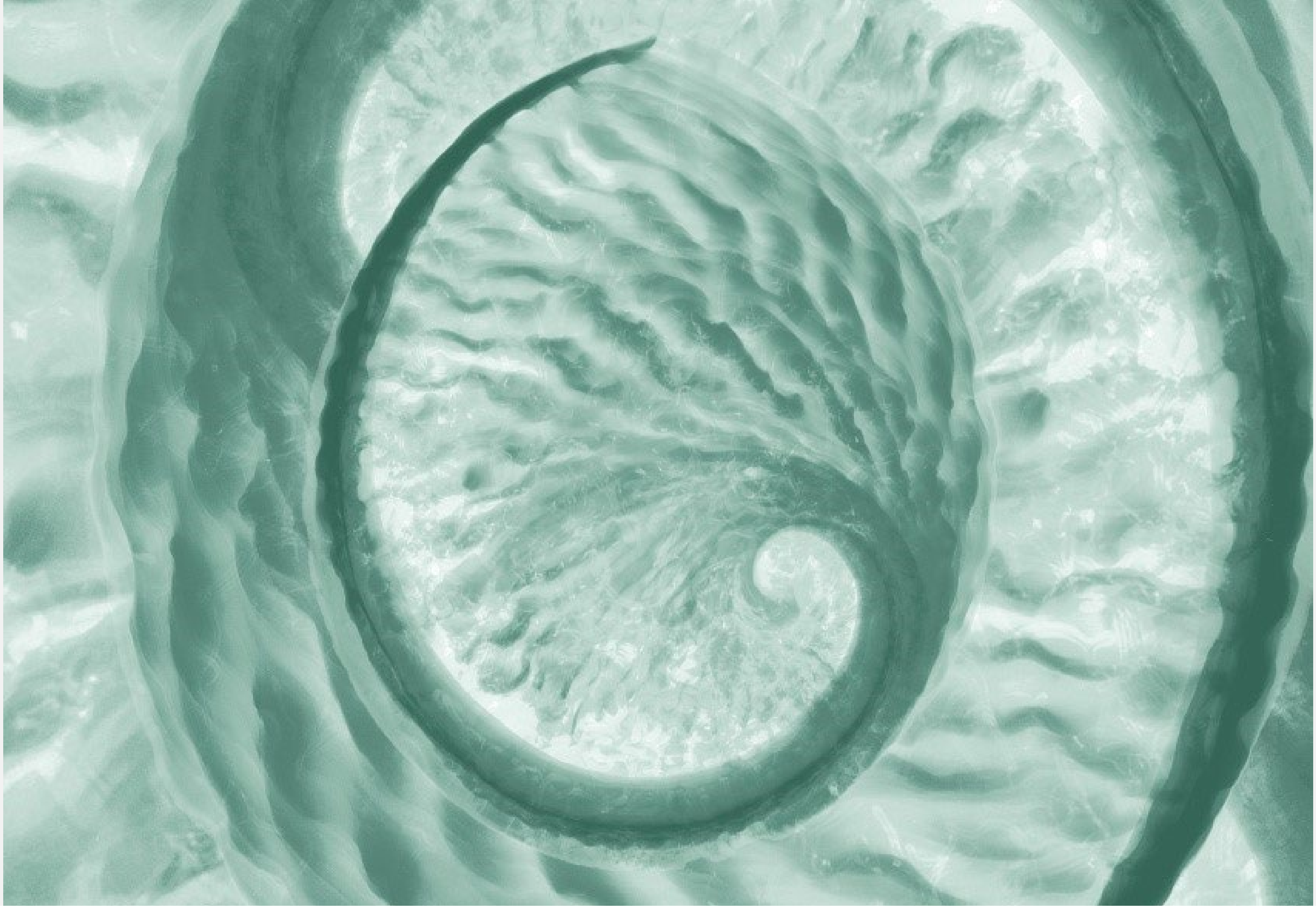

Legacy Site Services LLC

Feasibility Study

Arkema Inc. Facility, Portland, Oregon

September 2023

Project No.: 0682894

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September 2023

Feasibility Study

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Abbreviations

Name	Description
°C	degrees Celsius
$1x10^{-6}$	0.000001
AC	activated carbon
Acid Plant Area	The former manufacturing and processing facilities
alpha-BHC/HCH	aldrin, alpha-hexachlorocyclohexane/hexachlorocyclohexane
AOP	advanced oxidation processes
ARARs	applicable and relevant or appropriate requirements
Arkema	Arkema Inc. (formerly known as Pennsylvania Salt Manufacturing Company, Pennsalt Chemicals Corporation, Pennwalt Corporation, Atochem North America Inc., Elf Atochem North America Inc., ATOFINA Chemicals Inc.)
AS	air sparging
ASAOC	Administrative Settlement Agreement and Order on Consent
AST	aboveground storage tank
beta-BHC/HCH	Beta-hexachlorocyclohexane/hexachlorocyclohexane
bgs	below the ground surface
BPA	Bonneville Power Administration
CaSx	calcium polysulfide
CDD/CDF	chlorinated dibenzodioxins and chlorinated dibenzofurans
CLU-IN	Contaminated Site Clean-Up Information
COC	Contaminant of concern
COIs	chemicals of interest
COPCs	constituents of potential concern
CRBG	Columbia River Basalt Group
CrIII	Trivalent chromium
CrVI	hexavalent chromium
CS	cross section
CSM	conceptual site model
DDT	dichlorodiphenyltrichloroethane
DDx	DDD, DDE, and DDT
Deep Zone	Deep Groundwater Zone
DEQ	Oregon Department of Environmental Quality
DNAPL	dense non-aqueous phase liquid

ERA	ecological risk assessment
ERH	electrical resistance heating
ERM	Environmental Resources Management, Inc.
ESA	environmental site assessment
FS	feasibility study "This FS" means this Arkema Upland feasibility study
FSWP	Feasibility Study Work Plan
FU(s)	functional unit(s)
GAC	granular activated carbon
gamma-BHC/HCH	gamma-hexachlorocyclohexane/hexachlorocyclohexane
GCL	geosynthetic clay liner
GBFS	ground granulated blast furnace slag
GCCs	gradient control clusters
GEE	groundwater extraction enhancement
gpm	gallons per minute
Gravel/Basalt Zone	Gravel/Basalt Groundwater Zone
GWBW	groundwater barrier wall
GWET	groundwater extraction and treatment
HCM	site hydrogeologic conceptual model
HHRA	human health risk assessment
HMX	octogen
HSE	hot spot evaluation
IH	heavy industrial use
Integral	Integral Consulting
Intermediate Zone	Intermediate Groundwater Zone
IRM	interim remedial measure
ISCO	insitu chemical oxidation
ISCR	insitu chemical reduction
ISS	insitu solidification and stabilization
LOF	locality of the facility
LSS	Legacy Site Services LLC, agent for Arkema Inc.
LtGW	leaching to groundwater pathway in the hot spot evaluation
Ma	million years ago

MCB	monochlorobenzene
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNA	monitored natural attenuation
MPR	monthly Progress Report
MPR Pond	manufacturing process residue pond
MW	monitoring well
NaCl	salt, sodium chloride
NAPL	non-aqueous phase liquids
NAVD 88	North American Vertical Datum of 1988
NMR	nuclear magnetic resonance
No. 2 Dock	northernmost dock
NPDES	National Pollution Discharge Elimination System
OAR	Oregon Administrative Rule
OCTF	Old Caustic Tank Farm
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PCE	tetrachloroethene
PDI	Preliminary Design Investigation
pg/L	picograms per liter
pH	potential of hydrogen
PMP	Performance Monitoring Plan
PRB	permeable reactive barrier
RAOs	remedial action objectives
RBC	risk-based concentrations
RBDM	Risk-Based Decision Making
RD/RA	remedial design/remedial action
RDX	hexogen
RI	remedial Investigation
RI/FS Work Plan	ATOFINA Acid Plant Area Remedial Investigation and Feasibility Study Work Plan
the river	The Willamette River
ROD	record of decision
RP	Rhone-Poulenc

Salt Dock	southernmost dock
SCM	source control measure
SEE	steam enhance extraction
Shallow Zone	Shallow Groundwater Zone
the site	the former Arkema Inc. (Arkema) Facility located in Portland, Oregon
SLLI	Star Link Logistics, Inc.
SLVs	screening level values
SVE	soil vapor extraction system
SVOCs	semi-volatile organic compounds xiixiiorganic compounds
TCDD	tetrachlorodibenzo-p-dioxin
TCDD TEQ	TCDD toxicity equivalent
TCE	trichloroethene
TCH	thermal conduction heating
The Order	Consent Order No. LQVC-NWR-08-04 (DEQ 2008)
TNT	trinitrotoluene
TPH	total petroleum hydrocarbon
UCS	unconfined compressive strength
USEPA	US Environmental Protection Agency
USGS	United States Geological Survey
VOCs	volatile organic compounds
ZVI	zerovalent iron
ZVZ	zero valent zinc
µg/L	micrograms per liter

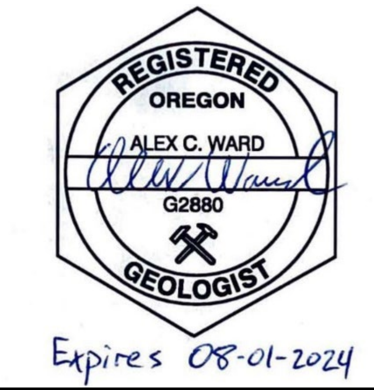
PROFESSIONAL ENGINEER'S CERTIFICATION

I, David Weymann, Licensed Professional Engineer in the State of Oregon, hereby certify to the best of my knowledge and belief that this document is true and correct and has been prepared in accordance with general industry standards and applicable federal, state, and local requirements, and hereunto set out hand and affix my seal this 8 September 2023.

David Weymann, PE, CPSS
Oregon Professional Engineer License No. 1996PE

PROFESSIONAL GEOLOGIST’S CERTIFICATION

I, Alex Ward, Licensed Professional Geologist in the State of Oregon, hereby certify to the best of my knowledge and belief that this document is true and correct and has been prepared in accordance with general industry standards and applicable federal, state, and local requirements, and hereunto set out hand and affix my seal this 8 September 2023.



Alex Ward, PG
Oregon Professional Geologist License No. G2880 PG

1. INTRODUCTION

This Feasibility Study (FS) screens cleanup technologies, assembles and ranks alternatives, and recommends preferred alternatives for the upland portions of the former Arkema Inc. (Arkema) Facility (the site) located in Portland, Oregon. Environmental Resources Management, Inc. (ERM) prepared this FS on behalf of Legacy Site Services LLC (LSS), agent for Arkema Inc. (Arkema).

The Oregon Department of Environmental Quality (DEQ) issued *Consent Order No. LQVC-NWR-08-04* on 31 October 2008 (DEQ 2008) (the Order), which requires an FS and describes its scope. Section 1 describes the site details, the regulatory framework, and LSS's general approach to the FS.

1.1 Site Overview

The site is located at 6400 NW Front Avenue in Portland, Oregon, and comprises approximately 55 acres along the west bank of the Willamette River (the river). Figure 1-1 is a site location map. Section 2 describes additional site details and historical operations.

The site is located at approximately river-mile 7.5 of the river in the Guild's Lake Industrial Sanctuary (formerly the Northwest Portland Industrial Sanctuary), zoned and designated "IH" for heavy industrial use. The site is bordered on the east by the river, on the south by CertainTeed Roofing Products Company, and on the north and west by Front Avenue. The site is generally flat with surface elevations ranging from approximately 25 to 38 feet North American Vertical Datum of 1988 (NAVD 88). Most of the site is surrounded by steel security fencing.

Lots 1 through 4 and Tract A along the river comprise the site (Figure 1-2). The northern portion of the site includes Lots 1 and 2 and is relatively undeveloped. No manufacturing has occurred on Lots 1 and 2 (ERM 2005). The southern portion of the site includes Lots 3 and 4, which comprise approximately two-thirds of the site (39 acres). The site has historically conducted manufacturing in the southern portion of the site, and has developed Lots 3 and 4 with buildings, paved roads, rail spurs, and associated tanks and piping to support manufacturing processes. Tract A is a narrow strip of property between the top of the bank and the mean high water line along the entire riverbank of the site. Today, the only structures that occupy the site include a building constructed to house treatment equipment for the Groundwater Extraction and Treatment (GWET) system, three small motor-control buildings, a temporary trailer used as the site office, and the remaining administration building.

1.2 Regulatory Basis and Guidance

This FS responds to the 2008 Order to conduct an FS for the upland portions of the site. The Order cites the regulatory basis and lists the applicable rules and guidance under which the following work must be performed.

1. **Feasibility Study.** The Order and the approved FS Work Plan (ERM 2022) describe the scope of the FS. This document is the FS for upland portions of the site.

- **Riverbank Erodible Soil Source Control Evaluation and Implementation.** The Order describes work to be completed on the riverbank. LSS is evaluating the riverbank under the 2020 US Environmental Protection Agency (USEPA) *Administrative Settlement Agreement and Order on Consent for Remedial Design at River Mile 7 West Project Area* (ASAOC) (USEPA 2020). This FS does not address remediation of the riverbank.

2. **Design and Implementation of Stormwater and Groundwater Source Control Measures.** LSS implemented stormwater source control measures (SCMs) at the site in accordance with the Order and the stormwater *Mutual Agreement and Order No. WQ/I-NWR-10-175* executed on 4 August 2010 (DEQ 2010). The stormwater *Final Design Report* (Integral 2011) describes the stormwater SCM.

The *Performance Monitoring Plan for Stormwater Source Control Measures* (Integral 2012) describes operation of the stormwater system. Annual reports summarize operation and performance of the stormwater treatment system.

LSS implemented a groundwater SCM on Lots 3 and 4 (see Section 3.4) in accordance with the Order between May 2012 and May 2014. Monthly and annual performance reports summarize the operation of the groundwater SCM. The *2022 GWET System Effectiveness Evaluation* (ERM 2023) summarizes the current performance and layout of the groundwater SCM, including upgrades and enhancements implemented in 2022.

3. **Additional Measures.** The Order defines "additional measures" as work elected by LSS or determined necessary by the DEQ to address issues at the site or to conduct the FS. Other than the modified GWET system, LSS has completed no such additional measures.

The specific objective of the FS is to identify treatment technologies and assemble and rank alternatives (combinations of technologies) to meet the remedial action objectives (Section 6.1) and the remedy selection balancing factors (Section 6.5). This FS recommends alternatives for each of the site's functional units (FUs) which are described in detail in Section 6.6.1.

This FS is written to comply with the Order. Section 6.2 summarizes Applicable and Relevant or Appropriate Requirements (ARARs) for the project and lists rules and guidance cited in the Order.

1.3 Scope and Approach of the FS

Attachment B to the Order lists the scope, objectives, and requirements of the FS. This FS addresses the upland portion of the site and does not specifically address the objectives related to stormwater and riverbank SCMs listed in the Order.

Per the Order, the objective of the FS is to "develop the information required to identify and evaluate remedial action alternatives and select or approve a final remedial action alternative to be taken at the facility." In addition to requirements of the Order, the DEQ has directed the schedule of the FS, the dataset on which the FS is based, and certain assumptions and other requirements of the FS.

The following documents are the primary basis of the FS.

- **Remedial Investigation (RI) Report.** The RI Report (ERM 2005) describes the site characteristics, historical operations, contamination sources, and the nature and extent of the contamination. The 2005 RI Report describes land and water use at Lots 3 and 4, includes a preliminary exposure model, and summarizes interim remedial actions.
- **Human Health Risk Assessment (HHRA).** The HHRA (Integral 2008) describes the site, summarizes the data, assesses possible exposures to site contaminants, and characterizes health risks to humans associated with possible exposures in upland areas.
- **Upland Level II Screening Ecological Risk Assessment (ERA).** The ERA (Integral 2009) describes the site, summarizes the data, and characterizes possible exposures and risks to upland ecological receptors.
- **FS Work Plan.** The FS Work Plan (ERM 2022a) describes the site background, summarizes the site conditions, characterizes the nature and extent of contamination, and lists the remedial action objectives (RAOs).
- LSS responded to and incorporated the DEQ's comments on drafts of the FS Work Plan. The DEQ modified the FS Work Plan and issued the *Final Modification Revised Upland Feasibility Study Work Plan, Arkema Facility* in 2019 (2019 FSWP) (DEQ 2019). LSS disputed the DEQ's modifications in a 30 January 2019 letter (LSS 2019). LSS's disputes centered on the DEQ's mandate to use outdated

groundwater data without the opportunity to collect current data to support the FS, the DEQ's use of overly conservative or non-promulgated screening values to assess risk, the DEQ's use of the mandated screening values to develop numeric RAOs, among other disputes.

- Notwithstanding LSS's objections to the DEQ's final modifications, ERM compiled the final *Revised Upland Feasibility Study Work Plan* (2022 FSWP) (ERM 2022a) to incorporate the DEQ's directed modifications on LSS's behalf. As acknowledged in ERM's transmittal of the final FS Work Plan, the DEQ agreed that LSS may conduct the following supplemental investigation and analysis as part of the remedial design after the FS is complete.

  - Remedial areas or development of action levels may be proposed in remedial design.

  - The remedial design may evaluate the potential for attenuation of contaminant concentrations in groundwater between the riverbank wells and the transition zone exposure point.

  - LSS may propose additional groundwater monitoring that may be incorporated into subsequent pre-remedial design submittals.

  - During remedial design, LSS may propose methods to assess leaching to groundwater (LtGW) and develop site-specific remedial action levels for both the groundwater and the leaching-to-groundwater pathway.

  - ERM and LSS may also propose additional sampling and analysis to refine areas, volumes, and characteristics of the FUs, as necessary, to design an effective remedy. The DEQ approved the FS Work Plan in 2022 (DEQ 2022).

- **Hot Spot Evaluation (HSE).** The Revised HSE (ERM 2021a) identifies hot spot screening criteria and compares the maximum concentrations in soil and groundwater to the criteria. The DEQ mandated the dataset and the criteria. The HSE delineated the location of hot spots for every contaminant of concern (COC) with concentrations that exceeded the criteria for the potentially complete exposure pathways.

LSS and the DEQ agreed to and followed a stepwise process to gain agreement during development and execution of the FS. Documents that are part of the FS stepwise process include the following.

- **Functional Unit Memorandum.** The Functional Unit Memo (ERM 2022b) identifies areas of the site with similar contaminants sources, soil or groundwater characteristics, exposure pathways, and risk drivers to facilitate screening of remedial technologies.

- **Technology Screening Memo**. The Technology Screening Memo (ERM 2023a) identifies treatment technologies applicable to the different FUs. Because the differing conditions and characteristics of the FUs may warrant different technologies, process options, and alternatives, the Technology Screening Memo and this FS screen technologies and develop alternatives for each FU separately. The DEQ provided comments on the Technology screening memo in a 17 March 2023 letter (DEQ 2023).

- **Interim FS Deliverable.** An interim deliverable (ERM 2023b) clarified the scope and structure of the FS. The interim deliverable responded to the DEQ's comments on the Technology Screening Memo and provided a draft outline of the FS content, an updated draft of the technology screening table, and an exemplar of an alternative screening process proposed in the FS. The DEQ responded to the interim deliverable in a 9 June 2023 letter. This FS incorporates the DEQ's comments.

- **FS Report.** The FS summarizes the technology screening and assembles the technologies into alternatives as applicable to the FUs.

This FS complies with the process and assumptions mandated by the DEQ, as outlined in the 2019 FSWP. As described in LSS's 30 January 2019 letter, LSS and ERM disagree with many of the assumptions and requirements imposed by the DEQ in their final modifications to the 2019 FSWP.

This FS uses the data and assumptions mandated by the DEQ. The additional investigations outlined above will provide the necessary data to verify and/or substantially alter the conclusion of this FS. The pre-design investigation data may demonstrate the need for changes to the hot spots and support site-specific action levels that are significantly different than the DEQ prescribed cleanup levels. If so, the technologies and alternatives outlined in this FS may be subject to change. Accordingly, LSS considers this FS to be preliminary until the supplemental investigations and analyses listed above and described below provide sufficient information to appropriately define actions recommended in this FS, and to design the appropriate remedies. A DEQ staff report and record of decision (ROD) based on this FS must incorporate sufficient flexibility to accommodate possible substantive changes to the COC concentrations, hot spot configuration, FUs, technologies, and alternatives described in this FS. The alternatives recommended in this FS are relevant and appropriate for remediation at the site. The scope and extent of these recommended alternatives must be defined in pre-design investigations. An iterative/adaptive approach in the remedial design and implementation process is necessary to provide the best fit remedies, based upon the concurrent or adjacent (e.g., riverbank) remedial actions that will be implemented and the effect that each has on reducing contaminants and risk to receptors.

2. HISTORICAL OPERATIONS AND SITE CHARACTERISTICS

The Upland RI Report (ERM 2005) and the Preliminary Design Investigation (PDI) for the GWET Wellfield Enhancement (ERM 2021b) describe the site. Section 2 summarizes the information contained in these reports. This summary does not replicate all the information contained in the reports but does provide context for the nature and extent of COCs and the alternatives proposed for their cleanup in this FS. In cases where new interpretation is incorporated to enhance relevant understanding, the discussion describes updates from the previous source.

2.1 Historical Operations and Chemical Sources

The site was primarily undeveloped prior to 1941. In 1941, the facility began operating as a sodium chlorate plant manufacturing chlorine, sodium hydroxide, hydrogen, hydrochloric acid, and sodium chlorate. Most recently, the facility was an operating chlor-alkali plant until the plant shut down in 2001. Throughout the facility's operational history from 1941 to 2001, operations expanded to include various other products and processes.

2.1.1 Acid Plant Area

The facility manufactured the following chemicals in the Acid Plant Area during the indicated date ranges. Figure 2-1 shows historical operations areas.

- 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane or dichlorodiphenyltrichloroethane (DDT); 1947 to 1954
- Grass defoliant (chlorination of acetone with chlorine gas); several months in 1950
- Ammonium perchlorate (reaction of sodium perchlorate with ammonium chloride); 1958 to 1962
- Ammonia insecticide; mid-1950's to 1990
- Hydrochloric acid; 1966 to 2001

The facility shut down in 2001. Since then, all buildings and facilities have been decommissioned and demolished, except for the main office building. The only other buildings present are those associated with the operation of the GWET system.

Chemicals associated with the manufacturing of products include sodium chlorate, potassium chlorate, chlorine, sodium hydroxide, DDT, sodium orthosilicate, sodium hydroxide, magnesium chloride hexahydrate, ammonia, ammonium perchlorate, sodium perchlorate, and hydrochloric acid.

Materials-handling and manufacturing of DDT and associated wastes occurred in the Acid Plant Area. The raw materials used to manufacture DDT included the following.

- Chloral (trichloroacetaldehyde)
- Chlorobenzene (also known as monochlorobenzene [MCB])
- Oleum-104 percent (fuming sulfuric acid)

2.1.1.1 DDT

The facility manufactured DDT in the former DDT Process Building (Figure 2-2) from 1947 to 1954. Manufacturing process residues discharged to a floor drain in the DDT Process Building during the initial startup. This floor drain temporarily discharged through an underground pipe that ran to the south of the building and then east of the river. From 1948 to 1950, process residues were discharged directly to a manufacturing process residue pond (MPR Pond) located northeast of the DDT Process Building. A trench constructed in 1951 or 1952 extended north approximately 285 feet from the northeastern corner of the former MPR Pond. The reported purpose of the trench was to expand the capacity of the MPR Pond.

From 1950 until DDT manufacturing ceased in 1954, the manufacturing process residue was piped to an MCB recovery system and then into the shallow MPR Pond. The wastes were conveyed through piping to the MCB recovery system, which was reportedly located immediately west of the former MPR Pond. The recovery system consisted of a steam stripper, in which chlorobenzene was removed from the waste and returned to the DDT Process Building. The entire system was located on a curbed concrete slab. Wastes from the system were reportedly drained periodically to the former MPR Pond.

The raw materials chlorobenzene and oleum were purchased from outside sources and stored in aboveground storage tanks (ASTs) located adjacent to the eastern side of the DDT Process Building. Chloral was formulated from the chlorination of ethanol at the facility and stored in an AST located inside the DDT Process Building on a concrete floor. Chemical reactions to form DDT occurred inside the DDT Process Building, where portable metal pans several square feet wide were filled with hot DDT. After the DDT cooled, the material in the pans was broken with a jackhammer to form large fragments of crystalline DDT. The crystalline DDT was temporarily stored on an asphalt slab located in the Acid Plant Area until it was transferred to the southwestern corner of the No. 2 Warehouse for milling and grinding inside the No. 2 Warehouse. Finished DDT was loaded into bags and transported from the facility by railcar. The railcar loading area was located on the northern side of the No. 2 Warehouse. A small amount of material was dissolved in diesel fuel and loaded into trucks and possibly railcars as a solution. The aboveground dissolving tanks were located immediately adjacent to the western side of the DDT Process Building. The DDT manufacturing ceased in 1954, after which the former DDT Process Building was extended westward and was used to manufacture ammonium perchlorate as discussed below.

2.1.1.2 Ammonium Perchlorate

The facility manufactured ammonium perchlorate in the former DDT Process Building from 1958 to 1962. Sodium perchlorate (manufactured in the Chlorate Plant Area) was converted to ammonium perchlorate using ammonium chloride. Some ammonium perchlorate handling took place in the No. 3 Warehouse, in the southeast portion of the Acid Plant Area. The facility sold the ammonium perchlorate as rocket fuel.

2.1.1.3 Hydrochloric Acid

The facility produced hydrochloric acid in the Acid Plant Area, formerly located between the No. 2 Warehouse and the DDT Process Building, from 1966 to 2001. Hydrochloric acid was produced by burning hydrogen gas in the presence of chlorine gas and absorbing the vapor in water. The acid was stored in two ASTs in the Acid Plant Area. The acid was loaded into tanker trucks from the ASTs or was piped to either an AST near the Chlorine Cell Room or to an AST adjacent to Track #6. Known releases of hazardous substances in the Acid Plant Area include those associated with DDT manufacturing and a release of caustic from the rupture of a fiberglass sodium hydroxide storage tank.

2.1.2 Chlorate Plant Area

The facility manufactured sodium chlorate in the Chlorate Plant Area from 1941 to 2001. Chlorate was produced by electrolysis of a sodium chloride solution. Sodium bichromate was added to the process as a corrosion inhibitor and to improve the electrical efficiency of the process. The bichromate was received in a dry form. Historically, the material came to the facility in sealed bags and was stored inside the chlorate department. The bags were opened inside the Chlorate Cell Room and the contents were dissolved in tanks with water. The solution was fed into the circulating liquor in the Chlorate Cell Room.

Beginning in the early 1990s, sodium bichromate was received in 30-gallon metal drums. The drums were also stored inside the chlorate department. The bichromate material was dissolved in the 30-gallon drums and was siphoned into tanks for incorporation into the circulating liquor.

Historically, the sodium chlorate solution product contained sodium bichromate. Chlorate solutions were shipped either by truck or barge. Truck loading occurred on the southern side of the Chlorate Plant Area. Barge loading of chlorate solutions occurred at the No. 2 Dock. After the completion of a chlorate plant modernization project in 1990, very little sodium bichromate was contained in chlorate products. The sodium bichromate was separated from the chlorate solution and returned to the circulating liquor.

The facility also began manufacturing potassium chlorate in the Chlorate Plant Area in 1941. This operation terminated in approximately 1978. Manufacturing using potassium chlorate was similar to that using sodium chlorate, except that potassium chloride was used as the source of salt rather than sodium chloride.

From approximately 1952 to 1962, the facility produced a sodium chlorate-based cotton defoliant in the former No. 1 Warehouse. Magnesium chloride was hydrated to form magnesium chloride hexahydrate. The magnesium chloride hexahydrate was brought to the northern end of the Chlorate Plant Area where it was ground and mixed with sodium chlorate. The blended material was bagged and sold.

2.1.2.1 Sodium Perchlorate

The facility produced sodium perchlorate in the Chlorate Plant Area from 1958 to 1962, with a process similar to that of sodium chlorate. The sodium perchlorate was transferred to the former DDT Process Building in the Acid Plant Area where it was converted to ammonium perchlorate using ammonium chloride.

2.1.2.2 Sodium Chloride

The facility historically received sodium chloride (salt) by ship. The salt was transferred onto asphalt-lined Salt Pads in the southeastern corner of the site. The salt was dissolved in water while on the Salt Pads to produce brine for facility manufacturing operations. Salt was the primary raw material used at the facility throughout its operational history (1941 to 2001).

2.1.2.3 Sodium Hydroxide

The Old Caustic Tank Farm (OCTF), sometimes referred to as the Former Caustic Tank Farm, is located just south of the Acid Plant Area. Tanks within the OCTF were used to store sodium hydroxide from 1946 to 1996. Over the years, tanks were added to the OCTF as production of sodium hydroxide increased. The aboveground tanks were situated on soil.

2.1.3 Ammonia

The facility produced ammonia in the New Caustic Tank Farm Area from the mid-1950s until approximately January 1990. Here nitrogen was stripped from air and combined with hydrogen that was produced in the chlor-alkali process. The combined gases were compressed and cooled to form anhydrous ammonia. Some of the ammonia was mixed with water to produce aqueous ammonia. These products were shipped by truck and railcar.

2.1.4 Polychlorinated Biphenyls (PCBs)

Electrical transformers were historically located at various locations throughout the facility. The facility kept a master list of transformers, their status, locations, fluid capacity, and results of testing for PCBs. Thirteen transformers and five oil-filled power circuit breakers were in the Main Substation and one transformer was in the Substation Annex. These transformers and circuit breakers contained, or were assumed to contain, PCBs. In November 2001, PBS Environmental performed a Phase II Environmental Site Assessment (ESA) for the Bonneville Power Administration (BPA) at the Main Substation (PBS 2002). PCBs were detected in 9 of 64 soil samples analysed at concentrations ranging from 0.166 milligrams per kilogram (mg/kg) to 1.25 mg/kg (total of seven Aroclor® compounds) (PBS 2002). No volatile organic compounds (VOCs) (MCB, 1,1,1-trichloroethane, or BTEX) were detected in any of the soil samples collected (PBS 2002). During facility demolition, all transformers were removed from the site.

PCBs have been detected in groundwater that is immediately upgradient of the site, (west side of NW Front Ave) which is emanating from the Rhone-Poulenc site. The concentrations of PCBs detected on Rhone-Poulenc site are orders of magnitude higher than those observed on site, indicating that PCBs in groundwater on site are a trespass plume from the Rhone-Poulenc site.

2.2 Site Stormwater Conveyance and Treatment

Sewers have been in place since the mid-1950s and were designed to carry large volumes of cooling water. Many were also designed to drain building basements and process sumps and are therefore deep (approximately 12 feet below ground surface [bgs] in some locations). The stormwater drain system was separated into four smaller drainage areas. Each drainage system is connected to a separate large concrete Parshall flume and discharge pipe (identified as Outfalls 001 through 004) located on the riverbank. Outfalls 001, 002, and 003 are located between the southernmost dock (the Salt Dock) and the northernmost dock (No. 2 Dock). Outfall 004 is located north of the No. 2 Dock. Discharge pipes and diffusers extended out into the river from each Parshall flume.

The facility was issued a National Pollution Discharge Elimination System (NPDES) permit on 28 January 1993, which authorized the discharge of process wastewater, cooling water, and stormwater runoff. Figure 2-3 shows the historical stormwater system. The permit allowed a discharge flow of up to 37 million gallons per day, most of which was cooling water. In January 2004, a new NPDES permit was issued to Arkema solely for the discharge of adequately treated stormwater. In 2010, LSS and DEQ entered a Mutual Agreement and Order to install a stormwater treatment system.

The new stormwater conveyance and treatment system (source control measure) was installed in 2012. Figure 2-3 shows the facility's current stormwater SCM consisting of two swales draining the east and west parts of Lots 3 and 4. The swales convey the stormwater into a detention basin for primary solids removal, through a sand filter for second stage treatment, to Outfall 004. Outfalls 001 through 003 and existing stormwater conveyance lines on the site were abandoned and grouted with controlled low-strength material. Most (over 70 percent) of the site is capped with existing paving, historical building foundations, or clean gravel cap.

The NPDES stormwater permit was scheduled to expire in December 2008. LSS submitted a renewal application in June 2008. In February 2022, LSS received a gap analysis letter from DEQ with a request for additional stormwater monitoring pending the NPDES permit renewal. The 2004 NPDES permit, and conditions in the Mutual Agreement and Order remain in effect until the new NPDES permit is implemented by the DEQ.

2.3 Site Setting, Geology, Topography, and Soils

The Upland RI Report (ERM 2005) and the PDI for the GWET Wellfield Enhancement (ERM 2021b) describe the site's surficial geology as well as the physical characteristics of the site, including demography and land use, climate, geology, surface water hydrology, hydrogeology, and ecological resources. The following subsections below summarize the information that is most relevant to the FS.

The region overlies the Cascadia Subduction Zone and geologic evidence in the area records a history of volcanism, accretion of oceanic terrains, and tectonic deformation occurring over the past ~56 million years. The general geology of the Portland area is characterized by a broad basin incised by the Columbia and Willamette Rivers and bordered by the Cascade Mountains on the east and the Coast Range Mountains on the west. Northwest-trending faults dissect the basin, primarily consisting of dextral oblique-slip faults in the vicinity of Portland. The Tualatin Mountains are a northwest-trending anticlinal ridge that is faulted along its eastern flank by the Portland Hills Fault (Wells et al. 2020). The Willamette River flows along the base of the eastern side of the Tualatin Mountains, and the site is located on the west bank of the river (Beeson et al. 1991).

The Portland basin is underlain by the Columbia River Basalt Group (CRBG), which consists of flood basalts that erupted 17 to 6 million years ago (Ma). The CRBG is characterized by a thick sequence of dense basalt flows separated by permeable interflow zones. CRBG basalt flows which have been identified in the Greater Portland Metropolitan Area are limited to members of the Grande Ronde Basalt (16.5 to 16.1 Ma) and Wanapum (16.1 to 15.9 Ma) flows and are typically poorly preserved at the surface due to intensive weathering or capping by wind-blown loess (United States Geological Survey [USGS] 2020).

Following emplacement of the CRBG, continued subsidence occurred in the Portland basin which resulted in the deposition of up to 2000 feet of alluvium, lacustrine sediments, and volcanic rocks above the CRBG. The Pliocene through Miocene-aged Sandy River Mudstone and overlying Troutdale Formation conglomerate are present in the Portland basin above the contact with the CBRG at depths of up to nearly 1700 feet below sea level toward the center of the basin. The Troutdale formation is largely absent in the vicinity of the Tualatin Mountains although important regional aquifers are present in the Troutdale Formation near East Portland (Wells et al. 2020).

The geologic history of the region during the Pleistocene Is dominated by deposits from Cascade Range glacial outwash, volcanism and basaltic eruptions, embayment of the Columbia River Valley, and cataclysmic flood deposits associated with prehistoric Lake Missoula. Basalt and andesitic eruptions from the Boring Volcanic field occurred in the Greater Portland Metropolitan Area from 2.7-0.1 Ma, resulting in volcanic deposits in the Willamette, Tualatin, and southern Portland basins. Evidence of additional volcanism is evident from Mount St. Helens and Mount Hood-derived Pleistocene tephra, lahar deposits, alluvium, and dacites found throughout the region. Pleistocene age catastrophic flood deposits consisting of unconsolidated stratified clay, silt, sand, and gravel underlie much of the valley floor in the vicinity of Portland. Coarser-grained flood deposits were preserved as bouldery, cobbly, sandy gravel bars in the eastern Portland basin. The coarse-grained facies reach a maximum thickness of 60 to 100 feet, whereas the fine-grained facies reach a maximum thickness of 100 to 130 feet (Beeson et al. 1991). These flood deposits are also preserved as terrace surfaces on upland slopes throughout the Willamette and Columbia River valleys, although they typically do not exceed several meters in thickness and their distribution is irregular. Wind-blown glacial loess was deposited as a widespread cap on uplands in the region with a maximum thickness of approximately 130 feet in the Portland Hills.

