required for project management and technical support personnel to perform their work.

Table F-4

Cost Comparison for Ex Situ Groundwater Treatment Alternatives
Estimated Annual Operation & Maintenance Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

ITEM	QUANTITY	UNITS	UNIT COST	TOTAL COST
Ground Water Recovery System				
Routine System Checks[1]	26	man-days	$750	$19,500
Recovery Well Cleaning and Redevelopment[2]	20	allowance/well	$5,000	$100,000
Influent Ground Water Piping Cleaning[3]	1	allowance/event	$40,000	$40,000
Electricity[4]	270,000	kW-Hr	$0.10	$27,000
Replacement Parts[5]	3%	percent of equipment cost	$158,000	$4,800
Subtotal				**$191,300**
Groundwater Treatment System				
Generic Components				
Routine System Checks & Operation[6]	100	man-days	$750	$75,000
Subtotal				**$75,000**
Hydroxide Precipitation with Anaerobic Biological Treatment				
NaOH Usage[7]	80,000	gallons	$1.15	$92,000
Polymer Usage[8]	500	gallons	$15.00	$7,500
Solids Disposal[9]	24	event	$3,500	$84,000
Dewatering Tank Liner[10]	24	liner	$150	$3,600
FBR HFCS Usage[11]	12,600	gallons	$2.50	$31,500
Solids Filter Replacement[12]	52	filter	$50	$2,600
Biomass Solids Disposal[13]	1	event	$1,000	$1,000
GAC Replacement[14]	7,500	lbs	$3.00	$22,500
Electricity[15]	750,000	kW-Hr	$0.10	$75,000
Replacement Parts[5]	3%	percent of equipment cost	$1,205,000	$37,000
Subtotal				**$356,700**
Iron Co-Precipitation with Anaerobic Biological Treatment				
NaOH Usage[7]	80,000	gallons	$1.15	$92,000
Fe Co-Precipitation Polymer Usage[8]	500	gallons	$15.00	$7,500
Solids Disposal[9]	24	event	$3,500	$84,000
Dewatering Tank Liner[10]	24	liner	$150	$3,600
FBR HFCS Usage[11]	12,600	gallons	$2.50	$31,500
Solids Filter Replacement[12]	52	filter	$50	$2,600
Biomass Solids Disposal[13]	1	event	$1,000	$1,000
GAC Replacement[14]	7,500	lbs	$3.00	$22,500
Electricity[15]	750,000	kW-Hr	$0.10	$75,000
Replacement Parts[5]	3%	percent of equipment cost	$1,205,000	$37,000
Subtotal				**$356,700**
Alternate Process - Aerobic Biological Treatment				
EHC® Replacement - Media[16]	0.25	event	$230,000	$57,500
EHC® Replacement - Trucking[17]	0.25	event	$6,000	$1,500
EHC® Replacement - Disposal[17]	0.25	event	$60,000	$15,000
Solids Filter Replacement[12]	52	filter	$50	$2,600
Solids Disposal[18]	12	event	$3,500	$42,000
Electricity[19]	450,000	kW-Hr	$0.10	$45,000
Replacement Parts[5]	3%	percent of equipment cost	$1,710,000	$51,300
Subtotal				**$214,900**
Alternate Process - Anaerobic Biological Treatment				
EHC® Replacement - Media[16]	0.25	event	$230,000	$57,500
EHC® Replacement - Trucking[17]	0.25	event	$6,000	$1,500
EHC® Replacement - Disposal[17]	0.25	event	$60,000	$15,000
Solids Filter Replacement[12]	52	filter	$50	$2,600
Solids Disposal[18]	12	event	$3,500	$42,000
Electricity[19]	450,000	kW-Hr	$0.10	$45,000
Replacement Parts[5]	3%	percent of equipment cost	$2,170,000	$65,100
Subtotal				**$228,700**

Table F-4

Cost Comparison for Ex Situ Groundwater Treatment Alternatives
Estimated Annual Operation & Maintenance Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

Alternate Process - Air Stripping and Carbon Adsorption				
EHC® Replacement - Media[16]	0.25	event	$230,000	$57,500
EHC® Replacement - Trucking[17]	0.25	event	$6,000	$1,500
EHC® Replacement - Disposal[17]	0.25	event	$60,000	$15,000
Solids Filter Replacement[12]	52	filter	$50	$2,600
Solids Disposal[18]	12	event	$3,500	$42,000
Air Stripper Cleaning[20]	4	event	$2,000	$8,000
Liquid Phase GAC Replacement[21]	7,500	lbs	$3.00	$22,500
Electricity[19]	400,000	kW-Hr	$0.10	$40,000
Replacement Parts[5]	3%	percent of equipment cost	$1,020,000	$30,600
Subtotal				**$219,700**
System Performance Monitoring				
Monthly System Monitoring[22]	12	event	$3,500	$42,000
Semi-Annual Groundwater Monitoring[23]	2	event	$50,000	$100,000
Agency Reporting[24]	1	allowance	$5,000	$5,000
Subtotal				**$147,000**
Project Management and Technical Support				
Project Management (5% of Equipment/Const. Cost)[25]	1	allowance	$28,000	$28,000
Technical Support (5% of Equipment/Const. Cost)[26]	1	allowance	$28,000	$28,000
Expenses (10% of Project Management/Tech. Support)[27]	1	allowance	$5,600	$5,600
Subtotal				**$61,600**