Since the last glacial maximum, significant aggradation has occurred in the Columbia and Willamette River valleys associated with corresponding sea level rise. Late Pleistocene to Holocene alluvial sands, silts, and gravels associated with channel bottoms and floodplains of these rivers range up to 150 feet thick in the area (Beeson et al. 1991). Knickpoints and bedrock obstructions in the region have preserved some reaches of rivers in the greater Portland region as relict lowland fluvial landscapes such as the Willamette River above Willamette Falls. Locally, Holocene debris flow and landslide deposits are common in the greater Portland area in addition to colluvium and talus slopes along steep surfaces.

2.4 Site Geology and Stratigraphy

Several regional geologic formations described above are relevant to the site. The top of the CRBG is at the ground surface west of St. Helens Road (~0.5 miles west of the site) and was encountered at depths between 49 and 55 feet bgs in several RI borings. Additionally, the CRBG was encountered at a depth approximately between 50 and 90 feet bgs during the installation of the groundwater barrier wall (GWBW). On the east bank of the river, basalt depths are estimated to be between 300 and 450 feet bgs (Madin 1990) thus demonstrating a generally steep northeasterly dip at the contact between the bedrock surface of the CRBG and overlying sedimentary deposits in the vicinity of the site. However, the bedrock surface is approximately 50 feet deeper in the western portion of the site due to scouring of the bedrock surface by the river channel before migration to its current location. The Troutdale Formation is expected to be thin or locally absent at the site and thus is not a significant aquifer near the site. Cataclysmic flood deposits have not been documented west of the river in the immediate vicinity of the site although they have been mapped approximately 1 mile to the northwest (Wells et al. 2020).

Holocene through Anthropocene alluvium and artificial fill comprise the surficial geology of the site and directly overlie the CRBG at depth based on previous investigations at the site (ERM 2005 and ERM 2021b) and published geologic maps (Wells et al. 2020). In-situ Holocene alluvium generally exists as stratified clays, silts, and sands. Artificial fill is common along many of the floodplain terraces adjacent to the Willamette and Columbia rivers including the site. The riverbank area, generally between the No. 1 and No. 2 Docks, was filled with miscellaneous fill for many years. Generators of this fill material included the City of Portland, private excavation contractors, and Arkema. The primary source of the fill at the site is dredged material from the shipping channels and includes soil, asphalt, concrete, metal piping, and miscellaneous materials from spent chlorine cells, some of which have been shown to contain asbestos containing material. Most of the fill is within the Acid Plant Area. Other sources of fill have also been documented at specific sites.

Subsurface geologic investigations at the site since 2005 (ERM 2005 and ERM 2021b) have delineated approximately eight informal stratigraphic alluvium units above the CRBG, listed below in stratigraphic order:

- Artificial fill material
- CLAY with silt
- Sandy SILT
- Fine to medium SAND with silt and clay
- Interbedded SAND and SILT
- Fine SAND with clay
- SILT with clay
- GRAVEL
- CRBG

Each of the alluvial units are generally poorly sorted with the exception of the fine sand with clay unit which exhibits a higher degree of grain size sorting than the other units. These stratigraphic units generally correspond with distinct hydrostratigraphic units (with the exception of the Vadose Zone) at the site and are described in detail below.

2.5 Hydrostratigraphy

The following sections describe the hydrostratigraphic zones at the site. Table 2-1 summarizes the information. The RI and PDI reports refer to the following hydrogeological zones (from the surface to deepest):

- Vadose Zone
- Shallow Groundwater Zone (Shallow Zone)
- Shallow-Intermediate Silt Zone
- Intermediate Groundwater Zone (Intermediate Zone)
- Deep Groundwater Zone (Deep Zone)
- Gravel/Basalt Groundwater Zone (Gravel/Basalt Zone)

Figure 2-4 is the geologic cross section (CS) location map, and Figures 2-5 through 2-10 are CS-1 through CS-6. The cross sections include information on Lots 1 and 2 which were not included in the RI. The cross sections are updated with additional well logs and build on the interpretation in the RI and the PDI reports.

This FS consolidates these zones and refers to the following hydrostratigraphic zones:

- Vadose Zone
- Shallow Zone
- Shallow-Intermediate Silt Zone
- Intermediate Zone
- Deep Zone
- Gravel/Basalt Zone

2.5.1 Vadose Zone

The Vadose Zone is the unsaturated soil above the uppermost groundwater-bearing zone (i.e., the Shallow Zone). It extends from the ground surface to the top of the Shallow Zone and is laterally continuous across the site. In different parts of the site, the Vadose Zone consists of some or all four uppermost stratigraphic units: Fill, Clay with Silt, Fine to Medium Sand with Silt and Clay, and Sandy Silt.

In the southern portion of the site on Lot 4 (CS5), and on Lots 1 and 2 to the north (CS1 and CS2), the Clay with Silt or Sandy Silt unit is thin or discontinuous, and the uppermost water bearing zone is unconfined Fill or Fine to Medium Sand with Silt and Clay. In the central portion of the site (CS3 and CS4), the Clay with Silt and Sandy Silt overlies the upmost water-bearing zone, and these fine-grained sediments may be a confining aquitard in areas where they intersect the uppermost groundwater. These conditions are prominent near Gradient Control Cluster 1 (GCC1) and proximal wells (CS3, near PA-27d).

Because the Vadose Zone stratigraphy produces unconfined conditions in part of the site and confined conditions in the rest of the site, Table 2-1 refers to the Vadose Zone as “unsaturated” where the top of the uppermost groundwater is in the Fill or Fine to Medium Sand with Silt and Clay units, and “aquitard” where the top of the uppermost groundwater is in the Clay with Silt and Sandy Silt units. Such conditions in the Vadose Zone may have bearing on implementation strategies in groundwater during remedy design.

2.5.2 Shallow Zone

The Shallow Zone is the uppermost water-bearing zone at the site. The Shallow Zone generally consists of Fine to Medium Sand with Silt and Clay.

The Shallow Zone is predominantly unconfined in the southern portion of Lot 4 (CS5) and in Lots 1 and 2 (CS1 and CS2) where it includes the lower portion of the Fill and the Fine to Medium Sand with Silt and Clay. In the central and western portions of the site, the Shallow Zone is confined where overlain by the Clay with Silt (aquitard) or the Sandy Silt (aquitard) (Lots 3 and 4; CS3 and CS4). The bottom of the Shallow Zone is the top of the Interbedded Silt and Sand, which is also an aquitard (see CS1 through CS6).

Regionally, groundwater flow in the Shallow Zone is from west to east to the river. However, groundwater flow directions at the site are more complex where impacted locally by the historical river channel and by the GWBW and the extraction trench system (see Table 2-1). The vertical gradient in the Shallow Zone is generally downward. The gradient is occasionally upward near the river depending on the river stage. The relatively permeable fine to medium sand of the Shallow Zone is a possible pathway of COC transport in groundwater (see Section 2.6).

2.5.3 Shallow-Intermediate Silt Zone

The Shallow-Intermediate Silt Zone is an aquitard consisting of interbedded silt and sand. It is continuous beneath most of the site, but it may be thin or absent in places. The Shallow-Intermediate Silt Zone is thickest in the northern portion of the site (Lots 1 and 2; CS1 and CS2). In the southern portion of the site (Lot 4; CS4 and CS5), the Shallow-Intermediate Silt Zone thins and has discontinuities resulting from erosion along the bank of the river (Lot 4, CS4). Because it has an estimated low vertical hydraulic conductivity (see Section 2.6), it may be an aquitard where it is present and thick between the overlying Shallow Zone water-bearing unit and the underlying Intermediate Zone water-bearing unit.

2.5.4 Intermediate Zone

The Intermediate Zone is a semi-confined water-bearing zone comprised of Fine Sand with Clay. It is generally overlain by the silty Shallow-Intermediate Silt Zone aquitard and underlain by the Deep Zone composed principally of Silt with Clay. The Intermediate Zone is confined where it is overlain by the Shallow-Intermediate Silt Zone aquitard (Lots 1,2, and 3; CS1, CS2, and CS3). However, it is semi-confined or unconfined where the Shallow-Intermediate Silt Zone aquitard is thin or absent (Lot 4; CS4 and CS5).

The Intermediate Zone extends laterally throughout the site and is thinnest on Lot 4 (CS4 and CS5) and thickens to the north. The Intermediate Zone is thickest in Lots 1 and 2 (CS1 and CS2). The regional groundwater flow in the Intermediate Zone is toward the east, where it discharges to the river. However, groundwater flow directions at the site are more complex where the historical river channel, the GWBW, and the extraction trenches, affect groundwater gradients and flow. The vertical gradient in the Intermediate Zone is generally downward, but it is occasionally upward near the river when the river stage is high (Table 2-1).

2.5.5 Deep Zone

The Deep Zone is an aquitard consisting of Silt with Clay. The Deep Zone is below the Intermediate Zone and above the Gravel/Basalt Zone throughout the site. The Deep Zone thins to the North and is thickest in Lots 3 and 4 (CS3, CS4, and CS5) and thinner in Lots 1 and 2 (CS1 and CS2). The Deep Zone thins toward the river in areas where the underlying basalt rises.

Although the Deep Zone is saturated and will yield water to a monitoring well, the hydraulic conductivity estimates and mobile water fraction indicate that groundwater flow through the Deep Zone is low (see Section 2.6). Regionally, gradients in the Deep Zone are toward the river, but the groundwater SCM operations influence gradients and flow locally. The vertical gradient in the Deep Zone is generally downward; however, it is occasionally upward near the river depending on the river stage (Table 2-1).

2.5.6 Gravel/Basalt Zone

The Gravel/Basalt Zone consists of the basalt bedrock and the overlying gravel. The Gravel/Basalt Zone slopes upwards when viewed in the cross sections from upland towards the river. Section CS-6 shows that the Gravel/Basalt Zone appears at higher elevations in the northern and central portions of the site (Lots 1, 2, 3 and the northern portion of Lot 4; CS1 through CS4) and at lower elevations in the southern portion of the site (southern portion of Lot 4; CS5).

In some locations, gravel lenses on top of the basalt would likely transmit groundwater. For example, CS-2 on Lot 2 indicates a continuous thick layer of gravel through the entire section. On Lot 4, the gravel is discontinuous, thin, or absent and would not provide a pathway for groundwater flow and contaminant transport.

2.6 Hydraulic Conductivity

ERM estimated horizontal hydraulic conductivities of the site water-bearing zones using grain size analysis and Nuclear Magnetic Resonance (NMR) tools. The PDI report (ERM 2021b) discusses the methods. Table 2-2 below lists the hydraulic conductivity estimates.

Table 2-2 Summary of Hydraulic Conductivities

Hydrogeological Zone	Hydraulic Conductivity Average Value from Grain Size Analysis (ft/day)	Hydraulic Conductivity Estimate from NMR Study (ft/day)
Shallow Zone	37	1–10
Shallow-Intermediate Silt Zone	.01*	~1
Intermediate Zone	24	10–100
Deep Zone	.003	~0.1

~ = approximately; ft/day = feet per day
**Grain size samples from the Shallow-Intermediate Silt Zone were biased toward fine-grained soils*

The hydraulic conductivities vary between and within the hydrostratigraphic zones. The Shallow Zone has a moderate estimated hydraulic conductivity, as expected from its primarily sandy grain size. The Shallow Zone is heterogeneous, resulting in a wide range of estimated hydraulic conductivity values. The hydraulic conductivity of the Shallow-Intermediate Silt Zone is one to two orders of magnitude lower than the Shallow or Intermediate Zones, consistent with its description as an aquitard. The Intermediate Zone Fine Sand with Clay yielded the highest hydraulic conductivity estimate from the NMR Study and thus can be expected to readily transmit groundwater toward the river. The horizontal hydraulic conductivity of the Deep Zone is low and at least one magnitude lower than the Intermediate Zone. The thickness of the Deep Zone varies significantly across the site and likely transmits little groundwater toward the river based on NMR and grain size analysis results.

There are no data available for the hydraulic conductivity of the Gravel and Basalt Zones. The groundwater flow model used to design the GWET enhancement (ERM 2022c) assumed the hydraulic conductivities for the Gravel Zone, the Fractured Basalt Zone, and the Slightly Weathered Basalt Zone were 5 feet per day (ft/day), 1 ft/day, and 2.5 ft/day, respectively. These values were assumed based on professional judgment because limited data are available for these zones, and because flow through CRBG is complex (ERM 2007).

3. PREVIOUS INVESTIGATIONS AND INTERIM REMEDIAL MEASURES

3.1 Previous Investigations

This section describes the previous FS-related investigations performed at the site and the findings of those investigations.

In June 1995, Arkema requested a meeting with the DEQ to submit an "Intent to Participate Form" for the DEQ Voluntary Cleanup Program. In 1998, Arkema entered into a Voluntary Agreement (DEQ No. ECVC-WMCVC-NWR-97-14, dated 26 August 1998) with the DEQ to address impacts to environmental media associated with the manufacturing of DDT in the Acid Plant Area and sediment in the river adjacent to the site (*Voluntary Remedial Investigation/Feasibility Study Agreement for the Acid Plant Area Project* [DEQ 1998]). As discussed in Section 2 of this FS, the Acid Plant Area historically contained a large component of the facility's chemical manufacturing and processing (Elf Atochem 1999). As part of the Voluntary Agreement, Arkema prepared the *ATOFINA Acid Plant Area Remedial Investigation and Feasibility Study Work Plan* (the RI/FS Work Plan; Exponent 1998). The DEQ approved the RI/FS Work Plan in a letter dated 5 February 2003.

Initial environmental investigations at the site focused on the former DDT manufacturing area in the Acid Plant Area. During the RI, Arkema identified additional areas of potential environmental concern at the site and thus expanded the scope of the RI to include these areas, in accordance with the RI/FS Work Plan.

Arkema conducted the RI between September 1998 and March 2005 to supplement existing (i.e., pre-RI) site data in accordance with Oregon Administrative Rule (OAR) 340-122-080 and the Voluntary Agreement. This RI included all the investigative work through the completion of the monthly stormwater sampling in March 2005. However, additional investigative work has continued at the site through the implementation of several interim remedial measures (IRMs). Arkema implemented the IRMs in accordance with the DEQ-approved work plans and are detailed in Sections 3.2 through 3.5. Additional site data and information is provided to the DEQ periodically through progress updates and reports as described below.

The RI/FS Work Plan included a scope of work for conducting both the HHRA and ERA. ERM submitted the preliminary work for the HHRA and ERA to the DEQ under separate cover; the Human Health Baseline Risk Assessment Scoping Document (ERM 2004a) was submitted on 26 May 2004 and the Level I Site Ecology Scoping Report (ERM 2005a) was submitted on 3 February 2005. The Baseline Ecological Risk Assessment (Integral 2009) (BERA) and the Human Health Risk Assessment (Integral 2008) (HHRA) identified chemicals of potential concern to human health and ecological receptors.

The HSE expanded on the HHRA and BERA to identify hot spots at the site. ERM prepared this HSE for LSS, pursuant to the Order. The HSE identified areas of the site that will, in part, be evaluated in this FS for potential remedial actions. The HSE is an adjunct to the Revised FSWP for the site (ERM 2017). The DEQ revised and approved the 2017 FSWP by letter on 16 January 2019 (DEQ 2019). LSS disputed the DEQ's revisions in a 30 January 2019 letter, pursuant to Subsection 8.L. (dispute resolution) of the Order. The DEQ directed that LSS revise the HSE and submit it separately after receipt of comments on the HSE.

This revised HSE updated and superseded four previous HSE reports (ERM 2006a, ERM 2012, ERM 2013, and ERM 2017). The DEQ provided comments on the 2017 HSE (Appendix A to the 2017 FSWP) on 3 September 2019. The DEQ's comments incorporated comments on previous versions of the HSE and certain comments on the 2017 FSWP.

ERM provided draft HSE tables to the DEQ on 7 December 2019. The DEQ provided comments on the draft tables by letter on 10 December 2019, and found the content acceptable with consideration of additional comments. Along with other comments, however, the DEQ commented that the revised draft HSE tables had not used all the groundwater data collected by Star Link Logistics, Inc. (SLLI) in 2007, 2009, and 2009/2010. ERM merged the databases and reconciled data quality issues. On behalf of LSS, ERM provided reconciled HSE tables to the DEQ by email on 13 March 2020. The DEQ responded on 14 April 2020 with minor observations and approved the HSE tables for use. The updated database resulted in numerous additional and modified hot spots on the site, as compared to the 2017 submittal. Many of the new hot spots, however, include very few detections (many detections are laboratory estimates) or result from the very low and inappropriate screening values mandated by the DEQ.

The DEQ and LSS have discussed and agreed to a stepwise approach to conduct the FS. Following the acceptance of the FSWP and HSE, ERM submitted the first interim deliverable, the Functional Unit Memorandum (FU Memo), to the DEQ on 22 November 2022. The FU Memo introduces the concept of the FU, which is a concept to help segregate areas of the site to select remedial action alternatives. Following the DEQ's acceptance of the FU Memo on 27 December 2022, the site was segmented into 12 FUs with varying strata, depths, and constituents (see Section 6.6.1).

On 15 February 2023, ERM provided the draft of the Technology Alternatives Screening Memorandum. The purpose of this submittal was to provide a compilation of the potential technologies to be evaluated further in this FS. The DEQ provided comments on this report and directed ERM to incorporate them directly in the text of this FS.

3.2 Soil Interim Remedial Measures

During RI field activities, ERM observed evidence of DDx- (sum of DDD, DDE, and DDT concentrations) and MCB-impacted soil in and around the Acid Plant Area. Soils containing DDx and MCB at elevated concentrations were observed within the former MPR Pond and trench, in an unpaved area approximately 150 feet west of the MPR Pond and trench, in the unpaved area immediately north of the Acid Plant Area, and in the area north of the former MCB Recovery Unit Area and south of Warehouse No. 2. DDx and MCB were primarily identified from near ground surface to approximately 8 feet bgs. DDx and MCB were observed at a depth of up to 22 feet bgs in the immediate vicinity of the former 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 to:

- Remove DDx-affected soil in the above listed areas to the extent technically practicable.
- Construct site drainage improvements to allow proper drainage and reduce ponding of surface water.
- Install limited paving and a temporary surface cover to reduce transport of DDx and MCB.

The IRMs targeted DDT concentrations greater than 1,200 milligrams per kilogram. This targeted concentration, while equivalent to the DEQ'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.

3.2.1 Phase I Soil Removal

The Phase I Soil Removal IRM was performed between September and November 2000, and focused on excavation and offsite disposal of DDx-affected soil from the former MPR Pond and trench areas. Excavations were conducted to a maximum depth of 12 feet bgs. Approximately 3,800 tons of soil were excavated and removed as part of the Phase I Soil Removal IRM. Grading, paving, and stormwater conveyance improvements were installed within the excavated area. Additionally, a temporary surface cover consisting of a visqueen plastic layer between two layers of geotextile and overlain by 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 Removal IRMs are presented in the *Interim Remedial Measures Implementation Report* (ERM 2001).

3.2.2 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. A total of 91 tons of soil were excavated to a maximum depth of 7 feet bgs. Stormwater conveyance improvements and asphalt paving were also part of soil interim actions. A detailed description of the Phase II Soil Removal IRMs is presented in the *Phase II Soil Interim Remedial Measure Final Report* (ERM 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.

3.3 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 state-only hazardous waste during future excavation. 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 feet 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 the DEQ.

Detailed descriptions of the SVE system installation, operation, and monitoring, including analytical summary tables and laboratory analytical reports, are presented in monthly progress reports (MPRs) and the *Confirmation Soil Sampling Summary Report* (ERM 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, ERM observed MCB dense non-aqueous phase liquid (DNAPL) at one of the confirmation borings. The SVE system was not designed to address DNAPL, and, consequently, the system was shut down.

3.4 Groundwater Interim Remedial Measures

In response to observation of constituents of potential concern (COPCs) in groundwater at the site, LSS also implemented multiple prior targeted IRMs, including:

- Persulfate IRM
- Air Sparging (AS)/SVE IRM
- Hexavalent Chromium Reduction IRM

These prior groundwater IRMs are summarized below in the following subsections.

3.4.1 Insitu Persulfate Oxidation IRM

ERM implemented the Insitu Persulfate Oxidation IRM in 2005 to remediate dissolved MCB and DDT 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 DDT by direct oxidation and subsequently decrease the mobility of DDT 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). ERM injected a sodium persulfate solution 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 were injected at 23 locations, and a total of 70,691 gallons of 15 percent solution were injected at 83 locations.

ERM completed monthly groundwater sampling to evaluate the performance of the IRM from October 2005 through January 2006. MCB and DDT 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 3.4.2 of this FS. These analytical results, and the results of the DNAPL investigations, described in Section 3.4.2, suggested that MCB DNAPL may be present and distributed over a larger area than originally anticipated. Given the uncertain distribution of DNAPL and potential recontamination of treated areas, the Insitu Persulfate Oxidation IRM was suspended in April 2006 pending evaluation of source control alternatives for the residual MCB DNAPL.

3.4.2 Air Sparging/SVE IRM

After investigating in 2002 to characterize the extent of MCB DNAPL, ERM conducted a subsequent study involving the installation, operation, and monitoring of a pilot-scale remediation system including AS/SVE technologies. The pilot study was completed over an approximate 5-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, ERM designed and implemented an AS/SVE IRM 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.

ERM conducted performance monitoring of the Shallow Zone every 6-months following initial system startup sampling in March and June 2005. 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 Insitu Persulfate Oxidation IRM performance monitoring results (see Section 3.4.1), additional investigation was warranted to further characterize the MCB DNAPL.

Additional MCB DNAPL investigations were conducted in two phases in December 2005 and January/February 2006. The objective of Phase I of the investigation was to evaluate the effectiveness of the AS/SVE system approximately 1 year after implementation. To evaluate the ability of the system to remove DNAPL, ERM collected 17 soil samples 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.

ERM observed DNAPL 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 or observed in Phase I investigations, 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. ERM recommended evaluating additional options for containing and treating the DNAPL 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.

3.4.3 Hexavalent Chromium Reduction IRM

ERM implemented the Hexavalent Chromium Reduction IRM to treat dissolved hexavalent chromium (CrVI) in the Chlorate Plant Area of the site. This IRM involved insitu reduction of CrVI to trivalent chromium (CrIII), thereby decreasing the solubility and toxicity of chromium. The objective of this IRM was to reduce the CrVI concentration in groundwater to the JSCS SLV of 0.011 milligrams per liter (mg/L) in groundwater adjacent to the river.

ERM achieved reduction of CrVI in the Chlorate Plant Area by injecting calcium polysulfide (CaSx) into the three uppermost groundwater units (Shallow, Intermediate, and Deep Zones), where previous investigations indicated CrVI 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 CrVI 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 3 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 were injected into the three uppermost water bearing units at the site.
- 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 CrVI concentrations in the Shallow, Intermediate, and Deep Zones were significantly reduced by 75, 85, and 92 percent, respectively, by this IRM.

3.5 Groundwater Source Control Measures

A groundwater SCM was implemented at the site between May 2012 and December 2013. A detailed description of the groundwater SCM is provided in the *Revised Upland Feasibility Study Work Plan, Arkema Facility, Portland, Oregon* (ERM 2017), as modified by the DEQ in January 2019; however, a brief description of the groundwater SCM is provided below.

In February 2009, the DEQ and the USEPA approved the general approach for the groundwater SCM. This approach included installing a GWBW and a groundwater extraction and treatment (GWET) system, with treated water discharging to the river. The DEQ and the USEPA approved the *Arkema Portland Groundwater Source Control Measure, Groundwater Barrier Wall Final Design, Arkema Inc., Portland, Oregon* (ERM 2012) on 7 August 2012. Construction of the GWBW began in May 2012 and was completed in December 2012. The DEQ approved the *Arkema Portland Groundwater Source Control Measure, Groundwater Extraction and Treatment Final Design, Arkema Inc., Portland, Oregon* (ERM 2013) on 2 April 2013. Construction of the GWET system began in December 2012 and was completed in December 2013.

GWET startup and optimization commenced in May 2014. The groundwater SCM includes:

1. A GWBW to physically separate the affected upland portions and in-water portions of the site.
2. Hydraulic control to minimize flow of groundwater containing unacceptable concentrations of COPCs around, over, and under the GWBW.
3. Management of extracted groundwater through a GWET system, with treated effluent discharged to the river under a NPDES Permit.

The GWET system was designed to handle groundwater flows of up to 110 gallons per minute (gpm), and individual recovery well pump tests conducted after the recovery wells were installed suggested a potential groundwater extraction capacity of up to ~135 gpm. The highest flow ever observed from the recovery wells was approximately 70 gpm. Average flows have ranged from approximately 15 to 40 gpm seasonally. The flow rate into the GWET system is highly dependent on the season, with higher flows observed in the spring when the river stage and groundwater elevations are higher, and lower flows in the summer and fall when the river stage and groundwater elevations are lower.

As stated in the *Revised Final Performance Monitoring Plan – Groundwater Source Control Measure, Arkema Inc. Facility, Portland, Oregon* (PMP) (ERM 2015), “The key objective of the groundwater SCM is to achieve hydraulic containment of the alluvial sequence at the site to prevent the flow of COPCs to the river. The site alluvial water-bearing zone sequence consists of the Shallow Zone, Intermediate Zone, Shallow-Intermediate Silt Zone, and the Deep Zone”. This objective defines the term capture zone Objective. Section 2.5 describes the hydrostratigraphy. Site hydraulic conditions are variable and subject to both daily tidal and seasonal fluctuations.

The GWBW component extends from the ground surface to the top of bedrock beneath the site, and the hydraulic control component consisted of 22 vertical recovery wells, 21 of which were in service as of May 2021, and pumping from the Shallow Zone and Intermediate Zone. The performance of the hydraulic control system is evaluated by a gradient control monitoring network consisting of six gradient control clusters (GCCs), with each cluster containing six monitoring points. Within each recovery well and GCC location, pressure transducers are continuously collecting high-resolution groundwater elevation data in the Shallow Zone, Intermediate Zone, and Deep Zone. The gradient control network provides hydraulic data within the alluvial sequence to inform hydraulic gradients across the GWBW and to evaluate hydraulic capture produced by the groundwater SCM with respect to the capture zone Objective, as described in the Adaptive Management Plan discussed in the PMP.

As discussed in ERM’s October 2020 MPR (ERM 2020a), the groundwater SCM is successfully impeding flow of groundwater to the river but has not been able to achieve the capture zone Objectives because the existing recovery wells are not removing sufficient groundwater to induce an inward hydraulic gradient.

During a meeting held at the DEQ’s offices on 4 November 2019, the DEQ stated that the existing recovery well infrastructure was insufficient to achieve the capture zone Objective, and that LSS should prioritize the installation of additional groundwater extraction wells. This led to the implementation of the Groundwater Extraction Enhancement (GEE) from June to October 2022.

The GEE consists of seven 50-foot deep and 50-foot-long groundwater extraction trenches in addition to the GWET system and GWBW. The GEE is designed to increase the groundwater extraction rate from the target capture zone behind the GWBW to achieve the target capture zone objectives.

The GWET system is an IRM that reduces the potential for recontamination of river sediments via the groundwater pathway. The GWET system is not a permanent stand-alone remedy but its contribution to hydraulic and mass removal is considered in the development of the alternatives discussed in Sections 8 and 9.

4. NATURE AND EXTENT OF CONTAMINATION

4.1 Contamination in Soil

4.1.1 Acid Plant Area Soil

Pre-RI investigative work (Phase I and II investigations, CH2M Hill 1997) roughly delineated the lateral and vertical extent of the former MPR Pond and trench and initiated the characterization of soil impacts in the Acid Plant Area. Results indicated that soil had been significantly impacted within the 56 by 60-foot footprint of the MPR Pond. Analyses conducted on soil samples indicated that DDT and MCB were present in soil within the former MPR Pond footprint at concentrations of up to 150,000 mg/kg (boring RP-SB-01, 8.5 feet bgs) and 200 mg/kg (boring RP-SB-15, 11 feet bgs), respectively. DDT concentrations decreased rapidly as distance increased from the MPR Pond and trench. The highest concentrations of MCB observed during the Phase I and II investigations were in the former MCB Recovery Unit area, where MCB was observed at a concentration of 42,000 mg/kg (boring RP-SB-18, 10 feet bgs).

During the RI, DDT was observed in soil samples at concentrations of up to 31,000 mg/kg (boring MWA-11i, 6 to 8 feet bgs). The footprint of DDT-impacted soil generally bounded north to south by the No. 1 and No. 2 Docks, and east to west by the river and the former Caustic Process building. In general, the lateral extent and concentrations of DDT (and its metabolites, DDD and DDE) is greatest in shallow soils and decrease with depth. Although a significant amount of DDT-impacted soil was removed during the Soil Removal IRMs, elevated DDT concentrations remain at concentrations of up to 63,000 mg/kg (Phase I investigation boring RP-SB-01, 15 feet bgs). The distribution of DDD and DDE in the Acid Plant Area soil is like that of DDT.

Chlorobenzene was observed locally at low concentrations in shallow and near-surface soil (0 to 4 feet bgs) in the Acid Plant Area. No shallow or near-surface soil contained MCB at concentrations greater than the preliminary screening level of 530 mg/kg (USEPA Region 9 PRG). Chlorobenzene was observed at significantly greater concentrations in soil deeper than 4 feet bgs, primarily in the former MCB Recovery Unit area, at concentrations of up to 66,600 mg/kg (boring CS-13, 8.5 feet bgs). The highest chlorobenzene concentrations and most of the chlorobenzene mass were observed just above the silt layer situated at approximately 7.5 to 8 feet bgs. Although some chlorobenzene-impacted soil was removed during the IRMs, vadose zone soil remains in the Acid Plant Area at a depth of at least 14 feet bgs, containing MCB at concentrations greater than the preliminary screening level (530 mg/kg).

4.1.2 Chlorate Plant Area

Per the RI, the total chromium was observed in soil in the Chlorate Plant Area at concentrations of up to 180J mg/kg (boring B-88) from 0 to 4 feet bgs, and up to 1,600 mg/kg (boring B-88, 10 to 12 feet bgs) greater than 4 feet bgs. The highest concentrations of chromium in the soil are found within the footprint of the Chlorate Cell Room. There were no detections of total or hexavalent chromium in the Chlorate Plant Area soil greater than their respective preliminary screening levels outside the footprint of the Chlorate Cell Room. Further, chromium concentrations decrease significantly within approximately 250 feet of the Chlorate Cell Room.

4.1.3 Riverbank

In the 2005 RI, pesticides, semi-volatile organic compounds (SVOCs), and metals were detected in riverbank soils. DDT, DDD, and DDE impacts were observed in nearly all riverbank and beach soil (sediment) samples. Only one metal (lead) was detected in a riverbank soil sample above its preliminary screening level of 128 mg/kg (sample RB-8).

4.1.4 BPA Main Substation

During the RI, PCBs were detected in soil during a Phase II ESA conducted by the BPA in the BPA Main Substation (referred to as the Pennwalt Substation, PBS 2002). PCBs were detected in Shallow-Zone soil (0 to 5 feet bgs) at concentrations of up to 1.25 mg/kg (total of seven Aroclor® compounds). In addition to PCBs, total petroleum hydrocarbon (TPH), seven polycyclic aromatic hydrocarbons (PAHs), lead, DDT, and DDD were detected at low concentrations in soil samples collected in the Pennwalt Substation area (PBS 2002a).

Soil samples collected in stormwater drainage swales north and south of the Pennwalt Substation did not contain PCBs above the detection limit of 0.05 mg/kg. Excavation of soil in the northwestern corner of the former Pennwalt Substation removed soil containing the highest observed concentrations of PCBs. Confirmation samples indicate that soil containing PCBs at concentrations of up to 4.5 mg/kg remain in soil, within the former Pennwalt Substation. Samples collected in the area between the substation and NW Front Avenue indicate that PCB concentrations in soil are less than 0.91 mg/kg. Based on these results, PCBs are included in the list of chemicals of interest (COIs) for evaluation in the *Baseline Risk Assessment.*

4.2 Contamination in Groundwater

4.2.1 Acid Plant Area Groundwater

The inferred groundwater flow direction is generally east to northeast (towards the river) in the Acid Plant Area. Three groundwater zones, designated as the Shallow, Intermediate, and Deep Zones, have been identified at the site. The Shallow and Intermediate Zones are separated by a thin, low permeability layer. The Deep Zone consists of silt with some clay or sand. The three groundwater zones are underlain by water-bearing basalt bedrock (i.e., the Gravel/Basalt Zone).

DDT and its metabolites were detected in Shallow and Intermediate Zone groundwater, downgradient of the Acid Plant Area. DDT is not typically observed in groundwater at concentrations greater than 1 microgram per liter (µg/L). However, due to co-solvency with chlorobenzene, DDT has been observed in groundwater at concentrations of up to 120,000 D µg/L (NMP-4D, June 2001). DDT has been observed in Deep and Gravel/Basalt Zone groundwater at concentrations of up to 0.43 and 0.022 µg/L, respectively.

Total DDD concentrations were similar in magnitude or approximately one order of magnitude greater than the total DDT concentrations in several of the monitoring wells, primarily DDD in riverbank wells downgradient of the former MPR Pond. DDD has a higher solubility limit than DDT, which may explain the higher DDD concentrations observed in groundwater. Total DDE concentrations were similar in magnitude or approximately one order of magnitude less than total DDT concentrations in most of the monitoring wells.

The horizontal extent of groundwater affected by DDT and its metabolites has been defined in the Shallow and Intermediate Zones. The plume is defined upgradient, downgradient (river), and cross-gradient (north and south) of the Acid Plant Area.

VOCs (primarily chlorobenzene) were detected in site groundwater, primarily in and downgradient of the Acid Plant Area. The maximum observed chlorobenzene concentration in a Shallow Zone monitoring well occurred within the footprint of the former MPR Pond (260,000 ug/L, MWA-15r, March 2001), and was approximately one order of magnitude greater than the maximum concentration observed in an Intermediate Zone monitoring well (38,000 ug/L, MWA-9i, January 1999). Additionally, the lateral extent of chlorobenzene impact is greater in the Shallow Zone. Significantly lower chlorobenzene concentrations were also detected in the Deep Zone. Since chlorobenzene is present in some locations in the Shallow

Zone as residual DNAPL, these results suggest that the lower-permeability silt layers separating the groundwater zones have impeded downward transport of chlorobenzene.

4.2.2 Chlorate Plant Area

The inferred groundwater flow direction in the Chlorate Plant Area is generally east to southeast. The same groundwater zones that occur in the Acid Plant Area exist in the Chlorate Plant Area; however, the silt separating the Shallow and Intermediate Zones becomes discontinuous downgradient of the Chlorate Plant Area. The underlying basalt deepens towards the south side of the site and was not observed in borings conducted in the Chlorate Plant Area.

Chromium impacts to Shallow Zone groundwater appear to extend from just upgradient of the former Chlorate Process Building on the west to the river on the east, and from the Old Caustic Tank farm on the north to about the site boundary on the south. The highest total and hexavalent chromium concentrations detected in Shallow Zone groundwater were 21 mg/L (MWA-27, April 2002) and 14.9 mg/L (MWA-36, December 2003).

Chromium impacts to Intermediate Zone groundwater are more prevalent downgradient of the Chlorate Cell Room and are more widely dispersed cross-gradient.

Chromium was detected in Intermediate Zone and Deep Zone groundwater at concentrations of up to 0.992 mg/L (MWA-16i) and 1.15 mg/L (MWA-31i(d)) during the June 2003 sitewide groundwater sampling event. These monitoring wells are downgradient of the area where the highest chromium detections have routinely been observed in shallow groundwater. This suggests that dissolved chromium has moved downward as it migrated downgradient from the Chlorate Plant Area. This is consistent with the local stratigraphy, which suggests that the silt between the Shallow and Intermediate Zones becomes discontinuous toward the southeast portion of the site. Perchlorate was detected in Shallow and Intermediate Zone groundwater, primarily in the Chlorate Plant Area, but also in a limited area downgradient of the Acid Plant Area. Concentrations of up to 290 mg/L (MWA-25, June 2003) and 200 mg/L were observed in the Shallow and Intermediate Zones, respectively, in the Chlorate Plant Area. Perchlorate impacts in Shallow Zone groundwater are more laterally extensive than those in the Intermediate Zone. The impacted area appears to be similar to that observed for Hexavalent Chromium.

Perchlorate was detected in Shallow Zone groundwater in the Acid Plant Area at concentrations of up to 1.4 mg/L (MWA-2, June 2003). Monitoring well MWA-2 was the northernmost well sampled for perchlorate. Sampling of the northernmost Shallow Zone well (MWA-5) is required to define the northern extent of perchlorate impacts to Shallow Zone groundwater in the Acid Plant Area. The highest perchlorate concentration observed in groundwater in the Acid Plant Area was 9.9 mg/L (MWA-17si, June 2003, Shallow Zone). Concentrations in the Intermediate Zone were approximately one order of magnitude lower than the maximum concentration in the Shallow Zone.

4.2.3 Salt Pads

Chloride was observed in groundwater at all monitoring wells during all sampling events. Chloride is a naturally occurring ion in groundwater. However, elevated chloride concentrations were observed on the downgradient side of the former Salt Pads, where salt was stockpiled and where salt brine was produced for use in manufacturing. Concentrations of up to 190,000 mg/L (MWA-30 dup, April 2002), 31,000 mg/L (MWA-32i, June 2003), and 61,100 mg/L (MWA-31i(d), June 2003) were observed in the Shallow, Intermediate, and Deep Zones, respectively.

While the highest concentrations of chloride exist in the vicinity of the downgradient edge of the Salt Pads, chloride concentrations exist across the site in all groundwater zones above the preliminary screening level of 230 mg/L. This is likely due to the ubiquitous use of brine in the manufacturing processes that took place during facility operations. Chloride has been observed in the most upgradient Shallow and Intermediate Zone monitoring wells at concentrations of up to 303 mg/L (MWA-7, January 1999) and 17.9 J mg/L (MWA-12i, April 1999).

4.3 Hot Spots in Groundwater and Soil

The Revised HSE (ERM, 2021a) identifies hot spots at the site. The DEQ Hot Spot Rules define hot spots in environmental media. For groundwater, a hot spot exists if contamination results in a significant adverse effect on the beneficial use of the resource and if restoration or protection of the beneficial use can occur within a reasonable amount of time. For soil, a hot spot exists if detected concentrations exceed calculated risk-based hot spot criteria and if the contamination is highly concentrated, highly mobile, or cannot be reliably contained. Results of the HSE for soil and groundwater are summarized below.

4.3.1 Hot Spots in Groundwater

The DEQ has identified the beneficial use of groundwater at the site as recharge to aquatic habitat (ERM 2005). As directed by the DEQ, the point of compliance for groundwater recharge to surface water is transition zone porewater in sediments (transition zone) of the river. The DEQ has required LSS to identify preliminary groundwater hot spots by screening upland groundwater concentrations directly against surface water criteria, without consideration of the physical, chemical, and biological processes that occur between upland groundwater monitoring locations, transition zone porewater, and surface water. At the DEQ's direction, the preliminary groundwater HSE uses the maximum detected concentrations of the COCs from sampling conducted by ERM between 2006 and 2010, and by SLLI between 2006 and 2010. Table HSE-4 in the HSE (ERM, 2021a lists screening levels for groundwater and the hot spot criteria. Figure 4-1 shows composite hot spots in groundwater.

4.3.1.1 Metals

There were few exceedances of hot spot criteria for cadmium, nickel, and zinc in groundwater on the site. These preliminary hot spots are generally associated with the Deep and Gravel/Basalt Zones on Lot 1. These hot spot criteria are hardness dependent. As directed by the DEQ, the approximate hardness of the river (25 mg/L calcium carbonate) was used to calculate these hot spot criteria. The actual site groundwater hardness is likely to be significantly higher than the river and results in a significant increase in applicable screening criteria. Further, there is no indication that historical site activities had an adverse impact on the Deep and Gravel/Basalt Zones in the Lot 1 portion of the site. A source control evaluation being conducted by SLLI/RP upgradient of the site will assess the offsite contribution of contaminants in groundwater across the site, particularly in the Deep and Gravel/Basalt Zones on Lots 1 and 2. LSS has concerns about the adequacy of the delineation of SLLI/Rhone-Poulenc COCs across Lots 3 and 4 in the deeper zones. These metals were never used at the site and are naturally occurring. Therefore, this FS does not consider treatment alternatives for naturally occurring metals where concentrations are within the range of published background concentrations and there is no known source of the metal in historical operations. Treatment/remediation of naturally occurring metals is Technically Impracticable.

There were few exceedances of hot spot criteria for cadmium, nickel, and zinc in groundwater on the site. These preliminary hot spots are generally associated with the Deep and Gravel/Basalt Zones on Lot 1. These hot spot criteria are hardness dependent. As directed by the DEQ, the approximate hardness of the Willamette River (25 mg/L calcium carbonate) was used to calculate these hot spot criteria. The actual site groundwater hardness is likely to be significantly higher than the Willamette River and results in a significant increase in applicable screening criteria. Further, there is no indication that historical site activities had an adverse impact on the Deep and Gravel/Basalt Zones in the Lot 1 portion of the site. A source control evaluation being conducted by SLLI/RP upgradient of the site will assess the offsite contribution of contaminants in groundwater across the site, particularly in the Deep and Gravel/Basalt Zones on Lots 1 and 2. LSS has concerns about the adequacy of the delineation of SLLI/ RP COCs across Lots 3 and 4 in the deeper zones. These metals were never used at the Site and are naturally occurring.

This FS does not consider treatment alternatives for naturally occurring metals where concentrations are within the range of published background concentrations and there is no known source of the metal in historical operations. Treatment/remediation of naturally occurring metals is technically Impracticable.

4.3.1.2 Inorganics

Chloride

The chloride hot spot criterion in groundwater is 230,000 μg/L. Chloride hot spots in groundwater are widely distributed in all the groundwater zones on the site.

There is a prominent chloride hot spot in the former Salt Pad Area, which the facility historically used for salt storage and brine production. Chloride concentrations in groundwater in this area of the site have decreased significantly since the facility ceased operations in 2001.

Historical chloride concentration results from the site and vicinity indicate that there is a potential upgradient source of chloride in groundwater that is migrating onto the site (ERM 2007). There were significant detections of chloride in the Deep and Gravel/Basalt Zones on Lots 1 and 2. Elevated concentrations of chloride in Gravel/Basalt Zone monitoring well RP-13-43, which is located on the northern site boundary, indicate these detections are part of RP's trespass plume. Chloride concentrations at the RP-02 monitoring well cluster increase by an order of magnitude between the Shallow and Gravel/Basalt Zones. Historical chloride data from the offsite, upgradient wells confirm the presence of an upgradient source of chloride. Data indicate that elevated, upgradient, Shallow Zone chloride concentrations migrate downward into the deeper zones and then flow on to Lots 1 and 2 (ERM 2007). The lining of Outfall 22B storm drain lines exacerbates current migration of chloride onto the site from the Rhone-Poulenc site.

Perchlorate

The perchlorate hot spot criterion in groundwater is 1,800 μg/L. Perchlorate in groundwater on the site exceeded the preliminary hot spot criterion in the Shallow, Intermediate, and Deep Zones. The preliminary perchlorate hot spots are located within the former Chlorate Plant Area on Lot 4. This location is consistent with historical production of perchlorate.

pH

The areas with elevated pH are associated with the location of the Old Caustic Tank Farm. Detections of pH in groundwater greater than pH 8.5 extend from the area of the Old Caustic Tank Farm to monitoring wells on the bank of the river.

4.3.1.3 Volatiles and Semi Volatile Organics

The extent of preliminary groundwater VOC hot spots identified in the Shallow and Intermediate Zones are generally limited to Lots 3 and 4. These preliminary hot spots are primarily due to the presence of chlorobenzene, chloroform, and tetrachloroethene (PCE). The locations of these hot spots are consistent with the site hydrogeologic conceptual model (HCM) (see Section 4.7 for site HCM details) and the DDT manufacturing area. These hot spots are generally within the capture zone of the Groundwater SCM. However, because the northern extent of the chloroform hot spot is uncertain based on the use of old data, this specific hot spot may extend a limited distance north of the Groundwater SCM target capture area.

Preliminary groundwater VOC hot spots identified on Lots 1 and 2 are generally present in the deeper groundwater zones (i.e., Deep and Gravel/Basalt Zones) and are primarily associated with 1,2-dichlorobenzene hot spots. Concentrations of groundwater VOCs on Lots 1 and 2 tend to increase with depth. There is a source control evaluation being conducted by SLLI/Rhone-Poulenc, upgradient of the site, to assess the contribution of offsite VOCs to groundwater across the site, particularly on Lots 1 and 2. The exceedances of the DEQ-determined VOC hot spot criteria in the deeper groundwater zones on Lots 1 and 2 are associated with upgradient sources (e.g., SLLI/Rhone-Poulenc), as has been established through numerous documents produced by both SLLI/Rhone-Poulenc and LSS.

4.3.1.4 Pesticides

Pesticides detected in groundwater at concentrations above the DEQ chronic aquatic life hot spot screening criteria include: Aldrin, alpha-hexachlorocyclohexane/hexachlorocyclohexane (alpha-BHC/HCH), beta-hexachlorocyclohexane/hexachlorocyclohexane (beta-BHC/HCH), gamma-hexachlorocyclohexane/hexachlorocyclohexane (gamma-BHC/HCH; lindane), chlordanes (total), sum of 2,4- and 4,4-DDD, 2,4- and 4,4-DDE, and 2,4- and 4,4-DDT, dieldrin, endosulfan (total), heptachlor, and cis-Heptachlor epoxide.

Direct comparison of detections in upland groundwater to aquatic life criteria does not reflect the likely exposure point concentrations and subsequent potential risk to receptors in surface water. Historical DDT manufacturing is a source of DDx in soil and underlying shallow groundwater on Lots 3 and 4. The former site DDT manufacturing area and associated hot spots are within the capture zone of the Groundwater SCM.

The extent of preliminary pesticide hot spots in groundwater is variable across the site in the Shallow, Intermediate, and Deep Zones. The very low hot spot criteria for DDx compounds result in sitewide hot spots in shallow groundwater (or non-detects). Given the DEQ’s directed hot spot screening criteria, this result does not achieve the HSE objective of identifying and prioritizing areas of the site for evaluation of remedial action in the FS. There are few detections of other pesticides, but detection limits were frequently higher than the very low hot spot criteria. Concentrations and detection limits generally decrease in the deeper groundwater zones.

On Lot 1, burial of DDT manufacturing process waste is a potential historical source of DDx to shallow groundwater (ERM 2005). The trench on Lot 1 was a clearly defined area amenable to an IRM. The trench was completely excavated in 1994 to regulatory standards applicable at the time. Approximately 1,700 tons of soil were removed and disposed of at the Waste Management Subtitle C landfill in Arlington, Oregon. Post-excavation confirmation sampling showed that surrounding soils met Oregon’s 1995 industrial soil cleanup levels. This soil removal action was documented in the Remedial Action Report, North Plant Area, dated April 1995 (CH2M Hill 1995).

On Lots 1 and 2, DDx constituents were detected consistently in the Gravel/Basalt Zone. The consistent presence of DDx in the Gravel/Basalt Zone and detections near the southern site line indicate an upgradient source of contamination from the SLLI/Rhone-Poulenc site from 1955 until 1969.

Due to the groundwater hot spot screening criteria being lower than or equal to the laboratory detection limit, the analytical results are extremely sensitive to sample interferences (i.e., entrained solids in the groundwater samples). When using such low screening criteria, such as the preliminary groundwater hot spot criteria, the effects of even small amounts of material entrained in the sample will cause sporadic exceedances of DDT. The effects of this sampling interference are more likely found in aged, improperly developed and/or sampled wells.

As stated in the approved FSWP, the remedial design will develop site-specific remedial action levels for both groundwater and the LtGW pathways. Additional pre-design sampling will be incorporated into the remedial design/remedial action (RD/RA). Analysis will incorporate the physical, chemical, and biological processes which occur between upland groundwater and transition zone porewater.

4.3.1.5 TCDD TEQ

Dioxins and furans are members of a family of chemicals with similar toxicity and chemical characteristics. 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) is one of a family of isomers referred to as dibenzo-p-dioxins. TCDD toxicity equivalent (TCDD TEQ) is a weighted quantity based on the relative toxicity of each member of the dioxin and dioxin-like compounds category of chemicals relative to the most toxic member of the TCDD category.

Dioxins and furans form by heating chlorinated organic chemicals. A potential onsite source was the Chlorine Cell Room area which is furan-dominated (ERM 2009).

The *Data Gaps Investigation Report* (ERM 2010) stated that debris associated with power pole demolition contributed to the presence of chlorinated dibenzodioxins and chlorinated dibenzofurans (CDD/CDF) in catch basin sediment. The DEQ’s 7 July 2010 comment letter agreed with this conclusion. The DEQ has also acknowledged that the CSM should consider possible contribution of offsite sources to site soils and catch basin sediment.

The TCDD hot spot criterion in groundwater is 0.00051 picograms per liter (pg/L). LSS notes that the very low hot spot criterion of 0.00051 pg/L for TCDD TEQ results in essentially any detection being identified as a hot spot. There are many poor-quality J-flagged data that provide questionable interpretation of the TCDD TEQ hot spot. Remaining bona fide detections are widely dispersed and would result in essentially the entire site being identified as a hot spot. Nonetheless, at the DEQ’s request, TCDD TEQ hotspots are delineated based on the available data, and these hot spots are included in the FS.

The very low hot spot criterion causes most detections to be hot spots in the Shallow, Intermediate, Deep, and Gravel/Basalt Zones. Likewise, the very low LtGW hot spot criterion results in the entire site being identified as a LtGW hot spot. The remedial design will assess whether leaching to groundwater causes TCDD TEQ hot spots in shallow groundwater. The highest TCDD TEQ concentrations in groundwater are in the Intermediate and Gravel/Basalt Zones on Lot 1. These results indicate TCDD TEQ contribution in the Gravel/Basalt Zones is from the Rhone-Poulenc site.

4.3.2 Hot Spots in Soil

This section presents the results of the HSE for potential direct exposure to soil by human and ecological receptors. Table 4-1 (Table HSE-1 in the HSE) lists exposure pathways and COCs that the HHRA found exceeded the DEQ Risk-Based Decision Making (RBDM) (DEQ 2017b) human health screening criteria, depth intervals, and COCs that define hot spots in soil. Highly concentrated hot spots apply to direct exposure (contact) by human or ecological receptors to soil. Direct contact may also occur though inhalation of vapors from soil or groundwater.

The hot spot screening criteria used in this evaluation are generic hot spot screening levels and do not account for site-specific risk-based exposure scenarios. The hot spot screening criteria are thus conservative and overestimate the actual risk posed to human and ecological receptors at the site. The ongoing implementation of the site SCMs, including scrub vegetation removal and subsequent capping with crushed rock, reduces potential ecological receptor exposure to contaminants via soil ingestion.

The DEQ directed that the Preliminary Numerical RAOs must be used as target levels during the development, analysis, and selection of cleanup alternatives in the FS. As stated in the DEQ-directed final FSWP, the remedial design may refine the remedial areas and develop site-specific remedial action levels.

4.3.2.1 Human Exposures

The HHRA identified the following human health exposure routes with potentially unacceptable risks.

- Trespasser exposure to surface soils
- Outdoor worker exposure to surface soils
- Outdoor worker exposure to surface and subsurface soils after redevelopment
- Construction worker and excavation worker exposure to surface and subsurface soils
- Vapor intrusion into buildings from soil or groundwater

A preliminary site-specific, acceptable carcinogenic risk of 0.000001 ($1x10^{-6}$) excess lifetime cancer risk to trespassers was back calculated using the site-specific exposure assumptions in the HHRA.

Metals

The HHRA identified arsenic as a COC in soil for trespassers on Lots 1 and 2 and the riverbank through the soil ingestion pathway. The preliminary hot spot criterion is 43 mg/kg. Based on this criterion, there are highly concentrated arsenic hot spots in the soil of Lots 1 and 2 and the riverbank through the soil ingestion pathway.

This FS does not consider treatment alternatives for naturally occurring metals where concentrations are within the range of published background concentrations and there is no known source of the metal in historical operations. Treatment/remediation of naturally occurring metals is practicable. For example, there is no known source of the arsenic in historical operations, and treatment of the metal is technically impracticable due to naturally occurring background concentrations.

Pesticides

The highly concentrated hot spots for human receptors are located near the former manufacturing and processing facilities (the Acid Plant Area), consistent with the CSM. Pink soil indicating the presence of DDT manufacturing process waste was observed in the bottom and side walls of the partial excavation of the MPR Pond and overflow trench. Confirmation samples were not collected from the bottom or sidewalls of the excavation. Therefore, soil within the footprint of the overflow trench and MPR Pond is identified as highly concentrated and/or highly mobile hot spots. This FS assesses alternatives to mitigate soil near the MPR Pond and the overflow trench.

In their comment letter on the draft FSWP (DEQ 2017a), the DEQ noted a data gap in delineation of 4,4-DDT near IB-43, IB-46, and US-01. The DEQ inferred from the sample spacing and detections that the 4,4-DDT hot spot might extend further toward the river. This data gap will be addressed in remedial design.

Dioxins and Furans

The HHRA identified 2,3,7,8-TCDD TEQ as a COC in soil for outdoor workers after redevelopment on Lots 1 and 2 and the riverbank through the soil ingestion pathway. The preliminary risk-based concentrations (RBC) and hot spot criteria are 0.000016 mg/kg and 0.00016 mg/kg, respectively. Based on these criteria, there are highly concentrated 2,3,7,8-TCDD TEQ hot spots in the soil, located near the riverbank in Lots 2 and 4 and on the southwest corner of Lot 4, north of the Chlorate Plant Area.

VOCs/SVOCs

There are no human health direct exposure highly concentrated hot spots for VOCs or SVOCs in the soil.

4.3.2.2 Ecological Exposure

The Level II Screening ERA (Integral 2009) identified the following ecological exposure routes with potentially unacceptable risks.

- Plant exposure to surface soils
- Invertebrate exposure to surface soils
- Bird exposure to surface soils
- Mammal exposure to surface soils

The upland parts of Lots 1 and 2 have been substantially altered by removal of invasive vegetation and other maintenance (surface grading, gravel placement, and construction of the stormwater SCM) conducted during the implementation of the stormwater and groundwater SCMs. These conditions were not reflected in the Level II Screening ERA. Site maintenance has returned Lots 1 and 2 to their industrial-use condition. Lots 1 and 2 have no viable ecological habitat, and this FS, therefore, considers Lots 1 and 2 under an appropriate industrial use scenario. Upland areas of the site were modified during construction of the stormwater and groundwater SCMs (e.g., basin excavation, berm construction, onsite management of excavated soil, erosion and sediment control actions, and placement of crushed rock cover). Ongoing maintenance of the stormwater and groundwater SCMs eliminates the potential for ecological exposures developing in the future.

To maintain consistency with previously DEQ-approved hot spot tables and directed changes to the FSWP, soil data from Lots 1 and 2 and the riverbank were screened against hot spot criteria. However, per the 2013 agreement (DEQ 2013), ecological exposure pathways are not complete on Lots 1 through 4, and, therefore, ecological exposures and subsequent hypothetical hot spots will not be considered in the FS.

4.4 Locality of the Facility

OAR 340-122-115(35) defines the locality of the facility (LOF) as “any point where a human or an ecological receptor contacts, or is reasonably likely to come into contact with, facility-related hazardous substances”, in consideration of several factors.

The Upland RI considered the LOF to be the Arkema Facility and the riverbank. The HSE included delineation of hot spots on the site parcels and the riverbank. Groundwater impacts may extend onto the riverbank. This FS does not consider remedial action alternatives for soil or on the riverbank or groundwater beneath it other than to acknowledge the interface between the upland sources and remedies and the in-water remedy that includes the riverbank. The in-water remedy is being conducted under the River Mile 7 ASOC (USEPA 2020).

4.5 Trespass Plumes

The upgradient Rhone-Poulenc site is a source of COCs in groundwater on the Arkema site. The Rhone-Poulenc site was an herbicide and pesticide manufacturing facility. Rhone-Poulenc produced large quantities of DDT from approximately 1955-1969 and other pesticides, such as dieldrin, aldrin, chlordanes. Rhone-Poulenc also produced herbicides, including 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) and 2,4-dichlorophenoxyacetic acid (2,4-D), and mixtures of these herbicides, which is commonly referred to as Agent Orange.

The Rhone-Poulenc HSE (SLLI 2018) delineated hot spots that extend from the Rhone-Poulenc site to the Arkema site. The Arkema HSE (ERM 2021) adopted the configuration of the Rhone-Poulenc hot spots that extend from the Rhone-Poulenc site onto the Arkema site. These plumes are referred to as "trespass" plumes. Examples of the trespass plumes include chlorobenzene, dichlorobenzenes, herbicides, pesticides (e.g., aldrin, dieldrin, chlordanes), PCBs, dioxins, vinyl chloride, and chloride.

The full extent of the trespass plumes is inferred and not known because data are limited. SLLI (2018) specifically identifies certain VOCs as hot spots sourced south of the Rhone-Poulenc site and extending onto Lots 1 and 2. There are other chemicals with similar distribution on Lots 1 and 2 that SLLI does not identify as hot spots sourced at Rhone-Poulenc, and there are hot spot detections on Lots 1, 2, 3, and 4 near the Rhone-Poulenc site boundary line that may also be attributed to an upgradient source.

The ability to detect hot spot concentrations in groundwater that may be sourced upgradient is limited by the monitoring well construction. For example, wells on Lots 3 and 4 may be too shallow, and deeper wells may identify more extensive hot spots from offsite sources to the south and east.

The DEQ has not made a trespass determination and has mandated that this FS identifies technologies and alternatives for likely trespass COCs. This FS identifies treatment technologies for all COCs on the site, including likely trespass plumes.

A separate submittal will describe trespass plumes. After the DEQ issues a determination, later negotiations with the responsible parties and the DEQ will identify an implementation strategy for the selected remedies and the identified trespass plumes.

4.6 Summary of Preliminary Hydrogeologic Conceptual Model

In this FS, the term hydrogeologic conceptual model (HCM) refers to a framework of information on hydrogeology, the rate and direction of groundwater flow, and an understanding of chemical fate and transport to interpret the current and potential future distribution of site-related contaminants. The HCM informs the risk CSMs in Section 5.1.3.

4.6.1 Potential COC Transport Pathways

Various current and historical transport pathways have potentially influenced the movement of COCs from source areas to where they are presently found in soil and groundwater. Overland stormwater flow and contaminant transport via air are potential migration pathways, but they have not been confirmed via sampling and are not considered in the HCM. Potential historical transport pathways from source areas affecting current COC distribution include:

- Infiltration
- Groundwater migration (via advection and hydrodynamic dispersion)
- DNAPL/dissolved phase migration
- Stormwater discharge from historical conveyance system

Infiltration, groundwater migration, and DNAPL migration (i.e., from the MPR Pond) have all been observed and/or inferred at the site and are integrated into the HCM. An evaluation was conducted in the RI to determine whether the historical storm drain system acted as a secondary conduit for constituents dissolved in groundwater infiltrating into the conveyance system then discharging to the river. Storm drain system manhole elevations were compared to groundwater elevations in monitoring wells nearest to the manholes. Invert elevations at 11 manholes in the Acid Plant and Chlorate Plant Areas were compared to minimum and maximum groundwater depths observed over the duration of the RI. The comparison indicates that storm drain system invert elevations are uniformly above groundwater in both the Acid Plant and Chlorate Plant Areas. Therefore, the storm drain system was not a potential secondary transport pathway for COCs in groundwater.

The historical stormwater conveyance system was a potential transport pathway for COCs (specifically DDx) via transport of stormwater solids. The stormwater SCM implemented in 2013 included decommissioning of the historical conveyance system and installation of stormwater channels, a detention pond, and a sand filter.

4.6.2 Potential Ecological Exposure Pathway

The Level II Screening ERA (Integral 2009) identified the following ecological exposure routes with the following potentially unacceptable risks:

- Plant exposure to surface soils
- Invertebrate exposure to surface soils
- Bird exposure to surface soils
- Mammal exposure to surface soils

The Level II Screening ERA concluded that the only likely exposures by ecological receptors would be to surface soils on portions of Lots 1 and 2 and the riverbank (from 0 to 3 feet bgs). During meetings and email communications between LSS and the DEQ in 2013, LSS and the DEQ agreed that after removal of nuisance colonizing vegetation, Lots 1 through 4 do not need to be carried forward as ecological hot spots in the FS. An 11 July 2013 email from Matt McClincy (DEQ 2013) documents the agreement. “Removal of nuisance vegetation” was conducted in 2013 and 2014 as part of implementing the surface water and groundwater source-control measures. Regular vegetation maintenance (i.e., mowing) has been conducted since 2014 to minimize re-growth of nuisance vegetation. Further details regarding ecological exposure pathways and COCs are presented in the HSE (ERM 2021a).

4.6.3 Uncertainty in Hydrogeologic Conceptual Model

At the DEQ’s direction, the preliminary groundwater HSE used the maximum detected concentrations of the COCs from sampling between 2006 and 2010 and by SLLI between 2006 and 2010. The DEQ did not allow use of contemporary data in the HSE. Accordingly, the data used in the HSE and as the basis for defining the FUs and for screening technologies are more than 10 years old and up to 17 years old. The age of the data used in the HSE introduces uncertainty in delineation of hot spots, which are the foundation of the FS. Pre-design investigation are required to address these uncertainties.

Natural attenuation processes including sorption, volatilization, biodegradation, oxidation, reduction, advection, dispersion, and dilution will have affected the concentration, toxicity, and mobility of contaminants in soil and groundwater over time. Several interim remedies have also treated specific COCs in targeted areas of the site (see Sections 3.2 through 3.4). Recent GWET performance reports indicate greatly diminished COC concentrations in groundwater upgradient of the GWET system.

For these reasons, and as stated in the approved HSE and FSWP, the data on which the FS is based does not represent the current site conditions, and site hot spots identified in this HSE are preliminary. The nature and extent of contamination will be re-evaluated based on the pre-design dataset.

Additional groundwater sampling and targeted soil sampling will be the basis of the remedial design. Due to uncertainty in the dataset, the technologies, alternatives, and costs in this FS are preliminary and subject to change.

5. SUMMARY OF RISK AND EXPOSURE ASSESSMENT

5.1 Risk Assessments

This section summarizes the conclusions of the 2008 Upland HHRA (Integral 2008) and the 2009 Upland Level II Screening ERA (Integral 2009). Table 4-1 summarizes the soil results of the HHRA and the Level II Screening ERA.

The risk assessments identified risks separately in Lots 1 and 2, Lots 3 and 4, and the riverbank areas of the site based on the surface conditions and likely future uses. Figure 1-2 shows the site lot boundaries. This FS further refines the site into FUs (see Section 6.6.1) based on the nature and extent of contamination as presented in the RI and HSE, the site characteristics (geology, nature and extent of contamination, etc.), and the likely cleanup strategies. The remedial design will develop points of compliance and action levels consistent with pathways of exposure identified in the risk assessments, pre-design data and analyses, refined risk screening, and the industrial zoning that will be maintained along the riverbank in accordance with the City of Portland Greenway regulations (City of Portland Code Chapter 33.440).

5.1.1 Human Health Risk Assessment

The HHRA evaluated COCs in soil and groundwater for potential exposure pathways and possible receptors in the three site subareas (Lots 1 and 2, Lots 3 and 4, and the riverbank areas). The HHRA evaluated the following potential scenarios for human exposure to site soils:

- Trespassers (0 to 3 feet bgs)
- Outdoor workers (0 to 3 feet bgs)
- Outdoor workers after redevelopment (0 to 15 feet bgs)
- Construction workers (0 to 15 feet bgs)
- Excavation workers (0 to 15 feet bgs)

The HHRA assessed incremental lifetime cancer risks and noncancer health effects for the COCs, including relevant exposure pathways and potential receptor combinations (Table 4-1). Although the riverbank was considered in the HHRA, remedies for the riverbank are not included in the scope of this FS.

Table 4-1 includes revisions mandated by the DEQ in the final 2019 FSWP. The DEQ mandated HSE used the highest detected concentrations of the COCs to identify hot spots, and this FS identifies potential remedial technologies and alternatives for the hot spots in each FU.

5.1.2 Level 2 Screening Level Ecological Assessment

Although the site is in an area zoned for heavy industrial use and has been largely modified and developed from its predevelopment state, potential ecological habitat remains along portions of the riverbank. Although the riverbank was considered in the Level II Screening ERA, remedies for the riverbank (i.e., FU-1) are not in the scope of this FS. Lots 1, 2, 3 and 4 are mostly covered by pavement, gravel, and building foundations that are poor ecological habitat. Lots 1 and 2 were partially covered by passively colonizing vegetation (that was removed in 2013), and thus included in the Level II Screening ERA. Lots 3 and 4 were excluded from the Level II Screening ERA. However, per the 2013 agreement (DEQ 2013), there are no ecological exposures on Lots 1 through 4 and ecological exposure pathways are not complete on Lots 1 through 4.

The Level II Screening ERA evaluated four categories of ecological receptors, including plants, invertebrates, birds, and mammals. Three COCs (chromium, lead, and DDx) exceeded the conservative generic screening level values (SLVs) for at least one ecological receptor. Table 4-1 lists the COCs for each receptor. Although the HHRA included the riverbank, remedies for the riverbank are not in the scope of this FS.

Table 4-1 includes mandated revisions made by the DEQ in their 2019 FSWP. In addition to listing the chemicals that exceeded the risk-based screening levels, the DEQ also included as COCs any chemicals with a hazard quotient (ratio of an exposure dose to an appropriate reference dose) greater than 1 for ecological receptors.

The remedial design will develop points of compliance and action levels that are consistent with current and reasonably likely future land use. The remedial design will further refine the ecological evaluation to be consistent with the site conditions following implementation of the SCMs and the river-dependent uses that must be maintained along the riverbank in accordance with the City of Portland Greenway regulations (City of Portland Code Chapter 33.440).

5.1.3 Preliminary Conceptual Site Models for Soil and Groundwater

A CSM verbally and/or graphically describes sources, releases, transport pathways, exposure routes, and human and ecological receptors that may result in exposure and risk. The CSM is also a tool used to assess actions along the exposure pathway to reduce risk. The 2008 Upland HHRA and the 2009 Upland Level II Screening ERA summarize the respective CSMs. Figures 5-1 and 5-2 are the HHRA ERA CSMs, respectively.

The HSE used the exposure pathways identified in the risk assessments to identify hot spot screening concentrations and to delineate hot spots. This FS identifies technologies and alternatives to treat hot spots in soils and groundwater. The remedial design will refine the hot spot delineation based on a pre-design dataset and additional assessment (see Section 6.4).

5.1.4 Residual Risk Assessment

OAR 340-122-0040 requires that remedies be protective of human health and the environment, as demonstrated through a residual risk assessment. OAR 340-122-0084(4) specifies that the residual risk assessment must demonstrate that the remedy will maintain acceptable risk levels, as defined in OAR 340-122-0115, in the LOF.

As specified in DEQ guidance, a residual risk assessment includes the following.

- A quantitative assessment of the potential risk resulting from concentrations of untreated waste or treatment residuals remaining at the facility at the end of any treatment, excavation, and offsite disposal, taking into consideration current and reasonably likely future land- and water-use scenarios, and the exposure assumptions used in the baseline remedial action.
- A qualitative or quantitative assessment of the adequacy and reliability of any institutional or engineering controls used for managing treatment residuals and untreated hazardous substances remaining at the facility.

This FS identifies technologies and alternatives to achieve the RAOs. The FS estimates the effectiveness and reliability of the alternatives to achieve the RAOs, including qualitative assessment of institutional and engineering controls implemented during the remedial action to prevent exposures.

This FS identifies and recommends alternatives for the site that will be protective, effective, implementable, and thus achieve the RAOs. Satisfying the RAOs will attain acceptable residual risk.

The following uncertainties related to the current site conditions, details of technologies to be implemented, and extent of contamination have bearing on the remedies and possible residual risk:

- The effectiveness of the groundwater SCM is being evaluated but is not yet known. The groundwater SCM removes contaminant mass, mitigates transport of COCs to the river, and is an interim remedial measure that is included in all alternatives being considered.
- The upland remedy will interface with the in-water remedy. The in-water remedy is being evaluated and designed but is not yet known.
- A contemporary dataset is needed to assess the current nature and extent of contamination in groundwater. A comprehensive set of groundwater data and targeted soil sampling will indicate the current extent of COCs in groundwater and refine the groundwater CSM.
- The flux of COCs from groundwater to the river is not known. Ongoing analysis (Integral and DOF 2020) will assess the groundwater to surface water connection and provide information to estimate the concentrations and flux of COCs that may reach the river through groundwater.
- Estimates of groundwater to surface water flux and attenuation will provide information to establish points of compliance and action levels to achieve the risk-based concentrations at the points of compliance.

These uncertainties make a quantitative residual risk assessment impractical now. The ROD will document the remedies selected by the DEQ. The remedial design will describe the residual risk assessments to be conducted during performance evaluation of the remedial action. The residual risk assessment will include the following:

- The effectiveness of institutional and engineering controls to mitigate exposures to residual contamination in soil or groundwater during the remedial action.
- Qualitative assessment of risks posed by remediation residuals (excavated soil, extracted groundwater, investigation derived waste, etc.).
- Quantitative or qualitative assessment of any untreated soil or groundwater in the LOF that remains at concentrations higher than cleanup or action levels at the conclusion of the remedial action.

5.2 Beneficial Land and Water Use

The Upland RI Report (ERM 2005) and the 2022 FSWP (ERM 2022a) describe land and beneficial water use determination for the site LOF (ERM 2005). This section summarizes the findings.

5.2.1 Land Use

In accordance with OAR 340-122-0080(3)I and DEQ guidance (DEQ 1998), selecting a remedial action must consider the following:

- Current land uses
- Zoning, comprehensive plan, or other land use designations
- Land use regulations from any governmental body having jurisdiction
- Concerns of the facility owner, the neighboring owners, and the community and
- Other relevant factors

The current and reasonably likely future land use in the LOF is industrial. The site is located in the Guild’s Lake Industrial Sanctuary, zoned and designated “IH” (City of Portland 2001). The sanctuary plan preserves land for industrial uses in the area generally bounded by Vaughn Street on the south, St. Johns

Bridge on the north, Highway 30 on the west, and the river on the east. The plan became effective on 21 December 2001.

The purpose of the industrial sanctuary is to maintain and protect this area as a dedicated zone for heavy and general industrial uses. The plan's vision statement, policies, and objectives were adopted as part of Portland's Comprehensive Plan and are implemented through amendments to the City's Zoning Code. Since the site is within the Guild's Lake Industrial Sanctuary, future land use in the LOF will be industrial.

5.2.2 Surface Water Use

A Phase II site Characterization (CH2M Hill 1997, Appendix G) and a beneficial water use survey conducted for a nearby facility (Woodward-Clyde 1997) determined the potential beneficial uses of nearby surface water (the river) to be industrial use, recreational use, and ecological habitat.