Table F-5

Cost Comparison for Ex Situ Groundwater Treatment Alternatives
Notes for Estimated Annual Operation & Maintenance Costs
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

1	Routine checks on the ground water recovery system includes one person spending 4 hours each week conducting a visual inspection and recording operating data (pressure, flow rate, total volume) for the ground water recovery wells to verify there are no operating problems with equipment and no leaks are observed.
2	Recovery well cleaning and redevelopment costs assume that each recovery well will need to be cleaned and redeveloped once a year to remove potential iron precipitate/biological growth that may accumulate in the well and on the submersible pumps. Work includes removing the pump and level controls, cleaning the pump and level controls, adding a cleaning agent (e.g., specialty product or mild acid) and letting stand in well per manufacturer's recommendations, redeveloping the well using the surge and block method, re-installing the submersible pump and level controls, and containerizing and disposing of redevelopment water. Pricing based on previous experience at the similar sites.
3	Influent ground water piping cleaning costs assume that this will be done once per year to clean out potential iron precipitate/biological growth that may accumulate in the piping. Work includes using a combination of line cleaning truck (equipped with power washing/jetting tools) and vacuum truck to clean out piping between cleanouts.
4	Electricity cost includes costs to operate 20 submersible pumps (2 HP) and miscellaneous control equipment.
5	Assuming cost for potential replacement parts at 3% of equipment purchase costs.
6	Routine checks of the ground water treatment system assume 1.5 days per week for ERM personnel to visually inspect the treatment system and record operating parameters to verify that there are no problems with the system, coordinate chemical/other material deliveries, changing out chemical drums/totes, changing filters, and other miscellaneous equipment maintenance. The total man-days was rounded up to 100 man-days as an additional contingency for miscellaneous items not otherwise covered.
7	NaOH consumption rate and unit cost of caustic estimated based on results of groundwater treatability studies and vendor-supplied information.
8	Polymer consumption rate and unit cost of polymer estimated based on results of groundwater treatability studies and vendor-supplied information. Assumes addition of ferrous sulfate not required for iron co-precipitation based on influent iron concentrations detected during groundwater treatability studies.
9	Solids disposal includes trucking and landfill disposal of non-hazardous solids. Assumed 2 events per month at 15 cubic yards per event.
10	Dewatering tank liner replaced during each solids disposal event
11	FBR HFCS usage rate (130 L/day) estimated by Adventus Group, based on results of groundwater treatability studies. Unit cost of HFCS-55 obtained from USDA price list with estimated delivery cost.
12	Filter replacement assumes disposable bag filters replaced once per week.
13	Biomass solids disposal calculated based on TSS results reported for groundwater treatability studies. Assumed 10 mg/L, with disposal as non-hazardous solid to landfill.
14	GAC replacement cost was based on vendor estimates and assumed VOC reduction in chemical precipitation unit.
15	Power requirements estimated by Siemens, based on similar existing system installations.
16	EHC® replacement schedule (every 4 years) and cost was estimated by Adventus.
17	EHC® is assumed to be non-hazardous solids waste, disposed of by truck to landfill. Approximately 19 trucks will be required to transport all of the spent EHC® media.
18	Solids disposal includes trucking and landfill disposal of non-hazardous solids. Assumed 1 event per month at 15 cubic yards per event.
19	Power requirements estimated based on experience with similar systems.
20	Air stripper cleaning costs assumes the air stripper will be cleaned four times per year to remove iron precipitate and biological growth that may have accumulated within the air stripper. Cleaning consists of two ERM personnel for one day to remove the air stripper trays from the air stripper, install backup trays, and pressure wash the removed trays.
21	Liquid phase GAC consumption estimated from vendor usage rates and assumes biological reactors do not reduce VOC concentrations (air stripper removes approximately 95% of VOCs).
22	Monthly monitoring includes one influent and one effluent sample collected for lab analysis, as well as groundwater level monitoring.
23	Semi-annual performance monitoring includes collecting 25 groundwater samples for lab analysis, reporting laboratory results, as well as system monitoring data for the previous 6 month period.

24	Agency reporting includes interactions with the state and federal agencies, and progress reporting.
25	Project management costs include staff and contractor coordination, managing the project budget and schedule, contracting/procurement, and project team communication.
26	Technical support costs include engineering support and technical evaluations that may be needed to address unexpected conditions that may be encountered during O&M, review operating data, and make recommendations to improve performance and/or cost effectiveness.
27	Expenses for project management and technical support include miscellaneous office and field expenses required for project management and technical support personnel to perform their work.