5.2.3 Groundwater Use

Groundwater is not currently used as drinking water, nor is such use reasonably likely in the future. A September 2023 search of the Oregon Water Resources Department records for wells within a 1-mile radius of the site identified wells within the search radius but concluded that there were no water supply wells located on or near the LOF, or downgradient of the site.

Due to the site's proximity to the river, future industrial water needs (e.g., non-contact cooling water) are likely to be met by surface water or, possibly, groundwater in productive interflows of the CRBG.

The beneficial use of groundwater at the site has been mandated as recharge to aquatic habitat and to the basalt water-bearing zone (ERM 2005). The potential beneficial uses of groundwater in the basalt include recharging to the river and industrial water supply.

The DEQ Hot Spot Rule defines hot spots in environmental media. A hot spot exists in water (groundwater beneath this site) if contamination results in a significant adverse effect on the beneficial use of the resource and if restoration or protection of the beneficial use can occur within a reasonable amount of time. The HHRA and ERA assessed potential effects of COCs in the upland soil and groundwater on the adjacent river environment (see Section 5.1). The upland remedy will be designed to protect beneficial uses of groundwater as recharge to the river.

As directed by the DEQ, this FS overconservatively assumes that highest measured COC concentrations from 2006 to 2010 in upland groundwater discharge unattenuated to surface water through the transition-zone porewater in sediments (transition zone) of the river.

6. REMEDIAL ACTION SCOPING

The sections below describe the remedial action objectives (RAOs), as specified in the FSWP, applicable regulatory requirements of the FS and remedy, and the criteria applied to ranking alternatives. Section 6.6 describes site-specific requirements and considerations for screening technologies and developing alternatives in the FS.

6.1 Remedial Action Objectives

The approved FSWP (ERM 2022A) lists the site-specific RAOs, as follows.

- RAO 1 – Reduce upland human health risks to acceptable risk-based levels from incidental ingestion, inhalation, and direct contact with soil under trespasser, outdoor worker, outdoor worker after redevelopment, and construction worker scenarios.
- RAO 2 – Reduce riverbank terrestrial ecological risks to acceptable risk-based levels from ingestion and direct contact with soil.
- RAO 3 – Prevent or reduce the potential for migration of COCs in surface soil and riverbank soil to accumulate in river sediment above acceptable risk-based levels.
- RAO 4 – Treat or remove soil hot spots to the extent feasible based on remedy selection factors.
- RAO 5 – Prevent or reduce the migration of groundwater COCs to the river above acceptable risk-based levels for surface water receptors.
- RAO 6 – Treat or remove groundwater hot spots to the extent feasible based on remedy selection balancing factors.
- RAO 7 – Reduce the potential for DNAPL to act as a continuing source of COCs in groundwater.
- RAO 8 – Treat or remove DNAPL hot spots to the extent feasible based on remedy selection balancing factors.
- RAO 9 – Reduce the migration of COCs in stormwater to the river that are at or above acceptable RBCs for surface water receptors.
- RAO 10 – Reduce the migration of COCs in stormwater to the river to prevent accumulation of COCs in river sediment above risk-based levels.
- Section 6.4 describes numerical RAOs.

6.2 Applicable and Relevant or Appropriate Requirements

Table 6-1 (Table 5.1 of the FSWP [ERM 2022A]) lists preliminary project ARARs. The ARARs list includes rules and regulations typically relevant for both upland and in-water actions. Although this FS is for the upland remedy only, the in-water ARARs are listed for completeness and for consistency with the Portland Harbor ROD.

The following regulations and guidance are most relevant to preparing this FS:

- OAR Chapter 340 Division 122: Hazardous Substance Remedial Action Rules. The Remedial Action Rules (‘Cleanup Rules") establish the standards and procedures to determine remedial actions to protect human health and the environment from the release or threat of a release of a hazardous substance. The cleanup standards provide remedial action levels and requirements for hazardous substances in upland soil and groundwater.
- OAR 340-122-090: Hot Spot Rules. The Cleanup Rules state that the DEQ must select a remedy that treats hot spots of contamination to the extent feasible. DEQ (1998B) provides guidance to identify hot spots of contamination. The guidance encourages the DEQ staff to exercise professional

judgment and to be “cognizant of how the identification of hot spots at a cleanup site can affect the type and cost of the remedy.”

- DEQ Guidance for Conducting Feasibility Studies(1998c). The DEQ provides guidance to identify and evaluate alternatives for the purpose of selecting an appropriate remedial action for a site. As for the hot spot guidance, the FS guidance encourages the DEQ staff to exercise professional judgment and to be “cognizant of how the identification of hot spots at a cleanup site can affect the type and cost of the remedy.”

6.3 Project Specific Requirements

In the FSWP, the DEQ directed that the evaluation of alternatives in this FS follow certain specific assumptions. LSS disputed DEQ’s 2019 revisions to the FSWP (DEQ 2019) in a 30 January 2019 letter (LSS 2019). In particular, the DEQ directed, LSS disputes, and the FSWP and this FS incorporate the following:

- The FS must be based on the 2006 to 2010 data set. The “current data set” consists of site characterization data from 2006 to 2010. Accordingly, the prescribed data are between 13 and 17 years old. LSS (2019) asserts, and data indicate, that current COC concentrations in groundwater have changed (ERM 2023b). Accordingly, Section 5.2.3 of the final FSWP allows that “additional pre-design sampling will be incorporated into the remedial design/remedial action (RD/RA).” The DEQ acknowledges that the nature and extent of COCs and delineation of hot spots may be updated based on pre-design sampling data. Accordingly, the boundaries of treatment areas or actions areas and the details of technologies and alternatives described in this FS may be modified based on pre-design sampling data and analysis.
- The FS must assume that there will be little or no attenuation in contaminant concentrations in groundwater between the riverbank wells and the transition zone exposure point. This assumption of the modified FSWP is not substantiated and may have a substantial bearing on selection of technologies and alternatives. The DEQ’s 16 January 2019 letter allows that attenuation may be evaluated as part of RD/RA but not as part of the FS. Section 5.2.3 of the final FSWP allows that LSS may develop site-specific remedial action levels during the RD/RA for both the groundwater and the LtGW pathways. Accordingly, the treatment areas described in this FS (or related action areas) may be modified based on pre-design sampling data and analysis.
- The FS must be based on the Preliminary Numeric Remedial Action Objectives (Preliminary Numeric RAOs) as established in the Portland Harbor Record of Decision (USEPA 2017). LSS (2019) disputes the DEQ’s use of overly conservative, scientifically unsound, or unsupported screening values to guide remedy selection in the FS.
- Despite LSS’s objections in the record, the HSE and this FS adopt the Portland Harbor ROD Preliminary Numeric RAOs as directed by the DEQ. Tables 4-4, 5-4, 5-5, 5-6, 5-7, 5-8 of the FSWP list the numerical RAOs. The HSE (ERM 2021a) incorporates the DEQ-mandated Preliminary Numeric Remedial Action Objectives. This FS considers treatment of hot spots as delineated in the HSE. Tables 6-2 and 6-3 list the numerical RAOs for soil and for groundwater and stormwater, respectively.
- The DEQ’s 16 January 2019 letter allows that action levels may be developed and proposed in the RD/RA, but not in the FS. Accordingly, the remedial design may result in treatment areas or volumes based on pre-design sampling data that substantially differ from those described in this FS.

6.4 Risk-Based Cleanup Levels and Action Levels

6.4.1 Risk Based Cleanup Levels

The final FSWP, as modified by the DEQ, prescribes numerical RAOs to align with the written RAOs (Section 6.1) and that apply to this FS. Tables 4-4, 5-4, 5-5, 5-6, 5-7, 5-8 of the FSWP list the numerical RAOs. LSS (2019) lists objections to using these conservative values. Tables 6-2 and 6-3 list the numerical action levels for the remedial action technologies and alternatives screened in this FS.

6.4.2 Action Levels

The DEQ (2019) allows the following:

During remedial design, LSS may propose methods to assess leaching to groundwater and develop site-specific remedial action levels for both the groundwater and the leaching to groundwater pathways. A technical memorandum will describe proposed sampling and analysis to refine soil action levels and remediation volumes in the design. Additional pre-design sampling will be incorporated into the RD/RA.

In this FS and in the future RD/RA the term “action level” is interpreted to mean:

Contaminant- and media-specific concentrations at a point or area of compliance below which further action (investigation, risk assessment, or remedial action) is not warranted.

The intent of action levels is to identify COC concentrations that will not result in unacceptable exposure by a receptor to a COC at a point of exposure. Examples of a point of compliance may be a specific well location, a depth of soil in a defined area, a groundwater zone at a defined boundary, or similar.

Data and analyses during RD/RA may include but are not limited to the following:

- Pre-design sampling of soil and groundwater, as necessary and relevant to assess contemporary concentrations.
- Modelling or sampling to characterize attenuation of COCs in soil and groundwater over time and distance to estimate concentrations at a point of exposure.
- Assessment by modelling, sampling, or testing of site-specific leaching from soil to groundwater and transport in groundwater to a point of exposure in the river. The HSE is based on conservative calculations using standard equations to assess leaching potential and the conservative assumption that any potential hot spot in groundwater is transported undiluted to the river. This method results in large hotspots at very low concentrations for some COCs that may be unlikely to leach from the soil (e.g., pesticides). Testing during remedial design will assess the true extent of LtGW hot spots.
- Estimation of COC flux from upland groundwater to the river and the resulting concentrations in the river (porewater or water column), as compared to risk-based concentrations.
- Modelling to assess attenuation of COCs through a possible in-water cap to achieve risk-based concentrations in the water column of the river.
- Quantitative risk assessment to assess site-specific risk-based concentrations in media at the point of exposure.

A work plan during remedial design will propose methods of analysis. The testing and results will inform the remedial design.

6.5 Remedy Selection Balancing Factors

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

In the context of this FS, the groundwater SCM is a component of several alternatives for certain FU's. Although the groundwater SCM provides source control and removes contaminant mass, the groundwater SCM alone is considered an interim measure and was not specifically and independently evaluated against the selection criteria of protectiveness (OAR 340-122-0090(2)) and preference to treat hot spots of contamination (OAR 340-122-0090(4)).

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

6.5.1 *Effectiveness*

The effectiveness criterion evaluates protection of human health and the environment, as aligned to the RAOs. The long-term effectiveness of the alternative is evaluated under the long-term reliability criterion. 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 in a residual risk assessment.

The effectiveness criteria used to evaluate remedial action alternatives include the following:

- Magnitude of risk from treatment residuals or untreated waste, taking into consideration any risk reduction through onsite 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.
- Time required to achieve treatment objectives.

6.5.2 *Long-Term Reliability*

Long-term reliability considers an alternative's protectiveness over time. Long-term reliability assesses the magnitude of residual risk at the conclusion of a remedial action. This criterion also evaluates the adequacy and reliability of engineering or institutional controls. Long-term reliability is generally a qualitative evaluation.

Evaluation of remedial action alternatives will consider the following, as appropriate:

- Reliability of technologies to meet treatment objectives.
- 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.
- Long-term management (e.g., operation, maintenance, monitoring) to maintain protectiveness.

6.5.3 *Implementability*

Implementability considers constructability and administrative and technical implementability. Administrative implementability considerations include legal, regulatory, and land-use considerations in consultation with applicable agencies. Technical feasibility considers constructability and operation and monitoring considerations and availability of services, materials, and expertise. Implementability is generally a qualitative analysis.

The implementability of an alternative considers the following, as appropriate:

- Potential difficulties and unknowns 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.
- Availability of required services, materials, and equipment (including offsite treatment, storage, and disposal services).

6.5.4 *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 during implementation of a remedial action. The risk associated with implementing a remedial action alternative is evaluated based on the following criteria, as appropriate.

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

6.5.5 *Reasonableness of Cost*

Reasonableness of cost is generally a two-part, semi-quantitative assessment that compares overall costs of alternatives. A cost estimate is first prepared for each remedial action alternative. Typically, the cost estimates are calculated within a +50 percent (50 percent higher than eventual actual) to -30 percent (30 percent lower than eventual actual) accuracy range. FS costs are calculated as net-present value to incorporate costs over time by discounting future costs to a common base year if the net-present value amount were invested in the base year. Net-present value cost analysis provides for comparison of overall costs of alternatives of different capital costs and long-term costs.

A cost sensitivity analysis should be completed to evaluate how the anticipated costs may vary in response to variability of assumptions in the costing (e.g., effective life of alternative, volume of contaminated material, etc.). The degree to which the costs are proportional to the benefits of 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 (“cost effectiveness”) will have a greater reasonableness of cost.

Cost effectiveness of alternatives is 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 of treating hot spots to protect or restore existing and reasonably likely future beneficial uses of water.
- Degree of sensitivity and uncertainty of costs.

6.6 Site-Specific Considerations for Technology Screening and Alternative Development

6.6.1 Functional Units

The FUs are a tool to segregate areas of the site by contaminants and characteristics to facilitate identification and evaluation of cleanup technologies and alternatives. The Functional Unit Memo (ERM 2022c) provided the rationale and description of the site FUs. Table 6-4 lists and describes the FUs. Figures 6-1 and 6-2 are maps of the soil and groundwater FUs, respectively.

- Functional Unit 1 – Riverbank. FU-1 consists of the top 3 feet of soil along the riverbank on the east side of Lots 1 through 4 from the top of the riverbank to the river (mean high water approximately 12 feet NAVD88). The riverbank has concentrations of metals (naturally occurring arsenic, chromium, lead, and zinc) and pesticides in soil that exceed criteria for direct and LtGW exposure pathways, and for VOCs in soil for the LtGW pathway. The riverbank will be addressed as part of the in-water remedy under the Portland Harbor ROD (USEPA 2020). This FS does not consider FU-1.
- Functional Unit 2 – Soil in all lots to a depth of 15 feet on Lots 1 through 4 (excluding the Acid Plant Area of FU-3 and FU-4, Figure 6-1). Soil in FU-2 has concentrations of metals and pesticides in soil that exceed criteria for direct exposure and LtGW pathways. This FU is a discrete soil volume with metals and pesticides, but no VOCs or DNAPL.
- Functional Unit 3 – Soil in Acid Plant Area and vicinity (Figure 6-1). FU-3 consists of soil to a depth of 15 feet in an area surrounding and riverward of the Acid Plant Area. FU-3 soil has similar contaminants as FU-2 soil (metals and pesticides), but it is a separate FU because there are VOCs in the soil, and it overlies the area where there is DNAPL in groundwater.
- Functional Unit 4 – Soil in Acid Plant Area (Figure 6-1). FU-4 consists of soil in the Acid Plant Area to a depth of 15 feet. Soil in FU-4 contains metals and pesticides at concentrations that exceed criteria for both direct exposure and LtGW pathways, VOCs in soil that exceed LtGW criteria, and DNAPL in soil. FU-4 overlies an area where there has been DNAPL in groundwater. The presence of DNAPL in the soil differentiates FU-4 from FU-3. FU-4 includes the former MPR Pond and overflow trench where spent chlorobenzene was disposed of.
- Functional Unit 5 – Shallow, Intermediate, and Deep Zone groundwater in Lots 1 and 2 (Figure 6-2). The Shallow and Intermediate Zone groundwater in Lots 1 and 2 of FU-5 contains VOCs, metals, furans, and dissolved VOCs in groundwater in all zones, and dissolved pesticides in the Shallow Zone. VOCs and some metals and pesticides in FU-5 are a trespassing plume from an upgradient source. Examples of trespasser contaminants include, but are not limited to, VOCs such as chlorobenzene, dichlorobenzenes, chloride and vinyl chlorides as discussed in the HSE (ERM 2021). The DEQ has not completed a formal trespass determination, but such determination may identify other trespass contaminants.
- Functional Unit 6 – Shallow, Intermediate, and Deep Zone groundwater in the riverside portion of Lot 3 that is not captured by the GWET system (Figure 6-2). FU-6 contains chlorinated VOCs and pesticides in Shallow Zone groundwater and chloride and metals in Shallow and Intermediate Zone groundwater. FU-6 is discrete from FU-5 and FU-8 because it includes a non-trespassing VOC plume that is not bound by the GWET extraction.
- Functional Unit 7 – Shallow, Intermediate, and Deep Zone groundwater in uplands portion of Lots 3 and 4 (Figure 6-2). FU-7 contains metals, pesticides, and furans in Shallow, Intermediate, and Deep Zone groundwater and chloride in Shallow and Intermediate Zone groundwater. FU-7 is discrete from FU-6 because it has no detected VOCs. Per the HSE, the presence of dieldrin (which was not produced at the site) in FU-7 indicates an offsite source.

- Functional Unit 8 – Shallow, Intermediate, and Deep Zone groundwater in the northern riverside portion of Lots 3 and 4, bound by the GWBW (Figure 6-2). FU-8 contains metals, chloride, VOCs, pesticides in the Shallow, Intermediate, and Deep Zones and furans in the Shallow Zone. FU-8 is a discrete unit from FU-10 because it has VOCs and is bound by the GWBW, but it does not have significant detections of perchlorate. Per the HSE, the presence of beta-BHC/HCH and heptachlor in groundwater is uncertain and is evidence of an offsite source.
- Functional Unit 9 – Shallow, Intermediate, and Deep Zone groundwater in the Acid Plant Area (Figure 6-2). The Shallow, Intermediate, and Deep Zones of FU-9 contain concentrations of metals, chloride, VOCs, and pesticides. The Shallow Zone of FU-9 additionally contains furans and DNAPL. FU-9 is a discrete FU because it has DNAPL in the Shallow Zone. Per the HSE, the source of heptachlor and endosulfan in groundwater is uncertain and is evidence of an offsite source.
- Functional Unit 10 – Shallow, Intermediate, and Deep Zone groundwater on the southern riverside portion of Lot 4, bound by the GWBW (Figure 6-2). FU-10 contains metals, chloride, perchlorate, pesticides, and VOCs in the Shallow, Intermediate, and Deep Zones. FU-10 is a discrete FU that includes most of the perchlorate plume.
- Functional Unit 11 – Gravel/Basalt Zone groundwater in Lots 3 and 4 (Figure 6-2). FU-11 contains metals, chloride, VOCs, pesticides, and furans in Gravel/Basalt Zone groundwater. FU-11 is a discrete FU because of hydrogeological differences between the Gravel/Basalt Zone and the overlying alluvial hydrostratigraphic units.
- Functional Unit 12 – Deep and Gravel/Basalt Zone groundwater in Lots 1 and 2 (Figure 6-2). FU-12 contains metals, chloride, VOCs, pesticides, and furans in the Deep and Gravel/Basalt Zone groundwater. This unit is a discrete FU due to the hydrogeologic differences between the Deep and Gravel/Basalt Zones and the shallow Zone. Contaminants including, but not limited to, VOCs (chlorobenzene, dichlorobenzenes, and vinyl chlorides) and some metals and pesticides in FU-12 are a trespassing plume from an upgradient source, as discussed in the HSE (ERM 2021). The DEQ has not yet completed a formal trespass determination. A trespass determination may identify other trespass contaminants and possible trespass plumes in other FUs.

6.6.2 Contamination from Historical Operations

The focus of technologies and alternatives in this FS is contamination resulting from historical operations and not naturally occurring COCs such as metals. Pre-design sampling and evaluations of the actual extent of COCs, and their fate and transport (i.e., potential for attenuation) will assess the need for and the design and sequencing of any remedial action.

6.6.3 Target Treatment Area, Depth, and Volumes

Areas and volumes used to calculate technology and alternative costs were delineated as the FUs (Section 6.6.1). Table 6-5 lists the areas and volumes of the FUs. For this FS, the target treatment areas and volumes were delineated based on the outline of the FUs, as depicted in the FU memo. It is likely conservative to use the FU areas and volumes as the treatment areas and volumes, as there are few datapoints for some constituents in some FUs and the data used are old and outdated. Additional data collected during remedial design will refine the treatment areas and volumes.

6.6.4 Hydraulic Influence of the Groundwater SCM

The groundwater SCM is an interim remedy to maintain hydraulic control of COCs in groundwater during development of an appropriate final remedy for the site (see Section 3.5).

Although the groundwater SCM is an important interim action, it was not envisioned to be the final/permanent treatment technology, and it will eventually be decommissioned. Ongoing performance evaluation of the groundwater SCM will assess its overall performance.

The remedial design will assess the effectiveness of the groundwater SCM to prevent unacceptable exposure in the river during implementation of the selected remedies and the benefits or conflicts between the groundwater SCM components (the GWBW and GWET system) and other objectives or elements of the remedy/remedies. Evaluation of the groundwater SCM performance against the RAOs during the remediation will identify when the GWET system can be turned off.

6.6.5 Bench and Pilot Testing of Treatment Technologies and Alternatives

The technologies being considered for the FUs may be implemented by several different process options. The technologies and alternatives evaluated in this FS reflect scientific and engineering experience. The complexity of the physical and geochemical characteristics of the site and contaminants, and the different process options of the technologies (e.g., treatment reagents, delivery options, and monitoring parameters) will require bench or field-scale testing to refine the technology, alternative, or final design. It is possible that significant deviation from the assumption in the evaluation in this FS could change the estimated costs of alternatives and even the ranking of alternatives.

The ROD should be written to identify broad remedial approaches. The remedial design will describe testing and analysis to refine the technologies and alternatives (also see Section 6.6.4).

6.6.6 Cleanup Times and Termination of Active Treatment

Cleanup times to achieve numerical RAOs or action levels vary substantially by media, contaminants, and treatment method. For example, excavation of hot spots in soil may take place over a short period after the remedy is selected and designed. If natural attenuation or bioremediation, is selected as a primary or polishing treatment based on protectiveness and balancing factors, it may take many years. In general, the alternatives recommended in this FS are measures to aggressively treat source areas and actual hot spots of contamination as technically practicable and cost effective. The alternatives in the FS are assembled in a manner that each phase has a post implementation evaluation process, so that any ensuing actions can be scoped, designed and implemented by an adaptive management approach. After source treatment, it is likely that natural attenuation and monitoring will demonstrate the remediation meets the numerical RAOs or action levels at a point of compliance.

The remedial design will provide methods to assess concentrations in soil or groundwater over time after completing active remediation. Periodic reviews will document concentration reductions. When COCs reach concentrations deemed protective (numerical RAOs or approved action levels) as demonstrated by methods and measures approved in the remedial design, then closure petitions will request termination of active treatment for applicable media or portions of the site.

6.6.7 Interface with In-Water Remedy

The primary exposure route to COCs in groundwater is by transport to and subsequent potential exposure in the river. Pre-design investigation and design of the in-water remedy are ongoing. Certain likely treatment technologies of the in-water remedy will interface with and support remediation of COCs that enter the porewater from upland groundwater. For example, partial dredging and capping of portions of the river bottom will remove contaminated sediment and mitigate transport of contaminants into the river water column. Such measures may also mitigate transport of and exposure to residual concentrations of COCs that enter the transition zone or sediment porewater from groundwater. Accordingly, the design of the upland remedy must consider possible elements of the in-water remedy.

Such analysis will be conducted by approaches described to develop action levels (Section 6.4.2) and described in technical memoranda written during the remedial design.

7. DEFINITION AND SCREENING OF CANDIDATE TECHNOLOGIES

7.1 Technology Screening Process

The Technology Screening Memo (ERM 2023) describes preliminary screening of treatment technologies. This section incorporates elements of the preliminary screening and incorporates the following concepts:

- RAOs (Section 6.1): Candidate technologies must be capable of meeting the RAOs under the site conditions. Additional assessment and testing may be necessary during remedial design to demonstrate technology effectiveness.
- Exposure point concentrations: The FS assumes that concentrations of COCs in groundwater are transported unattenuated to porewater in the river. Revisions to this concept will occur as part of the remedial design.
- Technology screening: Candidate technologies were identified and screened using the following sequence and tools.
    1. Identified applicable technologies from the USEPA's Contaminated Site Clean-Up Information (CLU-IN) database by COC and environmental media.
    2. Evaluated conceptual technologies under each balancing factor based on:
    - HCSM
    - Interim actions and ongoing remediation at the site and the effectiveness and applicability of those actions for additional remediation.
    - Analysis of similar technologies for similar sites.
    - The LSS project team's professional experience.
- FUs: The Functional Unit Delineation Memo (ERM 2022b) described the proposed FUs. The Technology Screening Memo described technologies for each FU.

The following sections describe and screen candidate technologies in consideration of the site conditions. Table 7-1 below describes and lists general response actions. Appendix B screens technologies based on qualitative evaluation of the five remedy-selection balance factors for each FU. Appendix B Table 7-2 is Table 1 of the FS interim deliverable (ERM 2023b).

7.2 General Response Actions

General response actions are broad remedial actions that will satisfy the RAOs. As specified in OAR 340-122-0085(2), general response actions must cover a range of options. Examples of general response actions include baseline action, engineering or institutional controls, treatment, or excavation and offsite disposal without treatment. The following general response actions are applicable to the Arkema site.

Table 7-1: Summary of General Response Actions

General Response Action	Definition (from DEQ, 1998d)
Baseline (no action)	A baseline alternative serves as a comparison to other potential remedial actions.
Engineering controls	Engineering controls are physical measures that prevent or minimize exposure to hazardous substances or reduce the mobility or migration of hazardous substances. Examples are fencing and physical barriers.
Institutional controls	Institutional controls are legal or administrative measures or actions that reduce exposure to hazardous substances. Examples are use restrictions, monitoring programs, and notifications.
Removal, treatment, and disposal	Removal is extraction of groundwater by pumping. Treatment is the elimination or reduction of toxicity, mobility, or volume of hazardous substances with the use of insitu or exsitu remedial technologies. Treatment can be performed on or offsite. For exsitu treatment, treated water is discharged to a suitable disposal system. Treatment can also include natural attenuation processes.

7.3 Technology Definitions

This section describes technologies that are considered for the alternatives developed in Section 8. The descriptions are common to applications in alternatives for various FUs. These detailed descriptions support alternative development and ranking in Section 8. Discussion of treatment technologies in this section and in Section 8 rely on DEQ's definition of treatment (DEQ 1998c): *Treatment is defined as the permanent and substantial elimination or reduction in the toxicity, mobility or volume of hazardous substances with the use of in situ or ex situ remedial technologies.*

7.3.1 Institutional Controls

Institutional controls are legal or administrative measures or site controls such as management plans and/or restrictions on land and water use or access. Institutional controls are not treatment, rather they are measures to provide notice and direct work and access so that the public or site workers are not exposed to unacceptable levels of contamination during or after implementing the remedy. Institutional controls are common elements to all the alternatives for the site (see Section 8.4)

7.3.2 Engineering Controls

Engineering controls are physical measures to prevent or minimize exposure to hazardous substances. Site controls are measures such as barriers, fencing, or signage that restrict access or warn of site conditions. The site is currently fenced and signed. Such measures are elements of the interim and future actions at the site.

7.3.3 Hydraulic Control

Hydraulic control refers to groundwater extraction or containment to minimize COC transport or exposure in groundwater. Although hydraulic control may be considered an engineering control, the site groundwater SCM, which includes both groundwater pumping and treatment (the GWET system) and a

GWBW, provides both hydraulic control and mass removal. In this context, the groundwater SCM is treatment. Hydraulic control and mass removal by the GWET system are integral to several groundwater FU alternatives discussed in Section 8.

Although the GWET system provides mass removal and treatment, the groundwater SCM is not a favoured long-term solution due to the low mass removal rate and high operation and management costs, as compared to other active or passive treatment technologies (e.g., reagent injections or a permeable reactive barrier [PRB]). Evaluations of alternatives in Section 8 consider the groundwater SCM as an interim treatment component of the groundwater FU alternatives. For example, the capture zone and the treatment processes of the GWET are considered in the evaluation of insitu chemical oxidation (ISCO) or insitu chemical reduction (ISCR) in the source area, because the resulting changes to groundwater conditions may influence operation and treatment of the GWET system.

7.3.4 Capping

A cap is a protective cover that limits infiltration of water and transport of contaminants and/or prevents direct contact with soil. Caps may be constructed of impermeable or semi-permeable materials, such as concrete, asphalt, geosynthetic liners, clay, and vegetative covers.

Caps are typically of minimum thickness and cover a target area to prevent or minimize human or ecological exposures, limit infiltration, and reduce erosion of contaminated soil. Capping is highly effective at preventing direct exposure and leaching to groundwater, depending on the capping material. Capping is reliable with proper maintenance and easy to implement. A cap is consistent with likely future site development for industrial use and is typically more cost effective than active treatment technologies.

Several existing caps cover large portions of the site. Existing caps consist of geosynthetic liner and gravel over the groundwater SCM extraction trench, compacted gravel, and foundations and pavement. Figure 7-1 shows existing caps. The existing caps are components of remedial alternatives for several soil FUs.

7.3.5 Excavation

Excavation is the mechanical removal of contaminated soil. Excavation is effective to minimize potential worker exposure and leaching to groundwater. Excavated soil may be treated onsite or disposed of offsite. Excavation is a common and proven technology, and it is readily implementable in most areas of the site.

The excavation design for site soil FUs will include selecting the appropriate area and depth of the excavation based on a suitable data set and developing appropriate dewatering, side slope stability, handling, transport, pre-treatment, and disposal options for the excavation.

Although excavation provides for a fast removal, it can be cost prohibitive for large volumes. For large excavations, large backfill volumes, transport costs, and disposal costs may not be cost effective. Excavation is effective and implementable to minimize potential worker exposures and to minimize leaching to groundwater. Excavation can be implemented as a stand-alone technology, or it can be used selectively to remove soil with the highest COC concentrations in combination with other technologies as part of an alternative.

Excavation may provide a reliable remedial option to some of the areas of the site, including FU-2 and FU-3. However, the presence of site infrastructure (e.g., the GWET system) may reduce the implementability of excavation on Lots 3 and 4.

7.3.6 Insitu Soil Flushing

Insitu flushing floods an area of contamination in soil with a flushing solution to remove the contaminants from the soil. Contaminants are first mobilized by dissolution, emulsification, or a chemical reaction with the flushing solution and then brought to the surface for treatment, disposal, recirculation, or reinjection.

Typically, insitu soil flushing uses water with surfactants to mobilize COCs. COCs are flushed from the soil into the groundwater, and the groundwater is then treated and reinjected in a closed loop system.

Effectiveness of soil flushing relies on uniform distribution of the flushing solution and a flushing solution that is suitable to the range of COCs (i.e., the ability to dissolve the COCs). Due to the complex combination of the COCs at the site, the large site area, and heterogeneous subsurface conditions, insitu soil flushing is not considered as a remedial technology in this FS.

7.3.7 Soil Vapor Extraction

Soil vapor extraction (SVE) refers to the application of a vacuum to unsaturated zone soil to induce airflow and remove VOCs and SVOCs (e.g., chlorinated ethenes/ethanes and petroleum hydrocarbons). SVE exploits the volatility of the COCs as the primary method of remediation. The SVE process induces a vapor pressure differential of COCs in soil, water, and soil gas.

The SVE process uses vapor extraction wells placed with screens in the vadose zone or around the contaminated soil. The vapor extraction wells are sealed at the surface and connected to a vacuum pump. An applied vacuum causes subsurface airflow to pass over COCs that are sorbed to soil or in solution in water films surrounding soil particles. Volatile COCs partition from the sorbed/liquid phases into the vapor phase and are recoverable by the vapor extraction wells. If the soil is initially saturated, it must be partially drained before there can be significant air flow and recovery of the volatile COCs. Low soil permeability and high soil moisture inhibit airflow and inhibit COC recovery by SVE.

SVE is usually limited to COCs with a boiling point less than 250 degrees Celsius (°C) and high vapor pressure (greater than 0.5 mm Hg). Those COCs with a Henry's Law constant of greater than 100 atmospheres tend to be removable from water by SVE, which does not include the larger class of pesticides and metals that are COCs at the site.

SVE implemented as an interim action (see Section 3.4.2) removed substantial mass of volatile COCs. Its effectiveness decreased over time, and the system has been decommissioned.

SVE would not be effective on the residual COCs or on pesticides or metals. Heterogeneity of fill and presence of silts and clays could result in short-circuiting or poor penetration of subsurface airflow, resulting in low effectiveness and low reliability of SVE at the site. SVE is not considered as a remedial technology in this FS.

7.3.8 Phytoremediation

Phytoremediation uses plants growing on contaminated soil to remove contamination. The term phytoremediation applies to many different techniques and applications, and there are several mechanisms by which plants can remove, immobilize, or degrade COCs.

Phytoremediation may enhance the degradation of organic contaminants such as pesticides and hydrocarbons by microbial activity associated with the plant roots that accelerates the transformation of contaminants into nontoxic forms. Insitu and exsitu phytoremediation of amenable COCs requires suitable soil, adequate nutrients, suitable soil moisture and temperature, and a compatible soil ecosystem. Phytotoxicity and mass transport limitations or bioavailability may limit effectiveness of phytoremediation.

Phytoremediation is not considered as a remedial technology in this FS because the technology has not been proven effective for the suite of COCs at the site.

7.3.9 Insitu Solidification and Stabilization

Insitu solidification and stabilization (ISS) refer to the introduction of reagent(s) into soil to mitigate the release of COCs into the surrounding groundwater. ISS reagents physically or chemically immobilize COCs. Most frequently, ISS is implemented by uniformly mixing a reagent into impacted soil to prevent leaching of the COCs from the soil into the surrounding groundwater. Bench-scale treatability studies are commonly needed to determine effective ISS reagents and mixtures.

Solidification contains the COCs in a monolith to limit water movement into or out of the contaminated soil volume. Examples of solidifying agents are Portland cement, slag, fly ash, and bentonite. Stabilization uses various physical and chemical mechanisms to sequester COCs by physical or chemical reactions between the COCs and the reagents themselves to minimize their mobility or bioavailability in groundwater. Examples of stabilizing agents are lime and activated carbon. Lime stabilizes heavy metals by creating insoluble and immobile metal oxide precipitates. Activated carbon strongly sorbs organic COCs or metals to prevent their movement.

Solidification and stabilization are commonly combined because the methods together both immobilize COCs and improve the engineering properties of the treated soil. For example, Portland cement is used in combination with ground granulated blast furnace slag[1] where Portland cement is a solidifying agent to minimize permeability and regain the load bearing capacity of the mixture and granulated blast furnace slag provides chemical stabilization. Because ISS is typically implemented using soil mixing, it is common to combine ISS with other insitu remedial technologies that also benefit from soil mixing.

The effectiveness of ISS depends on the site conditions and the COCs. The design of ISS must consider the suitability of the reagent for the soil type and the COC, the reagent dose, the application rate, the cure time, the potential for transport of unreacted COC, the degradation rate of the reagent (if applicable), and the potential need to reapply the reagent. A critical cost consideration of ISS is the targeted depth of delivery, which dictates the implementation equipment and the implementation time. For example, conventional construction equipment working on moderate and stable slopes may accommodate delivery depths of up to 15 to 20 feet, whereas deeper ISS applications typically require longer and larger-diameter augers to distribute the reagents. Accordingly, deeper applications require larger equipment and more time and are, therefore, more expensive.

ISS is a viable treatment technology for several of the FUs, either by itself or in combination with other treatment technologies. Treatability studies will be required to determine effective ratios of ISS reagents.

7.3.10 Insitu Chemical Oxidation

ISCO is a technology that delivers chemical oxidants to contaminated media. The most common chemical oxidants are permanganate, persulfate, and hydrogen peroxide. ISCO can treat a wide range of COCs, including chlorinated ethenes and ethanes, petroleum hydrocarbons and their constituents, 1,4-dioxane, explosives and related chemicals, pesticides, phenols, among others. ISCO can also treat non-aqueous phase liquids (NAPLs).

Advanced oxidation is a form of ISCO that delivers a catalyst (e.g., iron or base) to activate chemistry capable of oxidizing more recalcitrant COCs (e.g., pesticides, 1,4-dioxane, and chlorinated alkanes).

[1] GBFS consists mainly of silicates, aluminosilicates of calcium and 4 percent of sulfate ion (SO_3^-), which provides the reducing power and the structure to stabilize and immobilize metals.

Advanced oxidation requires an oxidant, dosing, and activation catalyst (if needed) that are suitable to the COCs, since not all COCs can be treated effectively by all oxidants.

The effectiveness of ISCO depends on effective distribution of the oxidant in soil or groundwater and adequate contact time. Design considerations typically include the COCs to be treated, the lithology and associated soil chemistry, hydraulic conductivity of the formation, and the delivery method of the chemical oxidant to achieve maximum contact time with the COCs. Repeat application of oxidant and the activation catalysts typically are necessary to achieve the target goals.

Delivery methods for liquid oxidants include direct push, groundwater recirculation through horizontal or vertical extraction and injection wells, soil mixing, or a combination of these. Hydraulic fracturing can improve reagent delivery in low-permeability media. Regardless of the delivery method, repeat additions of the oxidants are typically necessary to achieve remedial goals.

Coupling ISCO with ISS by soil mixing both destroys and immobilizes COCs, thereby increasing certainty of treatment in a target treatment zone, and some ISS agents can activate ISCO oxidants. For example, when persulfate is combined with cement, the basic pH of cement can activate persulfate.

The oxidizing conditions generated by ISCO may change the ambient geochemistry that can temporarily mobilize certain metals, (e.g., chromium) and create secondary water quality concerns. These issues can be considered during treatability testing and managed by the design and implementation. Also, many ambient metals or other soil constituents may react under the oxidized conditions as nontargeted (“scavenging”) reactions. Such nontargeted reactions may result in short-term exceedances of relevant water quality criteria (e.g., chloride can be oxidized to chlorate or perchlorate under strong oxidizing conditions).

ISCO can stabilize certain metals arsenic indirectly. Geogenic iron forms oxyhydroxide solids with positive surface charges that sorb arsenic oxyanions. The solubility, mobility, and toxicity of arsenic in the environment depends on its oxidation state.

ISCO and ISS are candidate technologies for both soil and groundwater FUs. The choice of ISCO amendments should consider the target COCs, lithology, soil chemistry, and hydraulic conductivity. The specific conditions will influence selection of the delivery method needed to achieve necessary mixing and contact time between the amendment and the COCs. Coupling ISCO with ISS may improve treatment and reduce mobility of COCs. Mechanical and hydraulic mixing and direct push delivery will be considered. A bench-scale treatability study will be necessary to test and optimize an ISCO remedy, specifically focusing on the natural oxidant demand (i.e., scavenging of the chemical oxidant by nontargeted reactions) and secondary water quality concerns.

7.3.11 Insitu Chemical Reduction

Insitu chemical reduction (ISCR) refers to abiotic transformation of COCs using chemical reductants, typically through iron- or sulfur-based chemistries. Common chemical reductants include zero valent iron (ZVI), zero valent zinc (ZVZ), ferrous iron minerals, bi-metallic materials, polysulfide, dithionite, and other proprietary commercial materials such as furnace slag or iron scrap.

The ISCR technology is effective on chlorinated compounds (e.g., chlorinated solvents such as trichloroethene [TCE]), certain oxidized metals (e.g., hexavalent chromium or Cr^{6+}), explosives (e.g., trinitrotoluene [TNT], hexogen [RDX], and octogen [HMX]), and oxidized inorganics (e.g., perchlorate). ISCR can dechlorinate pesticides but may require natural attenuation or enhanced natural attenuation of dechlorinated intermediate compounds. ISCR can be combined simultaneously or sequentially with ISS by mixing amendments into soil. Hybrid amendments that combine ZVI emulsified in a carbon substrate are also used to treat chlorinated compounds. The carbon substrate creates strong reducing conditions to drive chemical reduction and biotic reductive dechlorination.

ISCR is used for soil and/or groundwater remediation and can treat dissolved COCs and halogenated DNAPLs. ISCR can be implemented using permeable reactive barriers (to intercept contaminant plumes), direct injection (with and without soil fracturing), or by mixing chemical reductants into the subsurface soil.

ISCR/ISS is a candidate technology for both soil and groundwater FUs using mechanical and hydraulic mixing and direct push injection. A bench-scale treatability study will be necessary to test and optimize an ISCR remedy, specifically focusing on the ambient geochemistry and any potential secondary water quality concerns.

7.3.12 Permeable Reactive Barrier

A PRB is a barrier of reactive media in a constructed trench, a series of overlapping borings, or grouped injection points to create a permeable "wall" oriented perpendicular to the direction of groundwater flow. The reactive media immobilizes or degrades dissolved-phase COCs within or near the PRB as the contaminated groundwater passes through the barrier. PRBs are designed to treat COCs by physical, chemical, and/or biological processes simultaneously or sequentially. Reactive media are selected for the COCs and for the characteristics of the water-bearing zone. Examples of PRB reactive media for site COCs include ZVI, zeolite, apatite, and activated carbon to address the range of VOCs, dioxins, pesticides, chloride, and metals. PRBs may include the combination of two or three media types.

A PRB is designed to accommodate passive groundwater flow through the reactive media. The permeability of the emplaced reactive media must be equal to or greater than the formation. The porosity and compaction of the emplaced media may influence the groundwater flux through the PRB and the achievable contact time. The design of a barrier uses the calculated flow velocity through the barrier and the anticipated reaction kinetics to determine the required residence time, mass of reactive media, and the width of the barrier.

PRBs are a candidate technology for groundwater FUs. Bench testing during the remedial design would assess effectiveness of the various reactive media. Hydrogeological testing, such as piezometric gauging or tracer testing, may also be necessary to assist the PRB construction in being undisruptive to the ambient groundwater flux.

7.3.13 Enhanced Aerobic/Anaerobic Bioremediation

Enhanced bioremediation refers to enhancement of the activity of naturally occurring or deliberately introduced microorganisms to break down COCs in the subsurface. The biodegradation metabolic pathway may use the COC as a source of electrons (anaerobic pathway) or as a terminal electron acceptor (aerobic pathway). In co-metabolism, biodegradation of a non-target chemical also breaks down the target COC. The state of practice of bioremediation technologies, in combination with physical and chemical treatment methods, is evolving.

Microorganisms can convert many organic COCs to carbon dioxide and water in the presence of sufficient oxygen, moisture (aerobic conditions), and nutrients. Enhanced aerobic bioremediation optimizes conditions for aerobic biodegradation by providing supplemental oxygen (chemically or physically), nutrients, or other amendments to soil or groundwater. Since biodegradation reactions occur in solution, enhanced aerobic bioremediation of COCs in soil requires adequate soil moisture. Enhanced aerobic bioremediation of unsaturated soil typically includes delivery of supplemental oxygen, water, and nutrients. Acclimated microorganisms may also be added (i.e., bioaugmentation). An infiltration gallery or spray irrigation may be used to deliver amendments and oxygen to shallow contaminated soils, and injection wells are typically used for deeper contaminated soils and groundwater.

Under anaerobic conditions, organic contaminants are converted to methane, limited amounts of carbon dioxide, and trace amounts of hydrogen. A range of anaerobic microorganisms use nitrate, iron, manganese, sulfate, and carbon dioxide as a terminal electron acceptor. Biodegradation under anoxic conditions is referred to as anaerobic bioremediation and uses a supplied electron donor (such as a carbohydrate) and the COC as the intermediate electron acceptor to transform the COC to a benign product. Enhanced anaerobic biodegradation involves adding hydrogen or creating anoxic conditions by adding reductants in soil and groundwater to support the growth and vitality of the indigenous anaerobic bacteria.

Design conditions for either aerobic or anaerobic bioremediation include homogeneous distribution of microorganisms, electron donor, electron acceptor, and nutrients. There are many other geochemical considerations that can be tuned to optimize bioremediation, such as temperature, pH, and salinity. Insitu bioremediation is an effective and efficient technology to address low levels of COCs. As such, there are numerous strategies and products to facilitate bioremediation of a wide range of COCs.

A two-step approach that alternates aerobic and anaerobic mechanisms or combines technologies with bioremediation may be successful on certain classes of contaminants. Anaerobic bioremediation enhanced with ISCR is an effective remedial approach for pesticides, chlorinated hydrocarbons, dioxins, and stabilization of metals (Cr -VI), followed by enhanced aerobic bioremediation. For example, the anaerobic stage may include augmenting aerobic bacteria under anaerobic conditions and then injecting oxygenated water to polish degradation byproducts such as benzene.

Enhanced anaerobic and aerobic bioremediation is a candidate technology to treat chlorinated VOCs (chlorobenzene), pesticides, and dioxins in groundwater. Bench-scale and/or pilot-scale testing will be necessary to validate this approach.

7.3.14 Insitu Thermal Treatment

Insitu thermal remediation uses heat to enhance recovery and/or destruction of COCs from soil or groundwater. Insitu thermal remediation may mobilize COCs via steam or hot air injection, volatilize COCs that are in solution or sorbed to soil particles, or thermally destroy organic COCs. Operating temperatures of commercial soil treatment systems can reach as high as 500 to 650 °C. Thermal treatment may alter the physical and chemical properties of the soil, which can influence the leachability of co-contaminants such as heavy metals.

Insitu thermal treatment is a general term used for three different technologies that are routinely implemented, including:

- Electrical resistance heating (ERH)
- Thermal conduction heating (TCH)
- Steam enhanced extraction (SEE)

Thermal technologies can accomplish steam stripping, volatilization, and boiling of VOCs and SVOCs from soils and groundwater. Insitu thermal treatment requires vapor recovery and aboveground treatment of recovered gases and liquids. The overall objective of insitu thermal treatment is to increase the vapor pressure, solubility, and diffusion rates while decreasing the viscosity of liquid contaminants, separating them from the environmental media, and collecting the liberated COCs for aboveground treatment.

Insitu thermal treatment is a common component of a remedy treatment train or phased approach, with the thermal technology used to treat NAPL and the highest concentrations and other technologies (such as groundwater extraction and treatment, insitu bioremediation, or ISCO/ISCR) used as polish treatments for the lower residual concentrations. In such cases, the residual heat from thermal remediation may also enhance the performance of biodegradation or some forms of chemical oxidation.

Insitu thermal treatment is a candidate technology for treating soil in FU-4. Due to the complex suite of COCs at the site, and the complex hydrostratigraphy, insitu thermal treatment is not considered for other FUs. While field-scale treatability testing is neither cost- nor scale-efficient, bench-scale testing is typically required to support a formal design and would be considered during the remedial design.

7.3.15 Monitored Natural Attenuation

Monitored natural attenuation (MNA) relies on intrinsic biotic and abiotic processes to decrease or “attenuate” COCs in soil and groundwater. Natural attenuation is a prescribed treatment approach under USEPA guidance that requires monitoring to demonstrate the mechanisms, progress, and rate of contaminant attenuation. MNA uses analysis of geochemical parameters and degradation trends to validate the degradation process and rate. If analyses indicate unfavourable geochemical conditions, an unacceptable remediation timeframe, or statistically significant increasing trends, active treatment may be required. It is common that MNA is a polishing step for active treatment for residual concentrations of COCs in soil or groundwater. The anticipated clean up time for MNA must be reasonable compared to other treatment approaches. MNA is a cost-effective cleanup method, as it requires minimal equipment, construction, and labor.

MNA is a likely polishing step to achieve numerical RAOs or action levels. MNA is a specific stand-alone alternative in some FUs.

8. DEVELOPMENT AND RANKING OF REMEDIAL ACTION ALTERNATIVES

This section describes development and ranking of remedial action alternatives. Section 6 describes details of remedial action scoping criteria.

8.1 Alternatives Development Process

This FS develops remedial action alternatives using engineering judgement, vendor expertise, and understanding of the site characteristics and limitations of the proposed technologies. Developing several alternatives for each FU provides a range of treatment strategies to identify the most appropriate remedial action for each FU. The alternative development process considered how alternative remedial actions in adjoining FUs would interact with one another the across FU boundaries.

8.2 Evaluation of Remedial Action Alternatives

This section evaluates each remedial action alternative both individually and comparatively to identify the alternative that best satisfies the evaluation criteria. The comparative evaluation ranks the alternatives to identify which alternative best balances the selection factors and provides the best comprehensive approach.

Remedial action alternatives developed below were evaluated and compared to identify a preferred alternative for each FU. Although the FU concept is useful in the FS to identify technologies and alternatives for areas of the site with similar conditions, the FU concept will not be used in remedial design.

This section describes the evaluation criteria, evaluates, compares, and recommends and alternative for each FU. each alternative, of remedial action alternatives, including:

8.2.1 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]). The remedy selection balancing factors are discussed further in Section 6.5.

8.2.2 Detailed Evaluation of Remedial Action Alternatives

Tables in the alternatives ranking sections below rank alternatives based on the remedy selection balancing factors. The alternatives are ranked 1 to 5 for each of the evaluation criteria, except for cost.

- A ranking of 1 indicates poor potential for an alternative to satisfy the criterion.
- A ranking of 3 indicates moderate potential for an alternative to satisfy the criterion.
- A ranking of 5 indicates high potential for an alternative to meet the criterion.

For example, Alternative 3 for FU-5 is an excavated ISCR PRB along the riverbank of the FU. An excavated ISCR PRB would likely be effective to prevent transport of COCs to the river and would likely be reliable to mitigate long-term exposure. Alternative 3, therefore, ranks high for effectiveness and long-term reliability (5 and 4, respectively). However, constructing an excavated barrier would require considerable planning and is relatively more difficult to construct. This alternative, therefore, scores lower for implementability (rating of 3). An excavated barrier poses implementation risk due to the size of the excavation, the need to mobilize equipment, and the proximity of the excavation to the riverbank, and implementability is rated as 3.

The sum of numerical ratings is the ranking subtotal. The alternatives with the lowest ranking subtotals were not carried forward to costing analysis. NPV costs were estimated for the alternatives with the highest-ranking subtotals. The preferred alternative is a high-ranking alternative with the lowest cost (i.e., the most cost effective). The most cost-effective alternative is the preferred alternative.

8.3 Cost Sensitivity Analysis

Uncertainties in site conditions and the corresponding assumptions about the scope and process options of alternatives lead to variability and uncertainty in the cost estimates. The results of pre-design investigations and testing could substantially modify the assumptions required by the DEQ in this FS, allowing modifications in the scope of the alternatives for a protective remedy. Given the cost uncertainties, after identifying the most cost-effective alternative for an FU, a cost sensitivity analysis was performed to develop low, medium, and high cost estimates for the preferred alternatives. Appendix A provides the cost ranges for the preferred alternatives.

8.4 Actions Common to Alternatives

The preferred alternatives build around treatment technologies. In addition to the treatment technologies, the following actions are common to the alternatives.

8.4.1 Pre-Design Investigation

After the DEQ selects a remedy, a pre-design investigation will assess the current nature and extent of contamination. The data will be used to refine the nature and extent of contamination in soil and groundwater within the LOF and update the layout and details of preferred alternatives for the refined nature and extent of contamination. Workplans will describe the scope and objectives of the pre-design investigations.

8.4.2 Institutional Controls

Institutional controls are legal or administrative measures such as management plans and restrictions on land and water use. Institutional controls are not treatments, rather they are legal or administrative measures to provide notice and control work and access to prevent or minimize exposure to contamination during implementation of the remedy. Institutional controls are common to all of the alternatives and will be implemented as needed as part of the remedial actions.

8.4.3 Engineering Controls

Engineering controls are physical measures to prevent or minimize exposure to hazardous substances. Site controls are measures such as fencing. Such measures are elements of the existing interim measures and future remedial actions at the site. Most of the site is currently fenced and signed.

8.4.4 Performance Monitoring, Reporting, and Periodic Review

Monitoring will demonstrate the performance of the remedies. The remedial design will develop the scope of the monitoring program, frequency of reporting, and measures of success.

8.4.5 Residual Risk Assessment

Performance monitoring, reporting, and periodic review will demonstrate residual risk (see Section 5.1.4) and will be the basis for site closure. The remedial design will specify details of the residual risk assessment.

8.5 Functional Unit 1: Riverbank Soil

FU-1 will be addressed under the ASAOC for River Mile 7 West. This FS does not consider alternatives for the riverbank.

8.6 Functional Unit 2: Sitewide Surface and Near-surface Soil

An engineered cap and institutional controls (Alternative 3) is the preferred alternative for FU-2 (see below for ranking). Figure 8-1 shows the extent of an engineered cap for Alternative 3 of FU-2. All the FU-2 alternatives include the institutional control for long term vegetation maintenance to prevent ecological habitat. The alternatives for FU-2 are discussed below.

8.6.1 Alternative 1: No Action

Alternative 1 is no action for the soil in FU-2.

8.6.2 Alternative 2: Excavation

Alternative 2 is excavation of the approximate top 3 feet of contaminated soil in the FU to reduce direct contact risk to human receptors and reduce potential the leaching to groundwater, if any. The depth of the excavation would vary by depth of COCs, which would be determined in pre-design investigations and remedial design. Alternative 2 has two sub-options detailed below. Alternative 2a and 2b assume excavation of the top 3 feet of soil. The remedial design would be determined in remedial design and incorporate pre-design assessment of leachability.

8.6.2.1 Alternative 2a: Offsite Disposal

Alternative 2a assumes that soil would be characterized and disposed of offsite as state-only hazardous waste, and the excavation would be backfilled with clean fill.

8.6.2.2 Alternative 2b: Onsite Treatment and Backfill

Alternative 2a assumes that soil would be either consolidated and managed onsite or treated and backfilled.

8.6.3 Alternative 3: Capping

Alternative 3 is an engineered cap and institutional controls to maintain the cap and protect onsite workers. Section 7.3.3 discusses different types of caps. Capping options include concrete, asphalt, geosynthetic liners, clay or vegetative covers, compacted aggregate, and clean gravel cap. Alternative 3 assumes an engineered cap consisting of compacted aggregate (i.e., clean gravel), similar to the gravel cap that exists across much of the site. The existing gravel cap was installed as part of stormwater and groundwater SCMs that were implemented in 2012 to 2015. A compacted aggregate cap would reduce direct exposure risks and slow infiltration to minimize leaching to groundwater, if any. Approximately 80 percent of the FU-2 is currently covered by either paving, clean gravel cap, or historical building foundations that will remain in place as part of the cap. Figure 8-1 shows the extent of an engineered cap on FU-2.

Capping would be implemented in phases to assess the need for and performance of other remedies (e.g., in-situ injections, excavated PRBs). The existing gravel caps would be maintained until performance data demonstrate that additional caping (or no additional capping) is needed. The stormwater SCM features (i.e., drainage trenches, detention pond, and sand filter) would also be retained. Additional site grading may be necessary to maintain drainage to the existing stormwater system.

8.6.4 Alternative 4: Institutional Controls, Focused Excavation

Alternative 4 is excavation of direct exposure hot spots. Alternative 4 assumes that the only direct-exposure hot spots are those identified in the HSE, and those hot spots would be further refined during remedial design. Alternative 4 has two sub-options detailed below.

8.6.4.1 Alternative 4a: Offsite Disposal, and Capping

Similar to Alternative 2a, Alternative 4a assumes that the excavated soil would be characterized and disposed of offsite as state-only hazardous waste. The remainder of the FU would then be capped, as described for Alternative 3.

8.6.4.2 Alternative 4b: Onsite Treatment/Disposal, and Capping

Similar to Alternative 2b, this soil would be either consolidated and managed onsite or treated and backfilled. Costing for Alternative 4b assumes the soil to be consolidated and managed onsite, and the excavation backfilled with clean fill. The remainder of the FU would then be capped using the same assumptions from Alternative 3.

8.6.5 Alternative 5: Institutional Controls, Focused Excavation, ISCO

Alternative 5 is excavation of direct-exposure hot spots as in Alternative 4. After excavation, FU-wide tilling with amendments would either treat the COCs or modify the soil so that the contaminants are less mobile. No cap would be applied to the site in this alternative.

8.6.6 Functional Unit 2 Alternatives Ranking Summary

Table 8-1 summarizes ranking of alternatives for FU-2.

Table 8-1: FU-2: Sitewide Surface and Near Surface Soil

	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
Alternatives	**Effectiveness**	**Long-term Reliability**	**Implement-ability**	**Implementation Risk**	**Ranking Subtotal**	**Cost (NPV)**	**Preferred**
Alternative 1: No Action	1	1	5	5	12	—	
Alternative 2a: Excavation and Offsite Disposal	5	5	1	2	13	—	
Alternative 2b: Excavation and Onsite Treatment and Backfill	4	4	1	2	11	—	
Alternative 3: Institutional Controls and Capping	4	4	4	4	16	$2.2 M	X
Alternative 4a: Institutional Controls and	5	5	4	4	18	$11.4 M	

Alternatives	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
	Effectiveness	Long-term Reliability	Implement-ability	Implementation Risk	Ranking Subtotal	Cost (NPV)	Preferred
Focused Excavation with Offsite Disposal and Capping							
Alternative 4b: Institutional Controls and Excavation with Onsite Treatment or Disposal and Capping	5	4	4	3	16	$5.0 M	
Alternative 5-Institutional Controls, Focused Excavation, ISCO	4	3	3	3	13	—	

Notes:
X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.

8.6.6.1 Comparative Analysis

Costs were not developed for Alternatives 1, 2a, 2b, and 5 due to their low-ranking subtotals. The HSE dataset indicate that no-action would not be protective of the direct-exposure pathway. Alternatives 2a and 2b scored poorly in implementability and implementation risk due to the difficulty of excavating a large area near the river and the associated safety risks.

Alternative 3 has a lower Alternative effectiveness ranking than Alternatives 4a and 4B due to leaving contaminants in place rather than excavating the hot spots. However, the engineered cap of Alternative 3 would be effective engineered to prevent leaching to groundwater and direct exposure.

The retained options were costed to an estimated -30 to +50 percent accuracy based on professional experience and consultation with vendors and contractors. Appendix A includes cost estimating details.

***8.6.6.2** Recommended Alternative*

Due to the advantages of not excavating the direct-exposure hot spots, Alternative 3 Institutional Controls and Capping is the preferred alternative. Due to the uncertainty of the design basis, a range of cost estimates were developed for the recommended alternative, consisting of the following:

- Low Cost - Existing cap maintenance only
- Medium Cost - Maintain existing cap with compacted gravel capping added to 20 percent of the site (assumed remedy for comparative analysis)
- High Cost - Maintain existing caps and enhance with geotextile-lined cap added 20 percent of the site

Appendix A includes the cost estimates and assumptions. Pre-design investigations would minimize the uncertainty, and the remedial design would develop the details of the remedy and phasing of implementation.

8.6.7 Functional Unit 3: Acid Plant Vicinity Surface and Near-Surface Soil

An engineered cap (Alternative 5) is the preferred alternative for FU-3 (see below for ranking). Figure 8-2 shows the extent of an engineered cap for Alternative 5 of FU-3. The alternatives for FU-3 are discussed below.

8.6.8 Alternative 1: No Action

Alternative 1 is no action for the soil in FU-3.

8.6.9 Alternative 2: Excavation, Backfill

Both Alternatives 2a and 2b include the excavation and backfill of the soil throughout the FU to address direct exposure and leaching to groundwater pathway risks. For the purpose of this FS, LSS assumes that depth of excavation would be limited to the near surface soil (i.e., 5 feet bgs). An additional objective of the soil excavation in FU-3 is to remove potential subsurface debris and obstructions to allow for insitu treatment program implementation in FU-8 and FU-9. The actual depth of the excavation could potentially be deeper than 5 feet bgs. The depth of the excavation would be determined in the pre-design investigation and remedial design, and incorporate any data collected to determine leachability.

8.6.9.1 Alternative 2a: Offsite Disposal

The excavated soil would be properly characterized and disposed of offsite, and the excavation would be backfilled with clean imported fill. Costs assume that the soil would be characterized as state-only hazardous waste. Large subsurface obstructions would be removed and disposed of offsite as non-hazardous waste.

8.6.9.2 Alternative 2b: Onsite Treatment

The excavated soil would be treated onsite using soil amendments and would be used as backfill in place of clean imported fill. Large subsurface obstructions would be removed and disposed of offsite.

8.6.10 Alternative 3: ISCO or ISCR and ISS (only if used in FU-8 and FU-9)

Alternative 3 is only an option for FU-3 if ISCO or ISCR and ISS is also being utilized in FU-8 or FU-9. It includes auger mixing the entire vadose zone from the top of the Shallow Zone up to the surface and includes stabilization using cement or other solidification methods. This alternative would likely require excavation of the top three feet of soil for implementability. Costs assume that ISCR reagents would be used in the applications on the periphery of the mixed area.

8.6.11 Alternative 4: Thermal and Capping

Alternative 4 is thermal treatment of the shallow vadose zone, followed with capping to remove any further leaching to groundwater and direct exposure risks. Section 7.4 discusses different types of caps. Capping options include concrete, asphalt, geosynthetic liners, clay or vegetative covers, compacted aggregate, and clean gravel cap. Alternative 4 assumes an engineered cap consisting of compacted aggregate (i.e., clean gravel), similar to the gravel cap that exists across much of the site.

8.6.12 Alternative 5: Capping

Alternative 5 is an engineered cap and institutional controls to maintain the cap. Similar to Alternative 4, this alternative assumes that a compacted aggregate cap would be used. Additionally, approximately 70 percent of FU-3 is currently covered by either existing paving, aggregate cap with HDPE liner or historical foundations that would remain in place as part of the cap.

8.6.13 Functional Unit 3 Alternatives Ranking Summary

Table 8-2 summarizes ranking of alternatives for FU-3.

Table 8-2: FU-3: Acid Plant Vicinity Surface and Near-Surface Soil

	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
Alternatives	**Effectiveness**	**Long-term Reliability**	**Implement-ability**	**Implementation Risk**	**Ranking Subtotal**	**Cost (NPV)**	**Preferred**
Alternative 1: No Action	1	1	5	5	12	—	
Alternative 2a: Excavation, Backfill, and Offsite Disposal	5	5	2	2	14	—	
Alternative 2b: Excavation, Backfill, and Onsite Treatment	4	4	2	2	12	—	
Alternative 3: ISCO or ISCR and ISS	4	4	4	4	16	$4.6M	
Alternative 4: Thermal and Capping	3	3	3	3	12	—	
Alternative 5: Capping	3	3	5	4	15	$0.8M	x

Notes:
X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.

8.6.13.1 Comparative Analysis

Historical data indicate that no-action is not protective of receptors in the river, and in FU-3, is also not protective against direct exposure risk. Therefore, Alternative 1 was screened out due to not meeting the remedial action objectives. Alternatives 2a, 2b, and 4 were screened out based on their low-ranking subtotals. Low ranking in 2a and 2b were largely due to the high risk of implementing such a large-scale excavation as a remedy and the lowered implementability due to the FU's location in close proximity to areas with large subsurface debris and obstructions, and soil with asbestos-containing material. Alternative 4, while not containing any "poor" scores, scored poorly overall due to not being particularly advantageous in any single category.

Alternatives 3 and 5 were carried forward into costing. Disadvantages to Alternative 3 include no likely feasible contingency options after this step is performed due to the creation of a large subsurface monolith. A similar ISS remedy to Alternative 3 was considered for groundwater contamination and DNAPL in FU-8 and FU-9. The interface and sequencing of the alternatives considered in FU-3 are detailed further in Section 9.

The two retained options were costed to an estimated -30 to +50 percent accuracy based on professional experience and consultation with vendors and contractors. Alternative 5 was more cost effective. Appendix A includes the cost estimates.

8.6.13.2 Recommended Alternative

Alternative 5 is the recommended alternative for FU-3. Alternative 5 adequately addresses both leaching to groundwater risks and direct exposure risks for the highest implementability and cost effectiveness. Due to the uncertainty of design basis, a range of cost estimates were developed for the recommended alternative, consisting of:

- Low Cost - Existing cap maintenance only
- Medium Cost - Maintain existing cap with compacted gravel capping added to 30 percent of the FU-3 area (assumed remedy for comparative analysis)
- High Cost - Maintain existing caps and enhance with geotextile-lined cap added 20 percent of the site.

Appendix A includes the cost estimates and assumptions. Pre-design investigations would minimize the uncertainty, and remedial design would develop the size of the cap, cap design, and phasing of capping.

8.7 Functional Unit 4: Acid Plant Area Surface and Near-Surface Soil

ISCO or ISCR/ISS (Alternative 5) is the preferred alternative for FU-4 (see below for ranking). Figure 8-2 shows the extent ISCO or ISCR/ISS for Alternative 5 of FU-4. The alternatives for FU-4 are discussed below.

8.7.1 Alternative 1: No Action

Alternative 1 is no action for the soil in FU-4.

8.7.2 Alternative 2: Excavation, Backfill

Alternatives 2a and 2b include the excavation and backfill of the soil throughout the FU to address direct exposure, leaching to groundwater pathway risks, and highly mobile (i.e., DNAPL) risks. This alternative assumes that the depth of the excavation from ground surface to the top of the Shallow Zone would be approximately 15 feet bgs. An additional objective of the soil excavation in FU-4 is to remove potential subsurface debris and obstructions to allow for insitu treatment program implementation in FU-8 and FU-9. Large subsurface debris and obstructions would be removed and disposed of offsite as non-hazardous waste. The actual depth of the excavation would be determined in the pre-design investigation and remedial design.

8.7.2.1 Alternative 2a: Offsite Disposal

All excavated soil would be characterized and disposed of offsite, and the excavation would be backfilled with clean imported fill.

8.7.2.2 Alternative 2b: Onsite Treatment

The excavated soil would be treated onsite using a soil amendment and would be used to backfill.

8.7.3 Alternative 3: Focused Excavation, Backfill, and Cap

Alternative 3 is excavation of the MCB recovery unit DNAPL plume to the top of the Shallow Zone to remove the soil NAPL as a source. The DNAPL-impacted soil would then be disposed offsite as listed hazardous waste. The excavation would be backfilled with clean fill, and then capped to address potential residual leaching to groundwater risks. For the purpose of this FS, the cost for both disposal of the soil as hazardous waste and state-only hazardous waste are calculated.

8.7.4 Alternative 4: Shallow Excavation, Backfill, and Cap

Alternative 4 is shallow excavation (i.e., to maximum depth of the entire FU to remove NAPL direct exposure risks). The soil would then be disposed of at Roosevelt Landfill, Washington. The excavation would be backfilled with clean fill, and the FU would then be capped to address potential residual leaching to groundwater risks. The depth of excavation is assumed to be 5 feet bgs. However, the depth of the excavation would be determined in the pre-design investigation and remedial design.

8.7.5 Alternative 5: ISCO or ISCR and ISS (only if used in FU-8 and FU-9)

Alternative 5 is only feasible in FU-4 if this technology is also being utilized in FU-8 or FU-9. It includes auger mixing up to surface and likely includes stabilization using Portland cement and slag or other solidification methods. This alternative would likely require excavation of the shallow surface soil and removal of subsurface debris and obstructions for implementability. Costs assume application of ISCR reagents along the periphery of the application zone. Additionally, estimates assume costs are shared between ISS alternatives in FU-9 and this alternative.

8.7.6 Alternative 6: Thermal and Capping

Alternative 6 is thermal treatment of the DNAPL followed by capping to address residual risks. Consistent with FU-2 and FU-3, this Alternative assumes that the cap would consist of a compacted aggregate layer.

8.7.7 Alternative 7: Capping

Alternative 7 is an engineered cap and institutional controls to maintain the cap. Section 7.4 discusses different types of caps. Capping options include concrete, geosynthetic liners, clay or vegetative covers, and compacted aggregate. Similar to Alternative 6, this Alternative the cap would consist of a compacted aggregate layer. Approximately 70 percent of FU-4 is currently capped by either paving, aggregate cap with HDPE liner, or historical building foundations that would remain in place.

8.7.8 Functional Unit 4 Alternatives Ranking Summary

Table 8-3 summarizes ranking of alternatives for FU-4.

Table 8-3: FU-4: Acid Plant Area Surface and Near-Surface Soil

Alternatives	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
	Effectiveness	Long-term Reliability	Implement-ability	Implementation Risk	Ranking Subtotal	Cost (NPV)	Preferred
Alternative 1: No Action	1	1	5	5	12	—	
Alternative 2a: Excavation, Backfill, and Offsite Disposal	5	5	1	2	13	—	
Alternative 2b: Excavation, Backfill, and Onsite Treatment	4	4	1	2	12	—	
Alternative 3: Focused Excavation, Backfill, and Offsite Disposal	4	4	4	3	15	\$7.4M (Haz) \$3.6M (non-Haz)	
Alternative 4: Shallow Excavation, Backfill, and Offsite Disposal	3	3	4	4	14	—	
Alternative 5: ISCO or ISCR and ISS	4	4	4	4	16	\$2.2M	X
Alternative 6: Thermal and Capping	3	3	3	3	12	—	
Alternative 7: Capping	3	3	4	5	15	\$1.2M	

Notes:
X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.

8.7.8.1 Comparative Analysis

Historical data indicate that no-action is not protective of receptors in the river, and in FU-4, is also not protective against direct exposure risk. Therefore, Alternative 1 was screened out due to not meeting the remedial action objectives.

Alternatives 2a, 2b, 4, and 6 were screened out due to their low-ranking subtotals. Low rankings in 2a and 2b were largely due to the high risk of implementing such a large-scale excavation as a remedy and the lowered implementability due to the FU's location in close proximity to areas with large subsurface debris and obstructions, and soil with asbestos containing material. Additionally, the implementability was scored lower in FU-4 than it was in FU-3 due to proximity to the GWET system. Similarly, to FU-3, Alternative 4 and Alternative 6, while not containing any "poor" scores, scored poorly overall due to not being particularly advantageous in any single category.

Alternatives 3, 5, and 7 were carried forward into costing. Similar to FU-3, Alternative 3 is only costed based on the marginal cost of excavating the soil FU overlaying FU-8 or FU-9. Disadvantages to

Alternative 5 include that there are likely no feasible options after this step is performed and large concrete chunks could prevent the ISS apparatus from penetrating to depth.

The three retained options were costed to an estimated -30 to +50 percent accuracy based on professional experience and consultation with vendors and contractors. Appendix A includes the cost estimates.

8.7.8.2 Recommended Alternative

Alternative 5 is the recommended alternative since it pairs well with alternative options in FU-9. It removes the primary source area of chlorobenzene risk and enhances the effectiveness of the recommended remedial actions in the underlying groundwater of FU-9.

8.8 Functional Unit 5: Lots 1 and 2 Shallow and Intermediate Groundwater Zones

FU-5 consists of Shallow- and Intermediate-Zone groundwater in Lots 1 and 2 (Figure 6-2). COCs include metals, dioxin/furans, and dissolved VOCs in groundwater in all zones, and dissolved pesticides in the Shallow Zone. VOCs, dioxins, and some metals and pesticides in FU-5 are considered a trespassing plume from an upgradient source. The exposure pathway for FU-5 is ecological risk derived from migration of contaminated groundwater to porewater and/or surface water via transition zone porewater. of any remedial action is contamination resulting from historical operations and not naturally occurring COCs, such as metals. Pre-design sampling and evaluations of the extent of actual COCs present, and their fate and transport in the environment (i.e., potential for attenuation) will assess the need for and the appropriate design and sequencing of any remedial action.

An injected PRB (Alternative 2) is the preferred alternative for FU-5 (see below for ranking). Figure 8-3 shows the extent of a PRB for Alternative 2 of FU-5. The alternatives for FU-5 are discussed below.

8.8.1 Alternative 1: No Action

Alternative 1 is the baseline condition, or the no-action alternative.