Appendix G
Cost Estimates for Treated Water Discharge Alternatives

Table G-1

Cost Comparison for Treated Water Discharge Alternatives
Groundwater Source Control IRM
Arkema Inc. - Portland, Oregon

	Discharge Options															
Item	**Discharge to Willamette River**				**Discharge to POTW**				**Reinjection to Shallow Groundwater**				**Reinjection to Deep Groundwater**			
	Unit Cost	Unit	Quantity	Extended Cost	Unit Cost	Unit	Quantity	Extended Cost	Unit Cost	Unit	Quantity	Extended Cost	Unit Cost	Unit	Quantity	Extended Cost
Well Installation	---	---	---	$ -	---	---	---	$ -	$ 15,000	well	5	$ 75,000	$ 50,000	deep well	3	$ 150,000
Piping/Trenching	$ 30	LF	2000	$ 60,000	$ 30	LF	2000	$ 60,000	$ 30	LF	2000	$ 60,000	$ 30	LF	2000	$ 60,000
Sewer/Outfall Tie-in	$ 10,000	LS	1	$ 10,000	$ 10,000	LS	1	$ 10,000	---	---	---	$ -	---	---	---	$ -
Pumps w/VFD	$ 5,000	each	1	$ 5,000	$ 5,000	each	1	$ 5,000	$ 5,000	each	5	$ 25,000	$ 10,000	each	3	$ 30,000
Flow Meters	$ 4,500	each	1	$ 4,500	$ 4,500	each	1	$ 4,500	$ 4,500	each	5	$ 22,500	$ 4,500	each	3	$ 13,500
SCADA System	---	---	---	$ -	---	---	---	$ -	$ 40,000	each	1	$ 40,000	$ 40,000	each	1	$ 40,000
Permitting	$ 10,000	LS	1	$ 10,000	$ 10,000	LS	1	$ 10,000	$ 25,000	LS	1	$ 25,000	$ 50,000	LS	1	$ 50,000
Design/Proj. Man.	$ 17,900	LS	1	$ 17,900	$ 17,900	LS	1	$ 17,900	$ 49,500	LS	1	$ 49,500	$ 68,700	LS	1	$ 68,700
Contingency (20%)				$ 22,000				$ 22,000				$ 60,000				$ 83,000
Capital Costs				**$ 129,400**				**$ 129,400**				**$ 357,000**				**$ 495,200**
Annual O&M	---			$ -	---			$ -	$ 22,500	annual	1	$ 22,500	$ 45,000	annual	1	$ 45,000
Permit Fee	$ 7,700	annual	1	$ 7,700	$ 7,700	annual	1	$ 7,700	$ 7,700	annual	1	$ 7,700	$ 7,700	annual	1	$ 7,700
Disposal	---			$ -	$ 5.86	unit	105,400	$ 617,644	---	---	---	$ -	---	---	---	$ -
Monitoring	$ 38,400	annual	1	$ 38,400	$ 38,400	annual	1	$ 38,400	$ 38,400	annual	1	$ 38,400	$ 38,400	annual	1	$ 38,400
Contingency (20%)				$ 10,000				$ 133,000				$ 14,000				$ 19,000
Annual Costs				**$ 56,100**				**$ 796,744**				**$ 82,600**				**$ 110,100**
Net Present Value (30-year design life)				**$ 800,000**				**$ 9,540,000**				**$ 1,340,000**				**$ 1,800,000**

Notes/Assumptions:
Includes piping from treatment system to Outfall #4.
Assumes manhole installation at tie-in location.
Assumes one pump required from treatment to tie-in.
Assumes one flow meter at tie-in location.
Requires updated NPDES permit.
Design/Project Management = 20% equip/permit costs
Assumes annual POTW permit as secondary option.
Assumes weekly, monthly, quarterly monitoring for NPDES permit requirements.
All costs in 2008 dollars with 7.5% discount rate.

Notes/Assumptions:
Ties into existing 60" sewer line on NW Front Ave.
1 water unit = 100 cubic feet = 748 gallons
150 gpm = 105,400 units/year
Assumes one pump required from treatment to tie-in.
Design/Project Management = 20% equip/permit costs
Assumes manhole installation at tie-in location.
Assumes one flow meter at tie-in location.
Annual permit fee cost provided by Portland BER.
Unit disposal fee provided by Portland BER.
Assumes weekly, monthly, quarterly monitoring for permit requirements.
All costs in 2008 dollars with 7.5% discount rate.

Notes/Assumptions:
Assumes 5 shallow wells, each equipped with flow meter.
Assumes 5 pumps required for injection wells.
Assumes SCADA system & electrical eqpt/conduit to wells.
Design/Project Management = 20% equip/permit costs
Assumes annual O&M = 30% well install cost
Assumes annual POTW permit as secondary option.
Assumes weekly, monthly, quarterly monitoring for permit requirements.
All costs in 2008 dollars with 7.5% discount rate.

Notes/Assumptions:
Assumes 3 deep wells, each equipped with flow meter.
Assumes 3 pumps required for injection wells.
Assumes SCADA system & electrical eqpt/conduit to wells.
Design/Project Management = 20% equip/permit costs
Assumes annual O&M = 30% well install cost
Assumes annual POTW permit as secondary option.
Assumes weekly, monthly, quarterly monitoring for permit requirements.
All costs in 2008 dollars with 7.5% discount rate.