8.8.2 Alternative 2: Injected ISCR PRB and GAC

Alternative 2 is insitu ISCR injections to form a PRB alongside the riverside portion of the FU. The PRB would treat COCs in Shallow- and Intermediate-Zone groundwater that flowed through the PRB. Costs assume one injection event in temporary injection points. A smaller scale injection event is assumed after 10 years to regenerate the reductive capacity of the PRB.

8.8.3 Alternative 3: Excavated PRB and GAC

Alternative 3 is the same as Alternative 2 but uses an excavated PRB as the installation method. While more costly, using an excavation instead of an injection program diminishes the risk that preferential pathways are formed during the injection process and enables higher volumes of reagent to be dosed. Costs assume the excavated PRB is 4 feet thick by 40 feet deep, consisting of 20 percent GAC by volume, with the remainder being clean fill. The actual thickness and depth of the wall and backfill mixtures would be determined in remedial design.

8.8.4 Alternative 4: Enhanced Biodegradation and Monitored Natural Attenuation

Alternative 4 is oxygen releasing compound delivered to stimulate aerobic degradation throughout the FU, or injecting soybean oil or other reductant to act as a carbon source for anaerobic biodegradation.

The amendment would be injected via temporary injection points along the riverbank boundary of Lots 1 and 2 (FU 5 and FU-6). The concentrations of COCs would then be monitored to evaluate level of risk to potential receptors in porewater.

8.8.5 Alternative 5: ISCO Injections

Alternative 5 is ISCO application throughout FU-5, targeted at degrading VOCs and pesticides. Section 7.3.8 describes details of the ISCO technology. Process options may include a combination of one-time direct-push injections, or injections though permanent injection points.

8.8.6 Alternative 6: ISCR Injections

Alternative 6 consists of ISCR application throughout the FU. Section 7.3.10 describes details of the ISCR technology. An enhanced ISCR amendment would be applied to reduce COCs, while also providing a suitable environment for anaerobic biodegradation. The ISCR reagent in Alternative 6 includes augmentation with facultative microbes and nutrients to support growth of anaerobic contaminant-degrading microorganisms. Costs assume one direct-push injection event of ISCR reagent.

8.8.7 Alternative 7: Hydraulic Control

Alternative 7 is expansion of the existing onsite GWET system to capture the Shallow- and Intermediate-Zone groundwater on Lots 1 and 2.

8.8.8 Functional Unit 5 Alternatives Ranking Summary

Table 8-4 summarizes ranking of alternatives for FU-5.

Table 8-4: FU-5: Lots 1 and 2 Shallow and Intermediate Groundwater Zones

	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
Alternatives	Effectiveness	Long-term Reliability	Implement-ability	Implementation Risk	Ranking Subtotal	Cost (NPV)	Preferred
Alternative 1: No Action	1	1	5	5	12	—	
Alternative 2: Injected ISCR (w/ GAC) PRB	4	4	4	4	16	$4.0M	X
Alternative 3: Excavated ISCR (w/ GAC) PRB	5	4	3	3	15	$10.8M	
Alternative 4: Enhanced Biodegradation and Monitored Natural Attenuation	3	2	4	4	13	—	

Alternatives	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
	Effectiveness	Long-term Reliability	Implement-ability	Implementation Risk	Ranking Subtotal	Cost (NPV)	Preferred
Alternative 5: ISCO Injections	3	2	3	2	10	—	
Alternative 6: ISCR Injections	4	4	4	4	16	$6.7M	
Alternative 7: Hydraulic Control	4	2	4	3	13	—	

Notes:
X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.

8.8.8.1 Comparative Analysis

The HSE (2021a) dataset indicates that no-action is not protective of receptors in the river. Therefore, Alternative 1 was screened out due to not meeting the remedial action objectives.

Alternatives 4, 5, and 7 were not carried forward into costing based on their low-ranking subtotals. Alternative 4's low ranking is primarily attributed to its limited effectiveness at treating the suite of contaminants present in the FU. Additionally, in the long-term, the remedy has not been shown to be as reliable as other alternatives. Alternative 5's low ranking is primarily attributed to implementation risk of ISCO injections on such a large scale, and relatively low rankings in other factors. Alternative 7's low ranking is largely attributed to the low long-term reliability of relying on pump and treat with hydraulic control. Hydraulic control is an existing technology at the site that can control groundwater sources in the long term, but not as an effective treatment in the short term. This alternative also has very high long-term operation and maintenance costs.

Alternatives 2, 3, and 6 were carried forward into costing. Alternatives 2 and 3, while both containing a similar remedy, vary on implementation risk, implementability, and effectiveness. Alternative 2 has a better score on implementation and implementation risk since it does not require an open excavation. Alternative 3 was given a better score on effectiveness since a larger volume of reagent would be used in the remedy, giving the PRB more capacity to treat contaminants.

8.8.8.2 Recommended Alternative

Alternative 2 is the recommended alternative because it mitigates risk to ecological receptors in the river, scores well in implementability, and is the most cost-effective costed remedy. The most conservative scenario was used for comparative analysis as HSE dataset indicates groundwater hotspots near the riverbank. Due to the uncertainty of design basis, a range of cost estimates were developed for the recommended alternative, consisting of the following:

- Low Cost – Monitored Natural Attenuation only
- Medium Cost – Injected ISCR with GAC, extending along northern portion of FU-5 (i.e., Lot 1) riverbank alignment only

- High Cost - Injected ISCR with GAC, extending along entirety of FU-5 riverbank alignment (assumed remedy for comparative analysis)

Appendix A includes the costs estimates and assumptions. Pre-design investigations would minimize the uncertainty, and the remedial design would develop the need for and the alignment of the injected PRB.

8.9 Functional Unit 6: Southern Riverside Portion of Lot 3 Shallow, Intermediate, and Deep Groundwater Zones

FU-6 consists of soil and groundwater in the saturated zone located in the area immediately north of the Acid Plant Area on the riverside portion of the site (Figure 6-2). Groundwater in FU-6 is located outside the target capture zone of the GWET system, but it immediately borders the target capture zone and lies underneath the GWET system building. COCs include chlorinated VOCs and pesticides in shallow groundwater and chloride and metals in shallow and intermediate groundwater. The exposure pathway for FU-6 is ecological risk from migration of contaminated groundwater to surface water via transition zone porewater.

An injected PRB (Alternative 2) is the preferred alternative for FU-6 (see below for ranking). Figure 8-3 shows the extent of a PRB for Alternative 2 of FU-6. The alternatives for FU-6 are discussed below.

8.9.1 Alternative 1: No Action

Alternative 1 is the baseline condition, or the no-action alternative.

8.9.2 Alternative 2: Injected ISCR PRB

Alternative 2 is ISCR injections via direct push to form a PRB alongside the riverside portion of the FU. This PRB would treat COCs in groundwater that flowed through the barrier. Similar to FU-5 Alternative 2, costing of this alternative assumes one large injection event with injection of ISCR amendments in temporary injection points. A second smaller scale injection event is assumed to be needed after 10 years to regenerate the reductive capacity of the PRB.

8.9.3 Alternative 3: Excavated PRB

Alternative 3 is the same as Alternative 2 but uses excavation as the application method. While more costly, using an excavation instead of an injection program diminishes the risk that preferential pathways are formed during the injection process and enables higher volumes of reagent to be dosed. Costing assumes that the excavated PRB is 4 feet thick and 40 feet deep, consisting of 20 percent amendment by volume, with the remainder an engineered sand and gravel mixture backfill. The actual thickness of the wall and backfill mixtures would be determined in the remedial design.

In FU-6, an excavated PRB presents technical challenges due to its proximity to the GWET system, job trailer, and subsurface utilities.

8.9.4 Alternative 4: Enhanced Biodegradation and Monitored Natural Attenuation

Alternative 4 is injection of an oxygen releasing compound to stimulate aerobic degradation throughout FU-6, or injecting soybean oil to act as a carbon source for anaerobic biodegradation. This alternative assumes one round of direct push injection events. The concentrations of COCs would then be monitored along the boundary with the riverbank to evaluate biodegradation progress and residual risk to receptors.

8.9.5 Alternative 5: ISCO Injections

Alternative 5 is ISCO targeted at degrading VOCs and pesticides. Section 7.3.8 describes details of the ISCO technology. Process options may include a combination of one-time direct-push injections, or injections though permanent injection points.

8.9.6 Alternative 6: ISCR Injections

Alternative 6 is ISCR throughout the FU-6. Section 7.3.10 describes details of the ISCR technology. An enhanced ISCR amendment would be applied to abiotically reduce COC mass, while also providing a suitable environment for anaerobic biodegradation as a polishing step. The ISCR reagent in Alternative 6 includes augmentation with facultative microbes and nutrients to support growth of anaerobic contaminant-degrading microorganisms. Costs assume one direct-push injection of ISCR reagent.

8.9.7 Alternative 7: Hydraulic Control

Alternative 7 is expansion of the Groundwater SCM to hydraulically control the migration of COCs in groundwater to the porewater. This alternative consists of extending the GWBW and expanding the groundwater extraction and treatment capacity of the existing GWET system to capture groundwater in the Shallow, Intermediate, and Deep Zones in the FU.

8.10 Functional Unit 6 Alternatives Ranking Summary

Table 8-5 summarizes ranking of alternatives for FU-6.

Table 8-5: FU-6: Southern Riverside Portion of Lot 3 Shallow and Intermediate Groundwater Zones

	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
Alternatives	**Effectiveness**	**Long-term Reliability**	**Implement-ability**	**Implementation Risk**	**Ranking Subtotal**	**Cost (NPV)**	**Preferred**
Alternative 1: No Action	1	1	5	5	12	—	
Alternative 2: Injected ISCR (w/ GAC) PRB	4	4	4	3	15	$1.5M	X
Alternative 3: Excavated ISCR (w/GAC) PRB	5	4	3	2	14	$5.7M	
Alternative 4: Enhanced Biodegradation and Monitored Natural Attenuation	2	2	4	4	12	—	
Alternative 5: ISCO Injections	3	2	3	2	10	—	
Alternative 6: ISCR Injections	4	4	3	4	15	$2.3M	
Alternative 7: Hydraulic Control	4	2	4	3	13	—	

Notes:

X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.

8.10.1.1 Comparative Analysis

The HSE dataset indicates that no-action is not protective of receptors in the river. Therefore, Alternative 1 was screened out due to not meeting the remedial action objectives.

Alternatives 4, 5, and 7 were not carried forward into costing based on their low-ranking subtotals. Alternative 4's low ranking is primarily attributed to its limited effectiveness at treating the suite of contaminants present in the FU. Additionally, in the long-term, the remedy has not been shown to be as reliable as other alternatives. Alternative 5's low ranking is primarily attributed to implementation risk of ISCO injections on such a large scale, and relatively low rankings in other factors. Alternative 7's low ranking is largely attributed to the low long-term reliability of relying on pump and treat with hydraulic control. Hydraulic control is an existing technology at the site that can control groundwater sources in the long term, but not as an effective treatment in the short term. This alternative also has very high long-term operation and maintenance costs. Alternatives 2, 3, and 6 were carried forward into costing. Alternatives 2 and 3, while both containing a similar remedy, vary on implementation risk, implementability, and effectiveness. Alternative 2 has a better score on implementation and implementation risk since it does not require an open excavation. Alternative 3 was given a better score on effectiveness since a larger volume of reagent would be used in the remedy, giving the PRB more capacity to treat contaminants.

8.10.1.2 Recommended Alternative

Alternative 2 is the recommended alternative because it mitigates risk to ecological receptors in the river, scores well in implementability, and is the most cost-effective costed remedy. Due to the uncertainty of design basis, a range of cost estimates were developed for the recommended alternative, consisting of:

- Low Cost – Monitored Natural Attenuation only
- Medium Cost – Injected ISCR with GAC, extending along southern portion of FU-6 (i.e., Lot 3) riverbank alignment only
- High Cost - Injected ISCR with GAC, extending along the entire FU-6 riverbank (assumed remedy for comparative analysis)

Appendix A includes the cost estimates and assumptions. Pre-design investigations would minimize the uncertainty, and the remedial design would develop the details of the remedy and phasing of implementation. The most conservative scenario was used for comparative analysis, as the HSE dataset indicates groundwater hotspots near the riverbank. The remedial design would develop the need for and the alignment of the injected PRB.

8.11 Functional Unit 7: Uplands Portion of Lots 3 and 4 Shallow, Intermediate, and Deep Groundwater Zones

FU-7 consists of soil and groundwater in the saturated zone located in the area upgradient (i.e., west) of the groundwater SCM target capture zone, and consists of most of Lots 3 and 4 (Figure 6-2). Groundwater in FU-7 is not bounded by the target capture zone of the GWET system. COCs include metals, pesticides, and dioxin/furans in Shallow, Intermediate, and Deep groundwater. FU-7 has no detected VOCs. The exposure pathway for FU-7 is ecological risk derived from migration of contaminated groundwater to surface water via transition zone porewater.

Institutional controls and MNA (Alternative 2) is the preferred alternative for FU-7 (see below for ranking). The alternatives for FU-7 are discussed below.

8.11.1 Alternative 1: No Action

Alternative 1 is the baseline condition, or the no-action alternative.

8.11.2 Alternative 2: Institutional Controls and Monitored Natural Attenuation

Alternative 2 is institutional controls and monitored natural attenuation. The success of this remedy is dependent on the implementation of remedies in immediately adjacent and downgradient FUs. Costing assumes six clusters of Shallow-, Intermediate-, and Deep-Zone monitoring wells and quarterly monitoring for years 1 through 15 and annual monitoring until year 25.

8.11.3 Alternative 3: ISCO Injections

Alternative 3 is ISCO targeted at degrading pesticides. Section 7.3.8 describes details of the ISCO technology. Costing assumes that ISCO injections would be located throughout the entire FU and extend from the top of the Shallow Zone to the top of the Deep Zone (i.e., between approximately 20 to 50 feet bgs). Costs assume a single direct push injection event of ISCR reagent.

8.11.4 Alternative 4: ISCR Injections

Alternative 4 is ISCR application throughout FU-7. Section 7.3.10 describes details of the ISCR technology. An enhanced ISCR amendment would be applied to abiotically reduce COC mass, while also providing a suitable environment for anaerobic biodegradation as a polishing step. Costs assume one direct-push injection event of ISCR reagent.

8.11.5 Functional Unit 7 Alternatives Ranking Summary

Table 8-6 summarizes ranking of alternatives for FU-7.

Table 8-6: FU-7: Uplands Portion of Lots 3 and 4 Shallow, Intermediate, and Deep Groundwater Zones

	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
Alternatives	**Effectiveness**	**Long-term Reliability**	**Implement-ability**	**Implementation Risk**	**Ranking Subtotal**	**Cost (NPV)**	**Preferred**
Alternative 1: No Action	1	1	5	5	12	—	
Alternative 2: Institutional Controls and Monitored Natural Attenuation	3	3	5	4	15	$1.2M	X
Alternative 3: ISCO Injections	4	2	4	3	13	$6.0M	
Alternative 4: ISCR Injections	4	4	4	4	16	$4.8M	

Notes:
X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.

8.11.5.1 Comparative Analysis

The HSE dataset indicates that no-action is not protective of receptors in the river. Therefore, Alternative 1 was screened out due to not meeting the remedial action objectives.

The remaining alternatives were carried forward into costing. Alternative 3 was given a lower score than Alternative 4 in both effectiveness and long-term reliability due to the presumptive ISCR reagent having a GAC component that is designed to provide additional treatment capacity. Additionally, Alternative 4 was given a higher score in implementation risk due to ISCR amendments generally having a lower risk in application.

Alternative 2 has the highest score of the costed remedies in implementability, because the installation includes drilling wells and does not include any subsurface injections. While being less effective at treatment in FU-7 than Alternatives 3 and 4, Alternative 2 has the advantage of leveraging downgradient remedies in FUs 6, 8, 9, and 10, all of which have a component of active treatment.

8.11.5.2 Recommended Alternative

Alternative 2 is the recommended alternative because it is the most implementable remedy, is the most cost-effective, and carries very little risk of not being protective of receptors in the river due to its reliance on downgradient active remedies.

8.12 Functional Unit 8: Northern Riverside Portion of Lots 3 and 4 Shallow, Intermediate, and Deep Groundwater Zones

FU-8 consists of soil and groundwater in the saturated zone in the area immediately surrounding and upland of the Acid Plant Area, and as far east as the top of bank (Figure 6-2). Groundwater in FU-8 is predominantly bounded by the target capture zone of the GWET system. COCs include chromium, pesticides, and VOCs in Shallow, Intermediate, and Deep groundwater. The exposure pathway for FU-8 is ecological risk derived from migration of contaminated groundwater to surface water via transition zone porewater.

Focused ISCR injections and an ISCR PRB (Alternative 7) is the preferred alternative for FU-8 (see below for ranking). Figure 8-4 shows the extent of a ISCR injections and PRB for Alternative 7 of FU-8. The alternatives for FU-8 are discussed below.

8.12.1 Alternative 1: No Action

Alternative 1 is the baseline condition, or the no-action alternative which consists of the existing operational groundwater SCM. Costing assumes half of the net present value (NPV) of 30 years of operating the GWET. The remaining half of GWET the operating costs is associated with FU-10, Alternative 1.

8.12.2 Alternative 2: ISCO Injections

Alternative 2 is ISCO injections targeted at degrading the high-concentration VOCs. Section 7.3.8 describes details of the ISCO technology. This alternative assumes a single direct push injection event of ISCR reagent.

8.12.3 Alternative 3: ISCO and ISS

Alternative 3 is ISCO with ISS using Portland cement applied by auger mixing in the saturated zone, and just ISCO for the unsaturated soil overlaying FU-8. Advantages of ISCO combined with aggressive mixing (to promote contact between COCs and reagents) and ISS are that any residual COCs after ISCO treatment would be bound in a concrete monolith. Further treatment would not be needed because transport of residual contamination to the points of exposure in the river would be controlled. This alternative assumes one injection event with sequential or simultaneous injection of ISCO and ISS amendments in temporary injection points.

8.12.4 Alternative 4: ISCR Injections

Alternative 4 is ISCR application throughout the FU. Section 7.3.10 describes details of the ISCR technology. An enhanced ISCR amendment would be applied to abiotically reduce COC mass, while also providing a suitable environment for anaerobic biodegradation as a polishing step. The ISCR reagent in Alternative 4 includes augmentation with facultative microbes and nutrients to support growth of anaerobic contaminant-degrading microorganisms. Costs assume one direct-push injection event of ISCR reagent with smaller polishing event one year after the initial event.

8.12.5 Alternative 5: ISCR Permeable Reactive Barrier

Alternative 5 is ISCR injections to form a PRB along the northern portion of the FU as a continuation of the current GWBW. These injections would allow groundwater to enter the target capture zone of the GWET system where it would be captured and treated.

Additionally, as a final step following GWET System shut down, this alternative includes breaching the GWBW by installing an excavated PRB with GAC and sand/gravel backfill mixture. This PRB is designed to treat residual COCs in groundwater as it passes through this “gate”.

Costs assume a second smaller round of ISCR injections to regenerate the reductive capacity of the PRBs after 10 years.

8.12.6 Alternative 6: Enhanced Biodegradation

Alternative 6 is injection of an oxygen-releasing compound to stimulate aerobic degradation, or injection of soybean oil to provide a carbon source to stimulate anaerobic biodegradation. This alternative assumes one round of direct-push injections.

8.12.7 Alternative 7: Focused ISCR Injections and ISCR PRB

Alternative 7 includes the same injected ISCR PRBs as discussed in Alternative 5, in combination with additional ISCR injections using the same assumptions used in Alternative 4. ISCR injections would only be applied in the area immediately surrounding the Acid Plant Area, and in areas of higher contaminant concentrations. Injection locations would be determined in remedial design.

8.12.8 Functional Unit 8 Alternatives Ranking Summary

Table 8-7 summarizes ranking of alternatives for FU-8.

Table 8-7: FU-8: Northern Riverside Portion of Lots 3 and 4 Shallow, Intermediate, and Deep Groundwater Zones on Both Sides of the GWBW

	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
Alternatives	**Effectiveness**	**Long-term Reliability**	**Implement-ability**	**Implementation Risk**	**Ranking Subtotal**	**Cost (NPV)**	**Preferred**
Alternative 1: No Action	2	3	5	5	15	$28.6M*	
Alternative 2: ISCO Injections	3	2	4	3	12	—	
Alternative 3: ISCO and ISS	4	4	4	3	15	—	
Alternative 4: ISCR Injections	4	4	4	4	16	$11.8M*	
Alternative 5: ISCR PRB	3	4	4	4	15	$8.4M*	
Alternative 6: Enhanced Biodegradation	2	2	4	5	13	—	
Alternative 7: ISCR Injections and ISCR PRB	5	5	4	4	18	$8.9M*	x

Notes:
X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.
** = Indicates the inclusion of the NPV of GWET operation over an estimated period continued operation. See Appendix A for more information.*

8.12.8.1 Comparative Analysis

Alternative 6 was screened out based on low effectiveness to meet RAOs and their ranking subtotals. Enhanced biodegradation, while possibly effective, has not been demonstrated to be effective on the entire suite of COCs that are present in the FU.

Alternative 2 was screened out based on low relative effectiveness and increased implementation risk when compared to Alternatives 3, 4, and 5. Alternative 2 was given a lower effectiveness rating compared to Alternatives 3, 4, and 5 due to its reliance on a single technology.

Alternatives 1, 3, 4, and 5 were carried forward into costing based on their ranking subtotals. Alternative 1 is protective of the risk to the receptors in the river through long-term prevention of groundwater transport to the river through hydraulic control. Alternative 5 was given a higher rating than Alternatives 3 and 4 in long-term reliability because it allows for continued treatment of residual contaminants after shutdown of the GWET system. Alternative 5 also received a higher score in implementation risk, due to having a comparatively lower risk during construction compared to the widespread injection programs in Alternatives 2, 3, and 4.

The three retained options were costed to an estimated -30 to +50 percent accuracy based on professional experience and consultation with vendors and contractors. Appendix A includes the cost estimates. As discussed in Section 8, the costs for these alternatives include the NPV of different lengths of the GWET operation.

8.12.8.2 Recommended Alternative

Based on the comparative analysis, Alternative 7 is the preferred alternative for FU-8 due to high effectiveness and high score in all categories. Due to the uncertainty of design basis, a range of cost estimates were developed for the recommended alternative, consisting of:

- Low Cost – ISCR PRBs only
- Medium Cost – Small area of ISCR injections, and ISCR PRBs
- High Cost - Focused ISCR injections, and ISCR PRBs (assumed remedy for comparative analysis)

Appendix A includes the cost estimates and assumptions. Pre-design investigations would minimize the uncertainty, and the remedial design would develop the details of the remedy and phasing of implementation. The most conservative scenario was used for comparative analysis as the HSE dataset indicates groundwater hotspots near the riverbank. However, remedial design would develop the need for and the extent and alignment of the ISCR injections and PRBs.

8.13 Functional Unit 9: Acid Plant Area Shallow, Intermediate, and Deep Groundwater Zones

FU-9 consists of soil and groundwater in the saturated zone located in the historical Acid Plant Area of the site, located on Lots 3 and 4 (Figure 6-2). Groundwater in FU-9 is predominantly bounded by the target capture zone of the GWET system. COCs include chromium, pesticides, and VOCs in Shallow, Intermediate, and Deep groundwater, and chlorobenzene DNAPL. The exposure pathway for FU-9 is ecological risk derived from migration of contaminated groundwater to surface water via transition zone porewater.

Enhanced ISCR and ISS (Alternative 3a) is the preferred alternative for FU-9 (see below for ranking). Figure 8-4 shows the extent of Enhanced ISCR and ISS for Alternative 3 of FU-9. The alternatives for FU-9 are discussed below.

8.13.1 Alternative 1: No Action

Alternative 1 is the baseline condition, or the no-action alternative.

8.13.2 Alternative 2: ISCO

Alternative 2 is ISCO targeted at the DNAPL plume and high-concentration VOCs. Section 7.3.8 describes details of the ISCO technology.

8.13.2.1 Alternative 2a: ISCO Injection Program

Alternative 2a is ISCO injections of activated sodium persulfate or similar ISCO reagent. Process options may include a combination of one-time direct-push injections, or injections though permanent injection points. For evaluation, this alternative assumes one injection event of ISCO amendments in temporary injection points.

8.13.2.2 Alternative 2b: ISCO and ISS

Alternative 2b is ISCO with ISS using Portland cement applied by auger mixing, large diameter auger mixing, or other application method, in the saturated zone. This process of ISCO combined with aggressive mixing (to promote contact between COCs and reagents) and ISS binds residual COCs remaining after ISCO treatment bound in a concrete monolith. This stabilization addresses transport of residual contamination to the point of exposure in the river. Costs assume one injection event with sequential or simultaneous injection of ISCO and ISS amendments in temporary injection points. Estimates assume costs are shared between ISS alternatives in FU-4 and this alternative.

8.13.3 Alternative 3: ISCR

Alternative 3 is ISCR. Section 7.3.10 describes details of the ISCR technology.

8.13.3.1 Alternative 3a: Enhanced ISCR and ISS

Alternative 3b combines enhanced ISCR and ISS using Portland cement to reduce contaminants, providing the ISCR benefit along with encapsulating residual COCs and degradation products in a matrix, while also providing a suitable environment for anaerobic biodegradation. Costing assumes amendment injection and soil mixing by auger mixing. The ISCR reagent in Alternative 3a includes augmentation with facultative microbes and nutrients to support growth of anaerobic contaminant-degrading microorganisms. Costs assume one application event with sequential or simultaneous injection of ISCR and ISS amendments. Estimates assume costs are shared between ISS alternatives in FU-4 and this alternative.

8.13.3.2 Alternative 3b: ISCR and ISS

Alternative 3b combines ISCR and ISS using Portland cement to reduce contaminants, providing the ISCR benefit along with encapsulating residual COCs and degradation products in a matrix. Costing assumes amendment injection and soil mixing by auger mixing. If Alternative 3b is chosen for groundwater in FU-9, ISCR would also be used for the unsaturated soil overlaying FU-9. The difference between Alternatives 3a and 3b is the ISCR reagent. The reagent in Alternative 3a includes additives to enhance biodegradation, and Alternative 3b does not include biodegradation additives. Costs assume one round of sequential or simultaneous injections of ISCR and ISS amendments in temporary injection points with an estimated ROI of 4 feet. Estimates assume costs are shared between ISS alternatives in FU-4 and this alternative.

8.13.4 Alternative 4: Enhanced Biodegradation

Alternative 4 is injection of an oxygen-releasing compound to stimulate aerobic degradation, or injection of soybean oil or a similar amendment to provide a carbon source to stimulate anaerobic biodegradation.

8.13.5 Functional Unit 9 Alternatives Ranking Summary

Table 8-8 summarizes ranking of alternatives for FU-9.

Table 8-8: FU-9: Acid Plant Area Shallow, Intermediate, and Deep Groundwater Zones on Both Sides of the GWBW

	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
Alternatives	Effectiveness	Long-term Reliability	Implementability	Implementation Risk	Ranking Subtotal	Cost (NPV)	Preferred
Alternative 1: No Action	1	1	5	5	12	—	

Alternative 2a: ISCO	3	2	4	3	13	—	
Alternative 2b: ISCO and ISS	4	4	3	3	15	$8.3M	
Alternative 3a: Enhanced ISCR and ISS	5	5	3	4	18	$8.1M	x
Alternative 3b: ISCR and ISS	4	4	3	4	16	$8.1M	
Alternative 4: Enhanced Aerobic/Anaerobic Biodegradation	2	2	4	5	12	—	

Notes:
X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.

8.13.5.1 Comparative Analysis

Alternative 1 and Alternative 4 were screened out based on low effectiveness to meet RAOs and their ranking subtotals. The HSE dataset indicates that no-action is not protective of receptors in the river. Enhanced biodegradation is not effective on DNAPL.

Alternative 2a was assessed against the remaining alternatives and was found to have lower effectiveness and long-term reliability, due primarily to the absence of ISS, which improves effectiveness and reliability in comparison to the other alternatives. Alternative 2a was not carried forward to costing.

Alternatives 2b, 3a, and 3b were carried forward to costing based on their ranking subtotals. ISCR Alternatives 3a and 3b have higher scores for implementation risk (lower risk), as compared to Alternative 2b, because ISCR reagents are safer to work with. Alternative 3a has a higher effectiveness score than 3b due to the bio-polishing component of enhanced ISCR.

The three retained options were costed to an estimated -30 to +50 percent accuracy based on professional experience and consultation with vendors and contractors. Appendix A includes costs estimating details.

8.13.5.2 Recommended Alternative

Based on comparative analysis, Alternative 3a is the preferred alternative for FU-9. Alternative 3a was chosen due to the improved effectiveness of enhanced ISCR which enhances microbial metabolism of chlorobenzene DNAPL, which is the primary COC in FU-9. Remedial design would develop the area and depth of application, specific amendment application rates, and delivery methods.

8.14 Functional Unit 10: Southern Riverside Portion of Lot 4 Shallow, Intermediate, and Deep Groundwater Zones

FU-10 consists of soil and groundwater in the saturated zone located in the area south of the Acid Plant area of the site, as far east as the FU-1 boundary (top of bank), extending to the southern site boundary, and is located on Lots 3 and 4 (Figure 6-2). Groundwater in FU-10 is predominantly bounded by the target capture zone of the GWET system. COCs include metals, chloride, perchlorate, pesticides, and VOCs in the Shallow, Intermediate, and Deep Zones. The exposure pathway for FU-10 is ecological risk derived from migration of contaminated groundwater to surface water via transition zone porewater.

Focused ISCR injections and ISCR PRB (Alternative 5) is the preferred alternative for FU-10 (see below for ranking). Figure 8-5 shows the extent of ISCR injections and ISCR PRB for Alternative 5 of FU-10. The alternatives for FU-10 are discussed below.

8.14.1 Alternative 1: No Action

Alternative 1 is the baseline condition, or the no-action alternative. Costs assume half of the NPV of 30 years of operating the GWET. The other half of GWET operating costs was included in FU-8, Alternative 1.

8.14.2 Alternative 2: ISCO Injections, Enhanced ISCR Injections, Anaerobic Biodegradation

Alternative 2 is ISCO injections to degrade the high-concentration VOCs along the northern edge of FU-10. Section 7.3.8 describes details of the ISCO technology. Alternative 2 also includes the broad application of an ISCR injection program. Section 7.3.10 describes details of the ISCR technology. Process options may include a combination of one-time direct-push injections, or injections though permanent injection points.

The ISCR reagent, applied by injection to reduce metals, pesticides, and VOCs, also provides a suitable environment for anaerobic biodegradation of perchlorate. The ISCR reagent in this alternative includes augmentation with facultative microbes and nutrients to support growth of anaerobic contaminant-degrading microorganisms. Costs assume one direct-push injection event of both ISCO and ISCR reagents.

8.14.3 Alternative 3: Enhanced ISCR Injections

Alternative 3 is enhanced ISCR to abiotically reduce COCs, while also providing a suitable environment for anaerobic biodegradation as a polishing step. The ISCR reagent in this alternative includes facultative microbes and nutrients to support growth of anaerobic contaminant-degrading microorganisms. Costs assume one direct-push injection event of ISCR reagents.

8.14.4 Alternative 4: ISCR PRB

Alternative 4 is ISCR injections to form a PRB along the southern portion of FU-10 as a continuation of the current GWBW. These injections would allow groundwater to enter the groundwater SCM target capture zone where it can be captured and any residual COCs can be treated by the GWET system. Costs assume a second smaller round of ISCR injections to regenerate the reductive capacity of the PRBs after 10 years.

Additionally, as a final step following GWET System shut down, this alternative includes breaching the GWBW by installing two excavated PRBs with GAC and sand/gravel backfill mixture. These PRBs are designed to treat residual COCs in groundwater as it passes through the “gates”.

8.14.5 Alternative 5: Focused ISCR Injections and ISCR PRB

Alternative 5 is a combination of Alternatives 3 and 4. It includes the same ISCR PRBs as Alternative 4 but includes ISCR injections in only the groundwater SCM target capture zone portion of FU-10.

8.14.6 Functional Unit 10 Alternatives Ranking Summary

Table 8-9 summarizes ranking of alternatives for FU-10.

Table 8-9: FU-10: Southern Riverside Portion of Lot 4 Shallow, Intermediate, and Deep Groundwater Zones on Both Sides of the GWBW

Alternatives	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
	Effectiveness	Long-term Reliability	Implement-ability	Implementation Risk	Ranking Subtotal	Cost (NPV)	Preferred
Alternative 1: No Action	2	3	5	5	15	$28.6M*	
Alternative 2: ISCO Injections, ISCR Injections, Anaerobic Biodegradation	4	3	4	4	15	$16.8M*	
Alternative 3: Enhanced ISCR Injections	4	5	4	4	17	—	
Alternative 4: ISCR (w/GAC) PRB	3	4	4	5	16	$10.4M*	
Alternative 5: Focused ISCR Injections and ISCR (w/GAC) PRB	5	5	4	4	18	$13.5M*	X

Notes:
X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.
** = Indicates the inclusion of the NPV of GWET operation over an estimated period continued operation. See Appendix A for more information.*

8.14.6.1 Comparative Analysis

Alternatives 2 and 3 were both given rankings of 4 in “implementation risk” since they are both FU-wide injection programs. Alternative 4 was given a lower ranking on effectiveness due to not directly addressing the source area. Alternative 1 is protective of the risk to the receptors in the river through long-term prevention of groundwater transport to the river through hydraulic control. Both the ISCR injection and ISCR PRB alternatives were given higher rankings for long-term reliability due to including a “capture” component by using ISCR reagents with GAC. Alternative 5 was given high ranking in both effectiveness and long-term reliability due to its treatment of primary source areas as well as long-term treatment methods.

8.14.6.2 Recommended Alternative

Alternative 5, while not the most cost-effective option, is the most effective at protecting receptors in the river. Remedial design would develop the area and depth of applications, as well as amendment application rates. Due to the uncertainty of design basis, a range of cost estimates was developed for the recommended alternative, consisting of:

- Low Cost – ISCR PRBs only
- Medium Cost – Small area of focused ISCR injections, and ISCR PRBs

- High Cost - Focused ISCR injections, and ISCR PRBs (assumed remedy for comparative analysis)

Appendix A includes the cost estimates and assumptions. Pre-design investigations would minimize the uncertainty, and the remedial design would develop the details of the remedy and phasing of implementation. The most conservative scenario was used for comparative analysis, as HSE dataset indicates groundwater hotspots near the riverbank. The remedial design would develop the need for and the extent and alignment of the ISCR injections and PRBs.

8.15 Functional Unit 11: Gravel/Basalt Zone Groundwater on Lots 3 and 4

FU-11 consists of Gravel and Basalt Zones located on Lots 3 and 4 (Figure 6-2). COCs include metals, chloride, VOCs, pesticides, and dioxins in Gravel/Basalt groundwater. The exposure pathway for FU-11 is ecological risk derived from migration of contaminated groundwater to surface water via transition zone porewater.

Institutional controls and MNA (Alternative 2) is the preferred alternative for FU-11 (see below for ranking). The alternatives for FU-11 are discussed below.

8.15.1 Alternative 1: No Action

Alternative 1 is the baseline condition, or the no-action alternative.

8.15.2 Alternative 2: Institutional Controls and Monitored Natural Attenuation

Alternative 2 includes Institutional Controls and MNA. Details of MNA are described in Section 7.3.4.11. Costs include installing four Gravel/Basalt-Zone monitoring wells and quarterly monitoring until year 15 and annual monitoring until year 25.

8.15.3 Functional Unit 11 Alternatives Ranking Summary

Table 8-10 summarizes ranking of alternatives for FU-11.

Table 8-10: FU-11: Gravel/Basalt Groundwater Zone on Lots 3 and 4

	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
Alternatives	Effectiveness	Long-term Reliability	Implement-ability	Implementation Risk	Ranking Subtotal	Cost (NPV)	Preferred
Alternative 1: No Action	1	1	5	5	12	—	
Alternative 2: Monitored Natural Attenuation and Verification in Remedial Design	2	4	5	3	14	$0.8M	X

Notes:
X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.

8.15.3.1 Comparative Analysis

The HSE dataset indicates that no-action is not protective of receptors in the river. Therefore, Alternative 1 was screened out due to not meeting the remedial action objectives. Alternative 2, while not providing active treatment, establishes a framework for determining residual risk in the Gravel/Basalt Zone on Lots 3 and 4. This approach would be verified in remedial design to mitigate risk to receptors in the river.

8.15.3.2 Recommended Alternative

Alternative 2 is the recommended alternative as it is the only alternative that is protective of risk receptors in the river.

8.16 Functional Unit 12: Deep and Gravel/Basalt Zone Groundwater on Lots 1 and 2

FU-12 consists of Deep and Gravel/Basalt Zones located on Lots 1 and 2 (Figure 6-2). COCs include metals, chloride, VOCs, pesticides, and dioxins in Deep and Gravel/Basalt groundwater. The exposure pathway for FU-12 is ecological risk derived from migration of contaminated groundwater to surface water via transition zone porewater.

Institutional controls and MNA (Alternative 2) is the preferred alternative for FU-12 (see below for ranking). The alternatives for FU-12 are discussed below.

8.16.1 Alternative 1: No Action

Alternative 1 is the baseline condition, or the no-action alternative.

8.16.2 Alternative 2: Monitored Natural Attenuation, Adaptive Management, and Verification in Remedial Design

Alternative 2 includes Institutional Controls and Monitored Natural Attenuation. Details of MNA are described in Section 7.3.4.11. Costs include four clusters of Deep- and Gravel/Basalt-Zone monitoring wells, monitoring them quarterly until year 15, and annually until year 25.

8.16.3 Functional Unit 12 Alternatives Ranking Summary

Table 8-11 summarizes ranking of alternatives for FU-12.

Table 8-11: FU-12: Deep and Gravel/Basalt Groundwater Zone on Lots 1 and 2

	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
Alternatives	**Effectiveness**	**Long-term Reliability**	**Implement-ability**	**Implementation Risk**	**Ranking Subtotal**	**Cost (NPV)**	**Preferred**
Alternative 1: No Action	1	1	5	5	12	—	
Alternative 2: Monitored Natural Attenuation and	2	4	5	3	14	$1.5	x

Alternatives	Preliminary Remedy Selection Balancing Factors (Rated 1-5)						
	Effectiveness	Long-term Reliability	Implement-ability	Implementation Risk	Ranking Subtotal	Cost (NPV)	Preferred
Verification in Remedial Design							

Notes:
X = The preferred alternative is the most cost effective.
See Section 8.2.2 for explanation of criteria weighting and selection of the preferred alternative.

8.16.3.1 Comparative Analysis

The HSE dataset indicates that no-action is not protective of receptors in the river. Therefore, Alternative 1 was screened out due to not meeting the remedial action objectives. Alternative 2, while not providing active treatment, establishes a framework for determining residual risk in the Deep and Gravel/Basalt zones on Lots 1 and 2. This approach would be verified in remedial design to mitigate risk to receptors in the river.

8.16.3.2 Recommended Alternative

Alternative 2 is the recommended alternative, as it is the only alternative that is protective of risk receptors in the river.

8.17 Summary of Recommended Alternatives

The sections above describe and tabulate the recommended alternatives. The recommended alternatives are proposed to be implemented in three phases. Phases group sequence remedy implementation based on risk reduction prioritization, design basis dependency on results of prior remedial actions, and additional remedial design data needs. The concept of a FU was useful for delineation of the site into discrete areas, strata, and allowed for an organized approach to conceptual designs and evaluation of specific technologies. Phased implementation of alternatives would be useful for designing, planning, and implementing individual remedial actions onsite.

The proposed phasing is as follows:

Phase 1

1. Immobilize and treat groundwater hot spots in FU-9 (i.e., DNAPL in Acid Plant Area) by ISCR/ISS and solidify hotspots in the vadose zone of FU-4 overlaying FU-9. The recommended alternative includes treatment via injection of ISCR reagents, as well as immobilization via injection of Portland cement.
2. Installation of caps and implementation of institutional controls for soil in FU-2 and FU-3 (Lots 1 & 2, western areas of Lot 3 & 4), where the recommended alternative is “Capping” to address unacceptable direct exposure and leaching to groundwater risks.
3. Implement monitored natural attenuation in groundwater FU-7, FU-11, and FU-12 (Lots 1 & 2, western area of Lots 3 and 4). The recommended alternative in these FUs is monitored natural attenuation with reliance on downgradient treatment methods.

4. Treat or immobilize via ISCR injection programs – in FU-10 (Chlorate Plant Area/Salt Pads), a portion of the recommended alternative includes ISCR injections to treat areas with unacceptable concentrations of perchlorate and hexavalent chromium. The specific injection areas will be defined further in remedial design and following the FU-9 performance monitoring.

Phase 2

5. Based on the results of Phase 1 remedial actions and pre-design studies, potential Installation of ISCR injected PRBs. In FU-5, FU-6, FU-8, and FU-10 (Lot 1 & 2 riverbank, north and south ends of the GWBW) a portion of the recommended alternative is the installation of an injected PRB designed to treat or immobilize contaminants to address unacceptable risk to receptors in the transition zone porewater, if any.
6. Treat or immobilize via ISCR injection programs – in groundwater FU-8 (Acid Plant Area outside of DNAPL area), a portion of the recommended alternative includes focused injections to treat specific areas to be defined further in remedial design following performance monitoring of the Phase 1 remedial actions.

Phase 3

7. Installation of excavated PRBs in the GWBW. In FU-8 and FU-10, along the top of bank in Lots 3 and 4, a portion of the recommended alternative is the installation of three “gates” of excavated ISCR PRBs in place of the current GWBW designed to treat or immobilize residual contaminants in groundwater followed by decommissioning of the GWET system.
8. Maintenance or installation of caps and implementation of institutional controls for soil in remaining eastern areas of Lots 3 & 4 (Acid Plant Area, top of bank in Lot 3 & 4).

Section 9 discusses the phased remedy implementation. Appendix A summarizes the costs of preferred alternatives and the cost ranges for those alternatives with significant cost uncertainty. The uncertainties will be addressed through pre-design investigations and the performance evaluations of previously implemented remedies.

9. IMPLEMENTATION PLAN AND SCHEDULE

9.1 Process of Remedial Action Approval

The DEQ will prepare a staff report that summarizes its findings on this FS and recommends a remedial approach based on the selection criteria applied above. The DEQ will issue the staff report to the public for review and comment. OAR 340-122-0100 specifies that the DEQ's staff report will be made available for a comment period of at least 30 days. If the notice generates significant public interest, additional public involvement can be included in the review process. For example, if a written request is received by 10 or more people, or from a group with 10 or more members, then a public meeting is required.

After the public comment period, the DEQ will finalize the staff report and issue a record of decision (ROD). The ROD includes elements of the staff report and includes a summary of the public comments and the DEQ's responses. The ROD also discusses how the remedy meets the requirements of the Oregon environmental cleanup law.

9.2 Remedial Design and Remedial Action

Remedial design will begin after the DEQ issues the staff report. Typical remedial action implementation is conducted in the following steps – pre-design investigation, design, implementation, and performance monitoring. As noted in previous sections, there are numerous conservative assumptions in this FS that must be addressed before a cost-effective remedy can be implemented (e.g., the current extent of hot spots of contamination). Also, the design and implementation of several alternatives would depend on the efficacy of a previous remedy implementation. For example, the extent of ISCR injections in the Acid Plant Area will be determined by the extent and the effectiveness of an ISCR/ISS remedy in the Acid Plant soil and groundwater. To address these uncertainties and incorporate future conditions, LSS intends to implement the DEQ-selected remedies in phases.

A cost sensitivity analysis estimates a range of costs for some preferred alternatives where the scale of a remedy could vary substantially. The sensitivity analysis accounts for uncertainties introduced by conservative assumptions in this FS, Low, medium, and high cost estimates in Appendix A reflect possible implementation scenarios of the preferred alternatives.

The phased approach will implement remedies in parallel where possible, and sequentially where needed. The intent of the approach is to build remedial actions on pre-design investigations and performance monitoring of the previous phase. The RD/RA work plan will describe the general scope of pre-design investigations and performance evaluation. Remedy-specific pre-design investigation workplans will provide details of investigation data quality objectives, data collection locations, methods, and analysis.

The following sections describe the phased remedy implementation approach. Figure 9-1 is a graphic roadmap to the phased approach.

9.3 Data Gaps and Site Wide Pre-Design Investigations

There are spatial and temporal gaps in the dataset used to prepare this FS. The FS approach mandated by the DEQ used conservative assumptions regarding to address the uncertainty.

The first step in the remedial design and implementation process will be to address data gaps through pre-design investigations. The objectives of the investigations will be to address the uncertainties in the soil leaching to groundwater, groundwater to surface water, and direct contact exposure pathways.

The following are objectives of the sitewide pre-design investigations:

- Contemporary data set to delineate current COC hot spots in soil and groundwater.

- Assessment of site-specific leaching of COCs from soil to groundwater and COC transport and exposure-point concentrations at a point of exposure in the river.
- Assessment of attenuation of COCs in soil and groundwater over time and distance to estimate concentrations at a point of exposure.
- Estimation of COC flux from upland groundwater to the river and the resulting concentrations in the river (porewater or water column).
- Assessment of attenuation of COCs through a possible in-water remedy.

The results of pre-design investigations will inform site-specific action levels and points of compliance for remedial design, performance monitoring, and residual risk assessment.

9.4 Phase 1 Remedial Actions

The remedial actions proposed for Phase 1 include:

1. Installation of caps and implementation of institutional controls for soil in FU-2 and FU-3 (Lots 1 & 2, western areas of Lot 3 & 4), where the recommended alternative is “capping” to address unacceptable direct exposure and leaching to groundwater pathways.
2. Immobilize and treat groundwater hot spots in FU-9 (i.e., DNAPL in Acid Plant Area) by ISCR/ISS and solidify hotspots in the vadose zone of FU-4 overlaying FU-9. The recommended alternative includes treatment via injection of ISCR reagents, as well as immobilization via injection of Portland cement.
3. Implement monitored natural attenuation in groundwater FU-7, FU-11, and FU-12 (Lots 1 & 2, western area of Lots 3 and 4). The recommended alternative in these FUs is monitored natural attenuation with reliance on downgradient treatment methods.
4. Treat or immobilize via ISCR injection programs – in FU-10 (Chlorate Plant Area/Salt Pads), a portion of the recommended alternative includes ISCR injections to treat areas with unacceptable concentrations of perchlorate and hexavalent chromium. The specific injection areas, if any, will be defined further in remedial design.

9.4.1 Phase 1 Pre-Design Investigations

The Phase 1 pre-design investigations would address uncertainties associated with the soil leaching to groundwater, groundwater to surface water, and direct contact exposure pathways, and provide the design basis for the ISCR/ISS program, ISCR injection program in the Chlorate Plant Area/Salt Pads, and engineered cap remedies.

The following are objectives of the Phase 1 pre-design investigations::

- Contemporary data set to delineate current soil and groundwater impacts.
- Assessment of site-specific leaching from soil to groundwater, and transport in groundwater to a point of exposure in the river.
- Assessment of attenuation of COCs in soil and groundwater over time and distance to estimate concentrations at a point of exposure.
- Estimation of COC flux from upland groundwater to the river and the resulting concentrations in the river (porewater or water column).
- Assessment of attenuation of COCs through a possible in-water remedy.

The outcomes of additional pre-design investigations included in Phase 1 are:

- Acid Plant Area ISCR/ISS – to provide the design basis of the remedy, including lateral and vertical extent of remedy, ISCR amendment selection and dosing, ISS amendment selection and mix design, application methods, and identification of constructability constraints (e.g., subsurface obstructions. Bench scale and pilot testing are likely components of this pre-design investigation.
- Chlorate Area/Salt Pads ISCR injection – to evaluate the current need for, and subsequent design basis of ISCR injections (if needed) including lateral and vertical extent of injection program, ISCR amendment selection and dosing, application methods, application rates and radius of influence, and identification of implementation constraints. Bench scale and pilot testing are likely components of this pre-design investigation.

9.4.2 Phase 1 Design and Implementation

Phase 1 remedial actions would be implemented concurrently. The Phase 1 remedial actions are in different areas of the site and are unlikely to have overlapping areas or interfere with each other. The Phase 1 remedial actions focus on sources of contamination that have the most significant impact on the design of subsequent remedial actions.

9.4.3 Phase 1 Performance Monitoring

The ongoing groundwater monitoring program assesses the groundwater SCM performance. Pre-design investigations for groundwater remedies will incorporate and expand on this existing program. Where MNA is the recommended remedial action, the performance monitoring can be implemented quickly. Pre-design groundwater data and monitoring for current baseline conditions in the ISCR/ISS and ISCR injection areas will be incorporated in these concurrent performance monitoring programs. The scope of performance monitoring and evaluation criteria will be detailed as part of the remedial design process. Phase 1 performance monitoring results will be used as part of the pre-design investigations for Phase 2 remedial actions.

9.5 Phase 2 Remedial Actions

The remedial actions proposed for Phase 2 include:

1. Installation of ISCR injected PRBs. In FU-5, FU-6, FU-8, and FU-10 (Lots 1 & 2 riverbank, north and south ends of the GWBW) a portion of the recommended alternative is the installation of an injected PRB designed to treat or immobilize contaminants to address unacceptable risk to receptors in the transition zone porewater, if necessary, based on the results of the pre-design investigations and studies. The scope, scale, or necessity of the implementation of these PRBs will be determined in pre-design investigations.
2. Treat or immobilize via ISCR injection programs – in groundwater FU-8 (Acid Plant Area outside of DNAPL area), pending the results of the Phase 1 performance evaluation, a portion of the recommended alternative includes focused injections to treat specific areas to be defined further in remedial design.

9.5.2 Phase 2 Pre-Design Investigations

The Phase 2 pre-design investigations would address uncertainties in contaminant transport in groundwater to the Willamette River along Lots 1 & 2, and in the Acid Plant Area.

The design of the Phase 2 remedial actions will depend on several factors and remedies, including the results of the leaching to groundwater and groundwater to surface attenuation evaluations; the site-specific actions and points of compliance; and the performance monitoring of the ISCR/ISS and focused excavation/capping remedies.

The outcomes of Phase 2 pre-design investigations are:

- Acid Plant Area ISCR Injections – to provide the design basis of the remedy, including lateral and vertical extent of remedy, ISCR amendment selection and dosing, application methods, and identification of constructability constraints (e.g., subsurface obstructions). Bench scale and pilot testing are likely components of this pre-design investigation.
- ISCR injected PRBs – to provide the design basis of ISCR injected PRBs including lateral and vertical extent of PRBs, ISCR and GAC amendment selection and dosing, application methods, application rates, and identification of implementation constraints. Bench scale and pilot testing are likely components of this pre-design investigation.

9.5.3 Phase 2 Design and Implementation

Remedial actions of Phase 2 would be implemented concurrently. These remedial actions are implementable in the same mobilization and require similar equipment. These remedial actions are focused on addressing the additional elevated concentrations that may or may not remain following implementation of Phase 1. The results of the implementation of Phase 2 remedial actions will have a significant impact on the design and scope of subsequent remedial actions.

9.5.4 Phase 2 Performance Monitoring

Performance monitoring for Phase 2 will incorporate and refine the program developed as part of Phase 1 performance monitoring. The Phase 2 monitoring will incorporate pre-design groundwater data and monitoring from Phase 1 implementation. The Phase 1 results will be the baseline to evaluate Phase 2. The remedial design will detail the scope of performance monitoring and evaluation criteria. The results of the Phase 2 performance monitoring will the basis of the pre-design investigations for Phase 3.

Phase 2 performance monitoring results will be used to determine if additional iterations of amendment applications or injection events are required to achieve the objectives of Phase 2 and allow for Phase 3 remedial actions to be implemented. The design of potential iterative amendment application will be based on the Phase 2 performance monitoring results and site conditions at that time.

9.6 Phase 3 Remedial Actions

The remedial actions proposed for Phase 3 include:

1. Installation of excavated PRBs in the GWBW. In FU-8 and FU-10, along the top of bank in Lots 3 and 4, a portion of the recommended alternative is the installation of three “gates” of excavated ISCR PRBs in place of the current portions of the GWBW designed to treat or immobilize residual contaminants in groundwater. A key aspect of this is to determine if residual concentrations following Phases 1 and 2 can be treated via PRBs in a funnel and gate arrangement.
2. Maintenance and/or Installation of caps and implementation of institutional controls for soil in remaining eastern areas of Lots 3 & 4 (Acid Plant Area, top of bank in Lots 3 & 4).

9.6.1 Phase 3 Pre-Design Investigations

The Phase 3 pre-design investigations would build on Phase 2 performance monitoring and identify concentrations of COCs that remain in the remedial action areas. The design of the Phase 3 remedial actions will depend on several future investigations and remedies, including the previous investigations discussed in this section, as well as performance monitoring from Phase 1 and Phase 2 remedies.

The following are objectives of the Phase 3 pre-design investigations:

- Installation of excavated PRB – to provide the design basis of the remedy, including lateral and vertical extent of remedy, ISCR amendment selection and dosing to build on selection in ISCR injection program, application methods, and identification of constructability constraints (e.g., subsurface obstructions). Bench scale and pilot testing are likely components of this pre-design investigation, although results from Phase 2 remedial actions will be used to inform the basis of design for this remedy.
- Maintenance and/or installation of caps and implementation of institutional controls for soil in remaining eastern areas of Lots 3 & 4 – to provide design basis of the remedy, including the lateral extent of additional capping, revisions to Phase 1 capping design, and addressing potential remaining soil hot spots.

9.6.2 Phase 3 Design and Implementation

Phase 3 remedial actions will be implemented sequentially. However, these remedial actions are implementable in the same mobilization and require similar equipment and will likely be conducted directly in sequence. These remedial actions are focused on addressing the additional elevated concentrations that may or may not remain following implementation of Phase 2.

9.6.3 Phase 3 Performance Monitoring

The performance monitoring for Phase 3 will incorporate and expand on the program developed as part of the Phase 1 and Phase 2 performance monitoring. Pre-design groundwater data and monitoring for conditions in the Phase 1 and Phase 2 implementation areas is expected to be incorporated as the baseline condition in these concurrent performance monitoring programs and the evaluation of these Phase 3 remedies. The scope of performance monitoring and evaluation criteria will be detailed as part of the remedial design process. Phase 3 performance monitoring results will be used to develop a plan to decommission the groundwater SCM, and its sequencing with the implementation of Phase 3 remedies.

Results of Phase 3 performance monitoring, in addition to the results of site MNA, will be used to inform the basis for site closure.

9.7 Remedy Implementation Roadmap

Pre-design investigations will begin after the DEQ approves the FS and issues a ROD. Figure 9-1 is an anticipated road map that outlines the implementation pathway. A remedial action work plan will develop the schedule for pre-design investigations, remedy design, remedy implementation, and performance monitoring.

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TABLES

Table 2-1
Site Hydrostratigraphy
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Hydrostratigraphic Unit Identification	Stratigraphic Units Included	Type of Hydrogeologic Unit	Horizontal GW Flow Direction[1]	Range of Average Horizontal GW Flow Gradient (feet/feet)[1]	Estimated Horizontal Hydraulic Conductivity (feet/day)[2]		Vertical GW Flow Direction[1]	Vertical Flow Gradient Range (feet/feet)[1,3]	Overlain By	Underlain By	Lateral Continuity
					From Grain Size	From NMR					
Vadose Zone[4]	Fill, Fine to Medium Sand with Silt and Clay	Unsaturated	N/A	N/A	N/A	N/A	N/A	N/A	Ground Surface	Shallow Zone	Across Site in all directions
	Sandy Silt, Clay with Silt[5]	Aquitard	N/A	N/A	N/A	N/A	N/A	N/A			In northeast portion of lot 3 (CS3) and in southwest corner of Lot 4 (CS4).
Shallow Zone[4]	Fill	Unconfined	North Corner Lot 4 - East to northeast; South Corner Lot 4 - East-southeast	November 2001 - 0.0024; February 1999 - 0.0069	N/A	N/A	Typically downwards, sometimes upwards depending on river stage	0.5448 (downward) to -0.2125 (upward)	Vadose Zone	Shallow-Intermediate Silt Zone	Across Site in all directions
	Fine to Medium Sand with Silt and Clay[5]	Semi-confined (confined where overlain by Clay with Silt unit)			36.9	1 - 10					Across Site in all directions
Shallow-Intermediate Silt Zone	Interbedded Silt and Sand	Aquitard	N/A	N/A	0.0142	1			Shallow Zone	Intermediate Zone	Across most of Site in all directions. Discontinuous and thin on south side of Site in Lot 4 (CS4 and CS5).
Intermediate Zone	Fine Sand with Clay	Semi-confined (confined where overlain by the Interbedded Silt and Sand unit)	North Corner Lot 4 - East-northeast; South Corner Lot 4 - East-southeast	June 1999 - 0.0038; September 1999 - 0.0069	23.9	10 - 100	Typically downwards, sometimes upwards depending on river stage	0.2063 (downward) to -0.0421 (upward)	Shallow-Intermediate Zone	Deep Zone	Across Site in all directions
Deep Zone	Silt with Clay	Aquitard	East-northeast	Feb 1999- 0.0093	0.00286	0.1			Intermediate Zone	Basalt	Across Site in all directions
Basalt Zone	Basalt	Confined	N/A	N/A	N/A	N/A	N/A	N/A	Deep Zone	N/A	Across Site in all directions

Notes:
[1] = *Hydrogeologic data from ERM 2005 Upland Remedial Investigation Report Lots 3 & 4 and Tract A – Revision 1.*
[2] = *See text, Figure 9, and Table 4 for additional details regarding estimates of hydraulic conductivity.*
[3] = *Negative is upwards and positive is downwards.*
[4] = *Contact between Vadose and Shallow Zones defined by either bottom of Clay with Silt unit (when in Localized Pressure Area) or potentiometric surface*
[5] = *Stratigraphic Unit details described in this row only where potentiometric surface is elevated from within Localized Pressure Area; Figures 4 and 6*
NAVD88 = Vertical Datum NAVD88. Bench Mark City of Portland #2528. COP Elev = 34.636, NAVD Elev 36.736
N/A = Not Applicable/Available
NMR = Nuclear Magnetic Resonance

Table 4-1
Human Health and Ecological Risk Assessment Summary, Soil Exposure
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Risk Assessment	Receptor	Potential Receptor Pathway		DEQ RBDM Exposure Pathway	COC with Non-Cancer Risk		COCs with Carcinogenic Risk (1)		COC Ecological Risk
		Area of Site	Exposure Depth		Hazard Index > 1	Hazard Index > 10	Compounds Exceeding RBDM SLVs	Carcinogenic Risk $> 1 \times 10^{-6}$	Hazard Quotient > 1
Human Health	Trespasser	Lots 1 & 2	0 to 3 ft	Residential	--	--	As, BaA, BaP, BbF, IcdP, PCBs, Aroclor 1248, DDD, DDE, DDT, TCDD-TEQ(4)	As, DDT, TCDD-TEQ(4)	N/A
		Riverbank	0 to 3 ft	Residential	--	--	As, Cr, Pb, BaA, BaP, BbF, BkF, DBahA, IcdP, PCBs, Aroclor 1248, DDE, DDT, Alpha-BHC, TCDD-TEQ	As, TCDD-TEQ	N/A
	Indoor Worker	Lots 3 & 4	0 to 15 ft	Occupational Worker	--	--	Dichlorobenzene, 1,4; PCE	1,4-Dichlorobenzene, PCE	N/A
	Outdoor Worker	Lots 1 & 2	0 to 3 ft	Occupational Worker	--	--	As, BaP, DDT, TCDD-TEQ(3)	As, DDT, TCDD-TEQ(4)	N/A
		Lots 3 & 4	0 to 3 ft	Occupational Worker	DDT (2.3)	--	PCBs, Aroclor 1248, DDD, DDE, DDT, BHC-alpha, MCB, TCDD-TEQ(4)	DDD, DDE, DDT, TCDD-TEQ	N/A
		Riverbank	0 to 3 ft	Occupational Worker	--	--	As, Cr, Pb, BaP, BbF, DBahA, DDT, TCDD-TEQ	As, TCDD-TEQ	N/A
	Outdoor Worker (Redevelopment)	Lots 1 & 2	0 to 15 ft	Occupational Worker	--	--	As, BaP, DDT	As, DDT, TCDD-TEQ(3)	N/A
		Lots 3 & 4	0 to 15 ft	Occupational Worker	DDT (2.3)	--	Cr, PCBs, Aroclor 1248, DDD, DDE, DDT, BHC-alpha, MCB, PCE, TCDD-TEQ(4)	DDD, DDE, DDT, TCDD-TEQ(4)	N/A
		Riverbank	0 to 3 ft	Occupational Worker	--	--	As, Cr, Pb, BaP, BbF, DBahA, DDT, TCDD-TEQ	As, TCDD-TEQ	N/A
	Construction Worker	Lots 1 & 2	0 to 15 ft	Construction Worker	--	--	As, DDT	As	N/A
		Lots 3 & 4	0 to 15 ft	Construction Worker	DDT (7.6)	--	Cr, PCBs, Aroclor 1248, DDD, DDE, DDT, MCB	DDT	N/A
		Riverbank	0 to 15 ft	Construction Worker	--	--	As, Cr, Pb, TCDD-TEQ	As, TCDD-TEQ(4)	N/A
	Excavation Worker	Lots 1 & 2	0 to 15 ft	Excavation Worker	--	--	--	--	N/A
		Lots 3 & 4	0 to 15 ft	Excavation Worker	--	--	Cr, DDT	--	N/A
		Riverbank	0 to 15 ft	Excavation Worker	N/A	N/A	N/A	N/A	N/A
	Indoor Worker	Site Wide	All Aquifers	Occupational Worker	--	--	Chloroform, Dichlorobenzene-1,4	Chloroform, Dichlorobenzene-1,4	N/A
Ecological	Plant	Lots 1 & 2, Riverbank	0 to 3 ft	Plant	N/A	N/A	N/A	N/A	Cr, Pb, Beta-HCH(2), As(2), Cu(2), Zn(2)
	Invertebrate	Lots 1 & 2, Riverbank	0 to 3 ft	Invertebrate	N/A	N/A	N/A	N/A	Cr(2), Pb,
	Bird	Lots 1 & 2, Riverbank	0 to 3 ft	Bird	N/A	N/A	N/A	N/A	As(2), Cr, Cu(2), Pb, Zn(2), alpha-HCH(2), DDX, DDD(2), DDE(2), DDT(2), TCDD-TEQ(3), PCBs(2), Aroclor 1260, PCB-TEQ
	Mammal	Lots 1 & 2, Riverbank	0 to 3 ft	Mammal	N/A	N/A	N/A	N/A	As(2), Cr, Cu(2), Zn(2), Pb(3), alpha-HCH(2), BEHP(2), DBahA, DDX, DDD(1), DDE(1), DDT(2), PCBs(2), TCDD-TEQ(2)

Notes:
(1) = Carcinogenic risk at the Reasonable Maximum Exposure (RME) concentration, calculated using the 90% upper confidence limit of the mean.
(2) = Per ODEQ's 15 March 2010 modification to the Arkema Level II Screening Ecological Risk Assessment.
(3) = Per 16 January 2009 Arkema Upland Level II Screening Ecological Risk Assessment.
(4) = 2,3,7,8-TCDD-TEQ added based on catch basin results.

-- = No Exceedance
Alpha-HCH = α-Hexachlorocyclohexane
As = Arsenic
BaA = Benzo(a)anthracene
BaP = Benzo(a)pyrene
BbF = Benzo(b)fluoranthene
BkF = Benzo(k)Fluoranthene
BEHP = Bis(2-ethylhexyl)phthalate
Beta-HCH = β-Hexachlorocyclohexane
Cr = Chromium
Cu = Copper
COC = Chemical of Concern
DDD = Dichloro-diphenyl-dichloroethane (2,4'-DDD + 4,4'-DDD)
DDE = Dichloro-diphenyl-chloroethane (2,4'-DDE + 4,4'-DDE)
DDT = Dichloro-diphenyl-trichloroethane (2,4'-DDT + 4,4'-DDT)
DDX = Sum Total of DDD, DDE, and DDT
DBahA = Dibenz(a,h)anthracene
IcdP = Indeno(c,d)pyrene
MCB = Monochorobenzene
N/A = Not Applicable
DEQ = Oregon Department of Environmental Quality
Pb = Lead
PCBs = polychlorinated biphenyls
PCB TEQ = polychlorinated biphenyl Toxicity Equivalence Quotient
RBDM = Risk-Based Decision Making, ODEQ (May 2018)
SLV = Screening Level Value
TCDD-TEQ = 2,3,7,8-Tetrachlorodibenzo-p-dioxin Toxicity Equivalence Quotient
Zn = Zinc

Table 6-1
Preliminary Project ARARs
Arkema Feasibility Study
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 remedial actions in the riverbank and in-water early action.
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.
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 removal or treatment actions 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 applicable as riverbank remedial actions may potentially impact listed species in and adjacent to the Willamette River.
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 some remedial actions 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 may be applicable because riverbank remedial actions may potentially 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 remedial 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.

Table 6-1
Preliminary Project ARARs
Arkema Feasibility Study
Arkema Inc.
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ARAR and Citation	Description	Applicability
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 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.	This regulation is only applicable if Native American remains or funerary objects are at the 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.
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.
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 a remedial action.
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 implementation of remedial 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 remedial actions.

Table 6-1
Preliminary Project ARARs
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

ARAR and Citation	Description	Applicability
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 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 remedial actions generate visible emissions of air contaminants.
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 implementation of a remedial action 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 to remedial actions in the riverbank.
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 a 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 a remedial action requires dredging and/or filling in the Willamette River.
City of Portland Industrial Wastewater Discharge Limits [Section 17.34 of the Portland Code]	The City of Portland Industrial Wastewater Discharge Limits establishes 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 Heavy Industrial overlay zone.

Table 6-2
Numerical RAOs for Soil
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

	Background Concentration(e)	RAO1[3] Direct Exposure Pathway for Human Health Receptors	RAO2[3] Direct Exposure Pathway for Ecological Receptors	RAO3 Soil Erosion to the Willamette River	RAO4[3] Direct Exposure Pathway for Human Health Receptors (Hot Spot Criteria)
FSWP Table Reference[1]	N/A	Table 5-4	Table 5-5	Table 5-7	Table 5-4
Contaminant of Concern	(mg/kg)	(mg/kg)	(mg/kg) N/A[2]	(mg/kg)	(mg/kg)
Inorganics					
Arsenic	8.8	0.43	18	3	43
Cadmium	-	-	-	1	-
Chromium (III)	76	120000	0.4	-	>Max
Chromium (VI)	-	0.3	-	-	30
Chromium (total)	76	-	76	111	-
Copper	N/A	-	28	-	-
Lead	79	400.00	79	196	4,000
Zinc	-	-	-	459	-
Organics					
alpha-Hexachlorocyclohexane	N/A	-	0.0025	-	-
Bis(2-ethylhexyl)Phthalate	N/A	-	0.925	0.14	-
beta-Hexachlorocyclohexane	N/A	-	0.00398	-	-
DDX	N/A	-	0.021	-	-
PCBs	N/A	-	0.05	-	-
Aroclor 1248	N/A	-	0.05	-	-
Aroclor 1260	N/A	-	0.05	-	-
Tetrachloroethene (PCE)	-	36	-	-	43000
1,4 - Dichlorobenzene	-	13	-	-	-
Chlorobenzene	-	4700	-	-	-
Chrysene	-	-	-	1.29	
Benzo(a)anthracene	-	1.1	-	1.05	110
Benzo(a)pyrene	-	0.11	-	-	11
BaP equivalents	-	0.11	-	-	11
Benzo(b)fluoranthene	-	1.1	-	-	100
Benzo(k)fluoranthane	-	11	-	-	1100
Benzo(g,h,i)perylene	-		-	0.30	

Table 6-2
Numerical RAOs for Soil
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

	Background Concentration(e)	RAO1[3] Direct Exposure Pathway for Human Health Receptors	RAO2[3] Direct Exposure Pathway for Ecological Receptors	RAO3 Soil Erosion to the Willamette River	RAO4[3] Direct Exposure Pathway for Human Health Receptors (Hot Spot Criteria)
FSWP Table Reference[1]	N/A	Table 5-4	Table 5-5	Table 5-7	Table 5-4
Contaminant of Concern	(mg/kg)	(mg/kg)	(mg/kg) N/A[2]	(mg/kg)	(mg/kg)
Dibenzo(a,h)anthracene	-	0.11	-	-	-
Indeno(1,2,3-cd)pyrene	-	1.1	-	0.10	-
PAHs-Total	-	-	-	23	-
cPAH (BaP eq)	-	-	-	0.01	-
Dieldrin	-	-	-	0.00007	-
DDD	-	2.2	-	0.11	22
DDE	-	1.8	-	0.23	180
DDT	-	1.9	-	0.25	190
DDX (Total)	-	-	-	0.006	-
alpha-Hexachlorocyclohexane	-	0.086	-	-	8.6
Hexachlorobenzene	-	-	-	0.02	-
Phenols					
Pentachlorophenol	-	-	-	0.25	-
PCBs					
PCB TEQ	N/A	-	0.000002	-	-
2,3,7,8-TCDD TEQ	N/A	0.0000047	0.000055	-	0.00047
PCBs (Total)	-	-	-	0.009	-
Dioxin/Furans					
2,3,7,8-TCDD	-	-	-	2.00E-07	-
1,2,3,7,8-PeDD	-	-	-	2.00E-07	-
1,2,3,4,6,7,8-HpDD	-	-	-	6.90E-04	-
2,3,7,8-TCDF	-	-	-	4.07E-07	-
1,2,3,7,8-PeDF	-	-	-	3.00E-06	-
2,3,4 ,7,8-PeDF	-	-	-	3.00E-08	-
1,2,3,4,7,8-HxDF	-	-	-	4.00E-07	-
1,2,3,6,7,8-HxDF	-	-	-	2.70E-06	-
1,2,3,7,8,9-HxDF	-	-	-	2.70E-06	-

Table 6-2
Numerical RAOs for Soil
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

	Background Concentration(e)	RAO1[3] Direct Exposure Pathway for Human Health Receptors	RAO2[3] Direct Exposure Pathway for Ecological Receptors	RAO3 Soil Erosion to the Willamette River	RAO4[3] Direct Exposure Pathway for Human Health Receptors (Hot Spot Criteria)
FSWP Table Reference[1]	N/A	Table 5-4	Table 5-5	Table 5-7	Table 5-4
Contaminant of Concern	(mg/kg)	(mg/kg)	(mg/kg) N/A[2]	(mg/kg)	(mg/kg)
2,3,4,6,7,8,9-HxDF	-	-	-	2.70E-06	-
1,2,3,4,6,7,8-HpDF	-	-	-	6.90E-04	-

Notes:
1. DEQ 2019. DEQ Final Modification "Revised Upland Feasibility Study Work Plan"
2. There is no viable habitat in upland soil on Lots 1, 2, 3, and 4.
3. For RAO1, RAO2 and RAO4, the lowest receptor concentration was selected as the numeric RAO.
- = Criteria not available, or compound screened out based on Human Health Risk Assessment or Baseline Ecological Risk Assessment.
N/A = Not Applicable
mg/kg = milligrams per kilogram
ug/L = micrograms per liter
cPAH = carcinogenic polycyclic aromatic hydrocarbon
DDD = Dichloro-diphenyl-dichloroethane (2,4'-DDD + 4,4'-DDD)
DDE = Dichloro-diphenyl-chloroethane (2,4'-DDE + 4,4'-DDE)
DDT = Dichloro-diphenyl-trichloroethane (2,4'-DDT + 4,4'-DDT)
DDX = Sum total of DDD, DDE, and DDT
DEQ = Oregon Department of Environmental Quality
HHRA = Human Health Risk Assessment
HSE = Hot Spot Evaluation
PAHs = Polycyclic aromatic hydrocarbons
PCBs = Polychlorinated biphenyls
PCE = Tetrachloroethylene
RAO = Remedial action objective
TCDD TEQ = 2,3,7,8-Tetrachlorodibenzo-p-dioxin Toxicity Equivalence Quotient

Table 6-3
Numerical RAOs for Groundwater and Stormwater
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

	Background Concentration[(e)]	RAO1[2] Direct Exposure Pathway for Human Health Receptors	RAO5 and RAO6[2] Groundwater Discharge to the Willamette River	RAO9 and RAO10 Stormwater Discharge to the Willamette River
FSWP Table Reference[1]	N/A	Table 5-4	Table 5-6, Table 4-4	Table 5-8
Contaminant of Concern	(ug/L)	(ug/L)	(ug/L)	(ug/L)
Metals				
Arsenic	3 - 5	-	2.1	0.018
Cadmium	-	-	0.094	-
Chromium III	-	-	23.81	-
Chromium VI	-	-	11	100
Copper	-	-	0.012	2.74
Iron (total)	-	-	1000	-
Manganese	-	-	430	-
Mercury (total)	-	-	0.012	-
Nickel	-	-	16.1	-
Zinc	-	-	36.5	36.5
Chloride	-	-	230,000	-
Perchlorate	-	-	1,800	-
VOCs				
Dichlorobenzene(o) 1,2	-	-	14	-
Dichlorobenzene(m) 1,3	-	-	7	-
Dichlorobenzene(p) 1,4	-	7100	15	-
Benzene	-	-	0.44	-
Dichlorobromomethane	-	-	0.42	-
Carbon Disulfide	-	-	0.92	-
Carbon Tetrachloride	-	-	0.1	-
Chlorobenzene	-	-	64	-
Chloroform	-	1600	28	-
Chlorodibromomethane	-	-	0.31	-
Hexachlorobutadiene	-	-	0.01	-

Table 6-3
Numerical RAOs for Groundwater and Stormwater
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

	Background Concentration(e)	RAO1[2] Direct Exposure Pathway for Human Health Receptors	RAO5 and RAO6[2] Groundwater Discharge to the Willamette River	RAO9 and RAO10 Stormwater Discharge to the Willamette River
FSWP Table Reference[1]	N/A	Table 5-4	Table 5-6, Table 4-4	Table 5-8
Contaminant of Concern	(ug/L)	(ug/L)	(ug/L)	(ug/L)
Methylene Chloride	-	-	4.3	-
Tetrachloroethylene	-	-	0.24	-
Trichloroethylene	-	-	1.4	-
Vinyl Chloride	-	-	0.022	-
sVOCs				
Pentachlorophenol	-	-	-	0.03
PAHs				
Benzo(a)anthracene	-	-	-	0.0012
Benzo(a)pyrene	-	-	-	0.00012
Benzo(k)fluranthene	-	-	-	0.0013
Chrysene	-	-	-	0.0013
Dibenzo(a,h)anthracene	-	-	-	0.00012
Indeno(1,2,3-cd)pyrene	-	-	-	0.0012
cPAHs	-	-	-	0.00012
Pesticides				
BHC Alpha	-	-	0.00036	-
BHC Beta	-	-	0.0016	-
BHC Gamma (Lindane)	-	-	0.08	-
Chlordane	-	-	0.000081	-
Dieldrin	-	-	0.0000012	-
Heptachlor	-	-	0.0000059	-
Heptachlor Epoxide	-	-	0.0000039	-
DDD 4,4'	-	-	0.000031	0.000031
DDE 4,4'	-	-	0.000018	0.000018

Table 6-3
Numerical RAOs for Groundwater and Stormwater
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

	Background Concentration(e)	RAO1[2] Direct Exposure Pathway for Human Health Receptors	RAO5 and RAO6[2] Groundwater Discharge to the Willamette River	RAO9 and RAO10 Stormwater Discharge to the Willamette River
FSWP Table Reference[1]	N/A	Table 5-4	Table 5-6, Table 4-4	Table 5-8
Contaminant of Concern	(ug/L)	(ug/L)	(ug/L)	(ug/L)
DDT 4,4'	-	-	0.000022	0.000022
DDx			-	0.01
Dioxin and Furans				
Dioxin (2,3,7,8-TCDD)	-	-	5.1E-10	5E-10

Notes:
1. DEQ 2019. DEQ Final Modification "Revised Upland Feasibility Study Work Plan"
2. For RAO1, RAO5 and RAO6, the lowest receptor concentration was selected as the numeric RAO.
- = Criteria not available, or compound screened out based on Human Health Risk Assessment or Baseline Ecological Risk Assessment.
N/A = Not Applicable
mg/kg = milligrams per kilogram
ug/L = micrograms per liter
cPAHs = carcinogenic polycyclic aromatic hydrocarbons
DDD = Dichloro-diphenyl-dichloroethane (2,4'-DDD + 4,4'-DDD)
DDE = Dichloro-diphenyl-chloroethane (2,4'-DDE + 4,4'-DDE)
DDT = Dichloro-diphenyl-trichloroethane (2,4'-DDT + 4,4'-DDT)
DDX = Sum total of DDD, DDE, and DDT
DEQ = Oregon Department of Environmental Quality
HHRA = Human Health Risk Assessment
PAHs = Polycyclic aromatic hydrocarbons
PCE = Tetrachloroethylene
RAO = Remedial action objective
sVOCs = Semi-volatile organic compounds
TCDD TEQ = 2,3,7,8-Tetrachlorodibenzo-p-dioxin Toxicity Equivalence Quotient

Table 6-4
Functional Units
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Functional Unit		Figure	COCs	Media, Depth, Units	Description	Exposure Pathways	Example Candidate Technologies
1	Soil Riverbank (addressed under in-water FS)	1	Metals, pesticides, and dioxins[1]	• Shallow soil • 0 to 3 ft • Riverbank, site wide	The entire riverbank is impacted by at least one COC, as delineated in the FSWP and HSE. See FSWP Figure 2-2. Previous negotiations (DEQ 2017) with the DEQ identified soil removal to a depth of 3 feet as the presumed remedy. Soil disposal in accordance with criteria established in the FS and in the RD/RA.	• Human: site workers (depth up to 3 feet), trespasser (surface) • Ecological: direct exposure, LtGW • Riverbank erosion	Excavation and capping is the presumed remedy
2	Soil Lots 1, 2, 3, and 4 (not including Acid Plant Area)	1	Metals and pesticides, LtGW Arsenic and pesticides, direct exposure	• Soil • 0 to 15 ft (LtGW) • 0 to 15 ft (direct exposure)	Composite hot spots of pesticides and metals with both leaching to groundwater and direct exposure.	• Ecological: LtGW • Human: site workers pesticides (depth up to 15 feet), trespasser arsenic Lot 1 (depth up to 3 feet)	Excavation, capping, in-situ remediation, institutional controls
3	Soil Acid Plant Area (not including DNAPL zone) Lots 3 and 4	1	Metals, pesticides, and VOCs in soil	• Soil • 0 to 15 ft	Historical releases of VOCs and composite hot spots of metals and pesticides leaching to groundwater. Area surrounding the former site of the acid plant.	• Human: site workers (depth up to 15 feet), trespasser (surface) • Ecological: Leaching to groundwater	Excavation, capping, in-situ remediation, institutional controls
4	Soil Acid Plant Lots 3 and 4	1	Metals, pesticides, VOCs, and DNAPL in soil	• Soil • 0 to 15 ft	Historical releases of VOCs, DNAPL (chlorobenzene), and composite hot spots of metals and pesticides, LtGW.	• Human: site workers (depth up to 15 feet), trespasser (surface) • Ecological: Leaching to groundwater	Excavation, capping, in-situ remediation, institutional controls
5	Groundwater Shallow and Intermediate Lots 1 and 2	2	Metals and pesticides in Shallow Zone, chloride in Shallow and Intermediate zones, VOCs in all zones of groundwater (trespasser plume)	• Groundwater • Shallow and Intermediate • Lots 1 & 2	Metals, pesticides, and chloride in groundwater in shallow and intermediate zone. VOCs in the shallow and intermediate zones.GW in the deep, and gravel/basalt zones are a part of FU-13.	• Ecological: Groundwater to surface water.	Monitored natural attenuation, in-situ remediation
6	Groundwater Riverside of Lot 3	2	Metals and pesticides in Shallow Zone, chloride and VOCs in Shallow, Intermediate, and Deep zones	• Groundwater • Shallow, Intermediate, and Deep • Riverside Lot 3	Riverside portion of Lot 3 not bound by the groundwater barrier wall (GWBW). VOCs and chloride in shallow, intermediate, and deep groundwater. Metals and chloride in shallow and intermediate zones.	• Ecological: Groundwater to surface water	Monitored natural attenuation, in-situ remediation
7	Groundwater Lots 3 and 4	2	Metals, chloride, and pesticides in Shallow and Intermediate zones	• Groundwater • Shallow and Intermediate • Lots 3 & 4	Shallow and intermediate groundwater with metals, pesticides, and chloride.	• Ecological: Groundwater to surface water	Monitored natural attenuation, in-situ remediation, hydraulic control
8	Groundwater Northern Portion of Site Bound by GWBW Lots 3 and 4	2	Chromium, pesticides, and VOCs in Shallow, Intermediate, and Deep zones	• Groundwater • Shallow, Intermediate, and Deep • Lots 3 & 4	Northern portion of the site in Lots 3 and 4 that is bound by the GWBW. Chromium, pesticides, and VOCs in shallow, intermediate, and deep groundwater.	• Ecological: Groundwater to surface water	Monitored natural attenuation, in-situ remediation, hydraulic control

Table 6-4
Functional Units
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Functional Unit		Figure	COCs	Media, Depth, Units	Description	Exposure Pathways	Example Candidate Technologies
9	Groundwater in DNAPL Plume Area Lots 3 and 4	2	Chromium, pesticides, and VOCs in Shallow, Intermediate, and Deep zones. DNAPL in Shallow Zone.	• Groundwater • Shallow, Intermediate, and Deep • Lots 3 & 4	Northern portion of the site in Lots 3 and 4 that is bound by the GWBW. Chromium, pesticides, and VOCs in shallow, intermediate, and deep groundwater. Includes chlorobenzene DNAPL underneath the acid plant area.	• Ecological: Groundwater to surface water	Monitored natural attenuation, in-situ remediation, hydraulic control
10	Groundwater Southern Portion of Site Bound by GWBW Lots 3 and 4	2	Chromium, pesticides, and perchlorate in Shallow, Intermediate, and Deep zones.	• Groundwater • Shallow, Intermediate, and Deep • Lot 4	Southern portion of the site that is bound by the GWBW. Chromium, pesticides, and perchlorate in shallow, intermediate, and deep groundwater.	• Ecological: Groundwater to surface water	Monitored natural attenuation, in-situ remediation, hydraulic control
11	Groundwater Deep and Gravel/Basalt Zone Lots 3 & 4	2	Metals, chloride, and VOCs	• Groundwater • Gravel/Basalt Zone • Lots 3 & 4	Gravel/basalt zone on southern portion of the site with chloride, metals, and VOCs.	• Ecological: Groundwater to surface water	Monitored natural attenuation, in-situ remediation
12	Groundwater Deep and Gravel/Basalt Zone Lots 1 and 2	2	Metals, chloride, and VOCs	• Groundwater • Gravel/Basalt Zone • Lots 1 & 2	Gravel/basalt zone on northern portion of the site with chloride, metals, and VOCs. VOCs in Lots 1 and 2 represent a trespasser plume.	• Ecological: Groundwater to surface water	Monitored natural attenuation, in-situ remediation

Notes:

(1) The focus of technologies and alternatives in this FS is contamination resulting from historical operations and not naturally occurring COCs such as metals. Pre-design sampling and evaluations of the actual extent of COCs, and their fate and transport (i.e., potential for attenuation) will assess the need for and the design and sequencing of any remedial action.

bgs = Below ground surface
COC = Contaminant of concern
DEQ = Oregon Department of Environmental Quality
DNAPL = Dense non-aqueous phase liquid
El. = Elevation
FS = Feasability Study
FSWP = Feasibility Study Work Plan
ft = Feet
GWBW = Groundwater barrier wall
HSE = Hot Spot Evaluation
LtGW = Leaching to groundwater
RD/RA = Remedial design/remedial action
VOCs = Volatile organic compounds

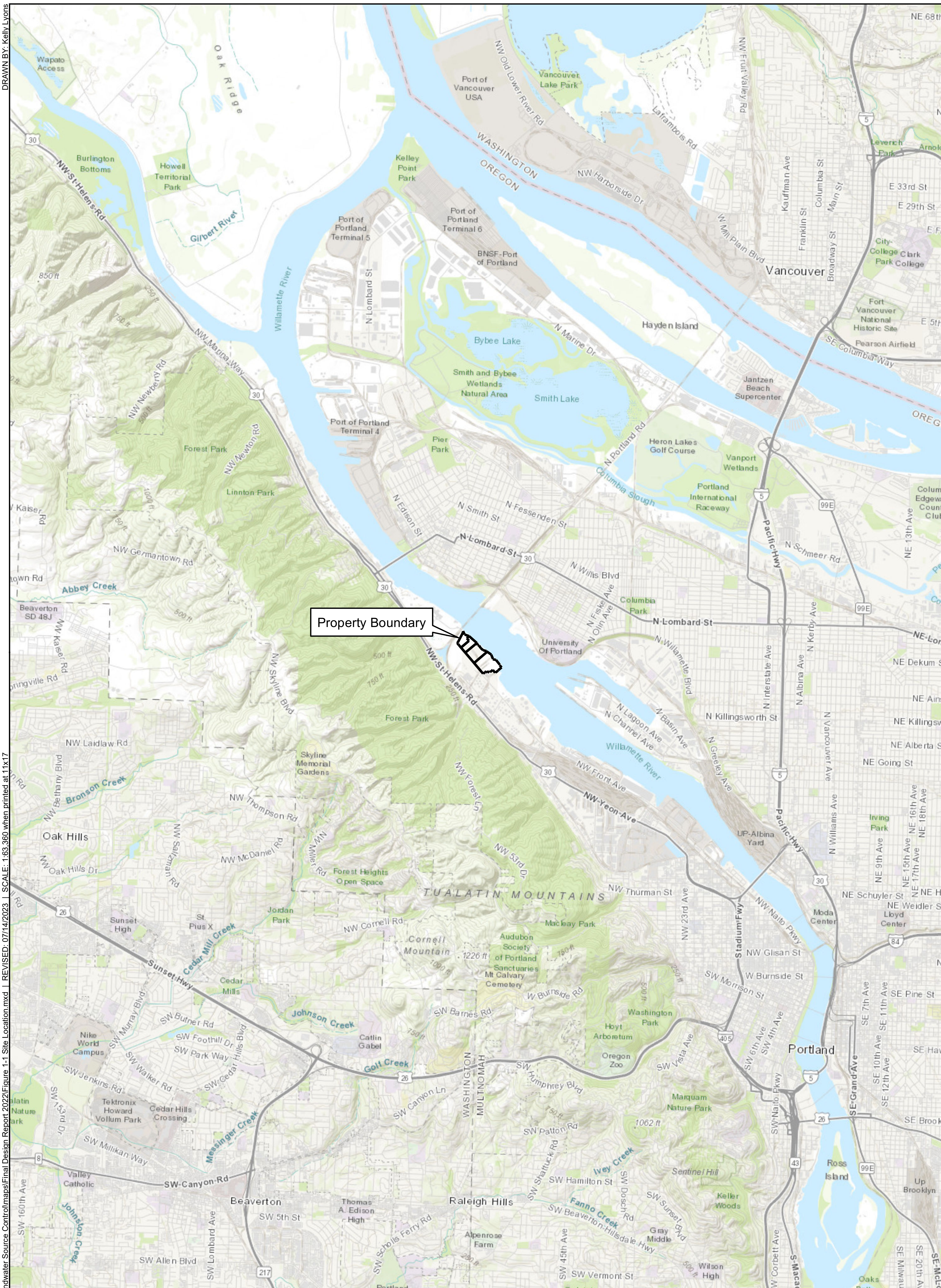
Table 6-5
Summary of Treatment Areas and Volumes
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

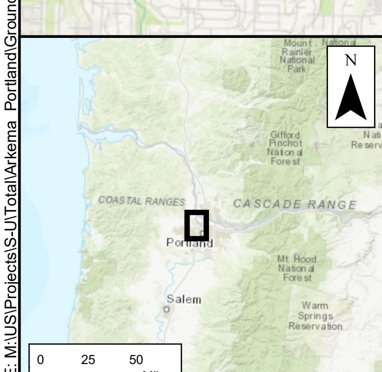
Functional Unit		Figure	COCs	Description	Media, Depth, Units	Depth interval / Elevation Interval	Unit Thickness (ft)	Area		Volume	
								ft^2	acres	ft^3	yds^3
1	Soil Riverbank (addressed under in-water FS)	1	Metals, pesticides, and dioxins	The entire riverbank is impacted by at least one COC, as delineated in the FSWP and HSE. See FSWP Figure 2-2. Previous negotiations (DEQ 2017) with the DEQ identified soil removal to a depth of 3 feet as the presumed remedy. Soil disposal in accordance with criteria established in the FS and in the RD/RA.	• Shallow soil • 0 to 3 ft • Riverbank, site wide	0 to 3 ft bgs	3	234,055	5.4	702,165	26,006
2	Soil Lots 1, 2, 3, and 4 (not including Acid Plant Area)	1	Metals and pesticides, LtGW Arsenic and pesticides, direct exposure	Composite hot spots of pesticides and metals with both leaching to groundwater and direct exposure.	• Soil • 0 to 15 ft (LtGW) • 0 to 15 ft (direct exposure)	0 to 15 ft bgs	15	2,286,441	52.5	34,296,617	1,270,245
3	Soil Acid Plant Area (not including DNAPL zone) Lots 3 and 4	1	Metals, pesticides, and VOCs in soil	Historical releases of VOCs and composite hot spots of metals and pesticides leaching to groundwater. Area surrounding the former site of the acid plant.	• Soil • 0 to 15 ft	0 to 15 ft bgs	15	165,980	3.8	2,489,701	92,211
4	Soil Acid Plant Lots 3 and 4	1	Metals, pesticides, VOCs, and DNAPL in soil	Historical releases of VOCs, DNAPL (chlorobenzene), and composite hot spots of metals and pesticides leaching to groundwater.	• Soil • 0 to 15 ft	0 to 15 ft bgs	15	53,493	1.2	802,394	29,718
5	Groundwater Shallow and Intermediate Lots 1 and 2	2	Metals and pesticides in Shallow Zone, chloride in Shallow and Intermediate zones, VOCs in all zones of groundwater (trespasser plume)	Metals, pesticides, and chloride in groundwater in Shallow and Intermediate zones. VOCs in the Shallow and Intermediate zones. GW in the Deep and Gravel/Basalt zones are a part of FU-13.	• Groundwater • Shallow and Intermediate • Lots 1 & 2	34 to 7 ft El.	29	636,957	14.6	18,471,756	684,139
6	Groundwater Riverside of Lot 3	2	Metals and pesticides in Shallow Zone, chloride and VOCs in Shallow, Intermediate, and Deep zones	Riverside portion of Lot 3 not bound by the GWBW. VOCs and chloride in Shallow, Intermediate, and Deep zones. Metals and chloride in Shallow and Intermediate zones.	• Groundwater • Shallow, Intermediate, and Deep • Riverside Lot 3	28 to -26 ft El.	33	151,432	3.5	4,997,249	185,083
7	Groundwater Lots 3 and 4	2	Metals, chloride, and pesticides in Shallow and Intermediate zones	Shallow and Intermediate zones with metals, pesticides, and chloride.	• Groundwater • Shallow and Intermediate • Lots 3 & 4	34 to 7 ft El.	29	630,167	14.5	18,274,831	676,846
8	Groundwater Northern Portion of Site Bound by GWBW Lots 3 and 4	2	Chromium, pesticides, and VOCs in Shallow, Intermediate, and Deep zones	Northern portion of the site in Lots 3 and 4 that is bound by the GWBW. Chromium, pesticides, and VOCs in Shallow, Intermediate, and Deep zones.	• Groundwater • Shallow, Intermediate, and Deep • Lots 3 & 4	20 to -28 ft El.	48	436,940	10.0	20,973,110	776,782
9	Groundwater in DNAPL Plume Area Lots 3 and 4	2	Chromium, pesticides, and VOCs in Shallow, Intermediate, and Deep zones. DNAPL in Shallow Zone.	Northern portion of the site in Lots 3 and 4 that is bound by the GWBW. Chromium, pesticides, and VOCs in Shallow, Intermediate, and Deep zones. Includes chlorobenzene DNAPL underneath the Acid Plant Area.	• Groundwater • Shallow, Intermediate, and Deep • Lots 3 & 4	17 to -20 ft El.	37	90,276	2.1	3,340,213	123,712
10	Groundwater Southern Portion of Site Bound by GWBW Lots 3 and 4	2	Chromium, pesticides, and perchlorate in Shallow, Intermediate, and Deep zones.	Southern portion of the site that is bound by the GWBW. Chromium, pesticides, and perchlorate in Shallow, Intermediate, and Deep zones.	• Groundwater • Shallow, Intermediate, and Deep • Lot 4	15 to -50 ft El.	66	1,053,648	24.2	69,540,749	2,575,583
11	Groundwater Deep and Gravel/Basalt Zone Lots 3 & 4	2	Metals, chloride, and VOCs	Gravel/Basalt Zone on southern portion of the site with chloride, metals, and VOCs.	• Groundwater • Gravel/Basalt Zone • Lots 3 & 4	0 to -50 ft El.	50	1,705,996	39.2	85,299,805	3,159,252
12	Groundwater Deep and Gravel/Basalt Zone Lots 1 and 2	2	Metals, chloride, and VOCs	Gravel/Basalt Zone on northern portion of the site with chloride, metals, and VOCs. VOCs in Lots 1 and 2 represent a trespasser plume.	• Groundwater • Gravel/Basalt Zone • Lots 1 & 2	-6 to -50 ft El.	46	636,957	14.6	29,300,027	1,085,186

Table 6-5
Summary of Treatment Areas and Volumes
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Notes:
bgs = Below ground surface
COC = Contaminant of concern
DEQ = Oregon Department of Environmental Quality
DNAPL = Dense non-aqueous phase liquid
El. = Elevation
FS = Feasability Study
FSWP = Feasibility Study Work Plan
ft = Feet
GWBW = Groundwater barrier wall
HSE = Hot Spot Evaluation
LtGW = Leaching to groundwater
RD/RA = Remedial design/remedial action
VOCs = Volatile organic compounds

FIGURES





Legend

— Parcel and Property Boundaries

N

0 1 2

Miles

Figure 1-1
Site Location
Feasibility Study
Arkema Inc.
Portland, Oregon

Environmental Resources Management
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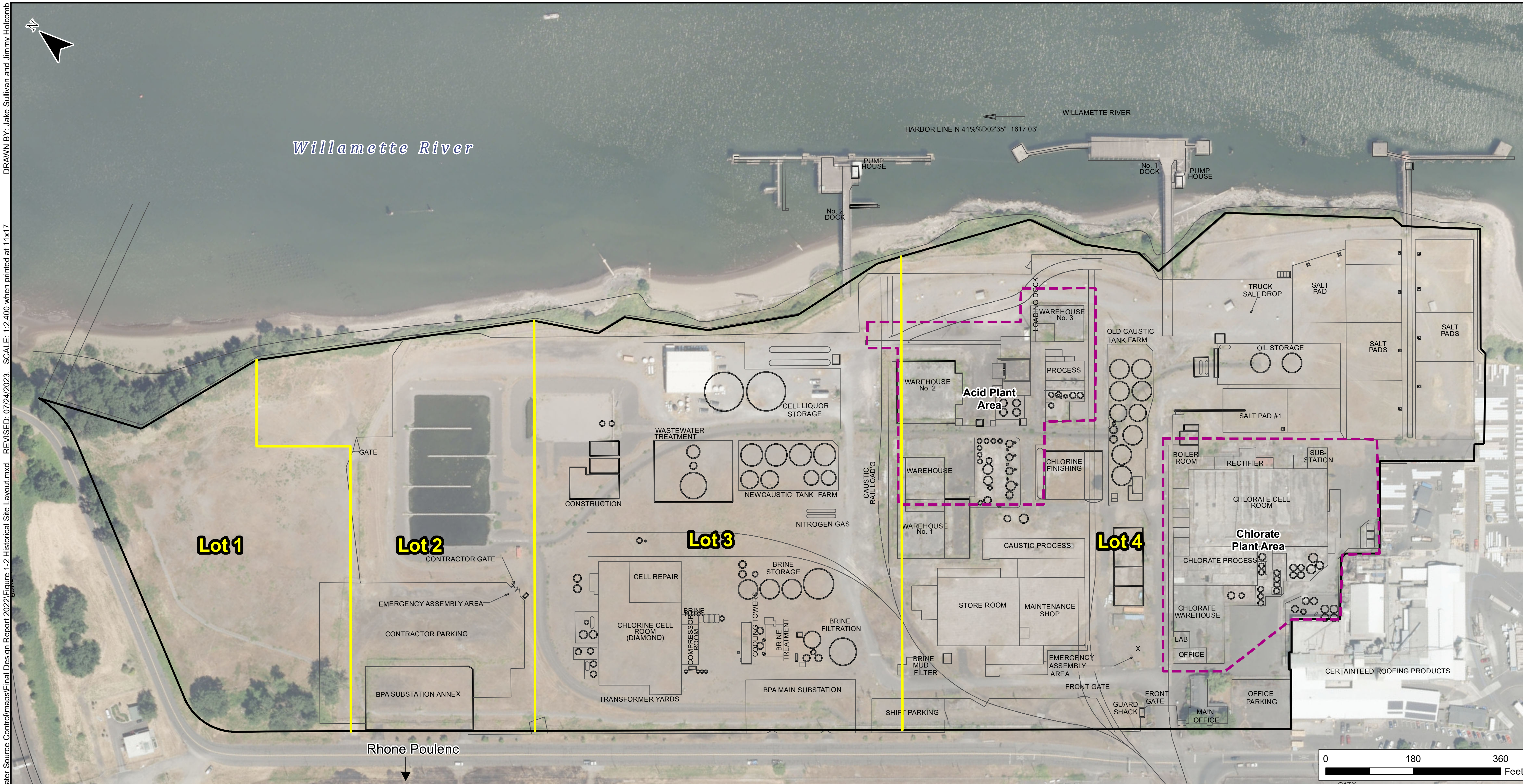
ERM

DRAWN BY: Kelly Lyons

FILE: M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 1-1 Site Location.mxd | REVISED: 07/14/2023 | SCALE: 1:63,360 when printed at 11x17

Source: Esri - World Topoographic Map; NAD 1983 StatePlane Oregon North FIPS 3601 Feet Intl



M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 1-2 Historical Site Layout.mxd, REVISED: 07/24/2023, SCALE: 1:2,400 when printed at 11x17, DRAWN BY: Jake Sullivan and Jimmy Holcomb

Legend

- Parcel and Property Boundaries
- Lot Boundaries
- Acid Plant Area and Chlorate Plant Area Boundaries

Note:
A number of the buildings and structures noted on this diagram have been demolished and/or removed.

Figure 1-2
Historical Site Layout
Feasibility Study
Arkema Inc.
Portland, Oregon

Environmental Resources Management
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ERM

Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl

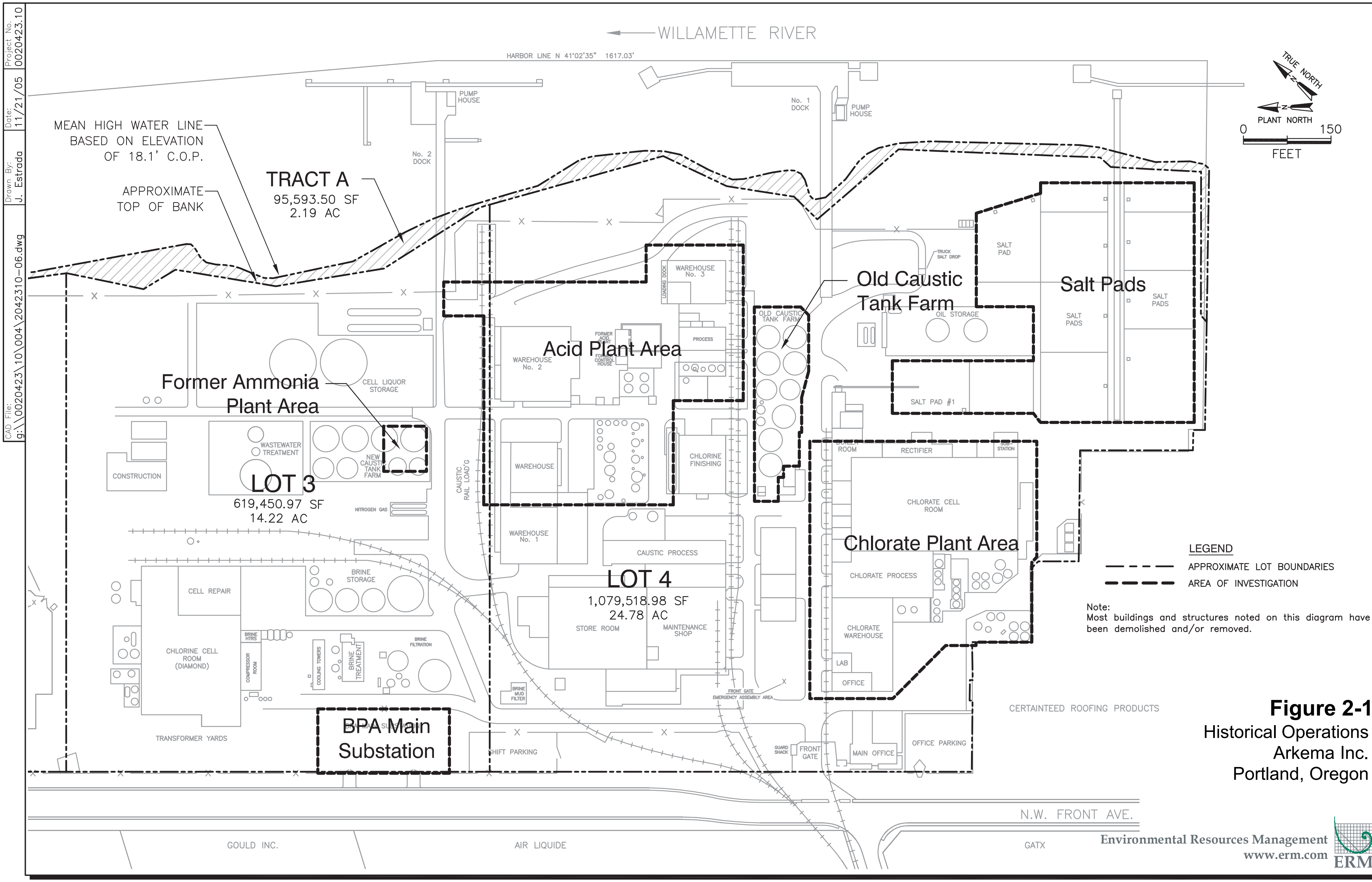

Figure 2-1
Historical Operations
Arkema Inc.
Portland, Oregon

CAD File:	Drawn By:	Date:	Project No.
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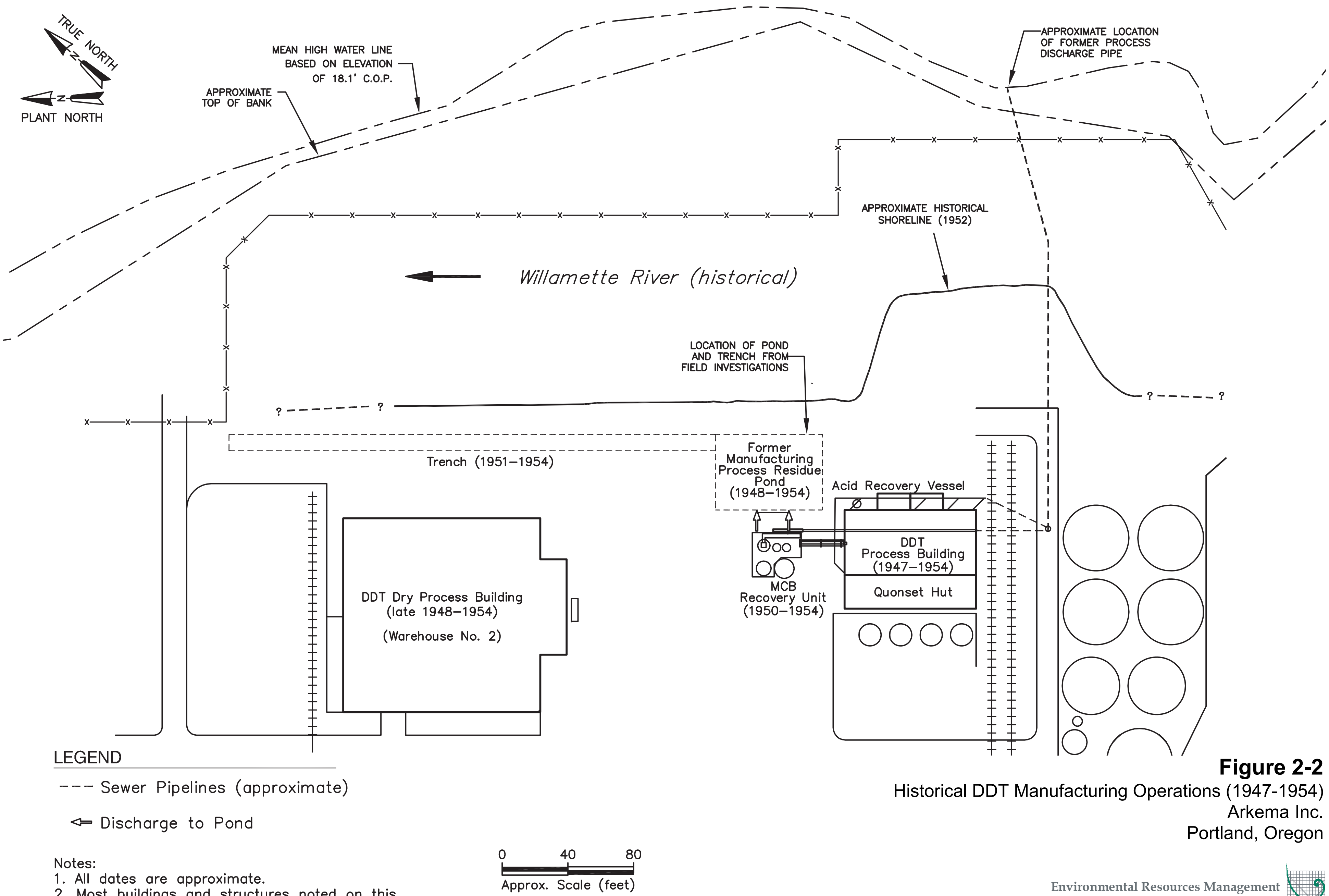

Figure 2-2
Historical DDT Manufacturing Operations (1947-1954)
Arkema Inc.
Portland, Oregon

LEGEND

--- Sewer Pipelines (approximate)

⇦ Discharge to Pond

Notes:
1. All dates are approximate.
2. Most buildings and structures noted on this diagram have been demolished and/or removed.

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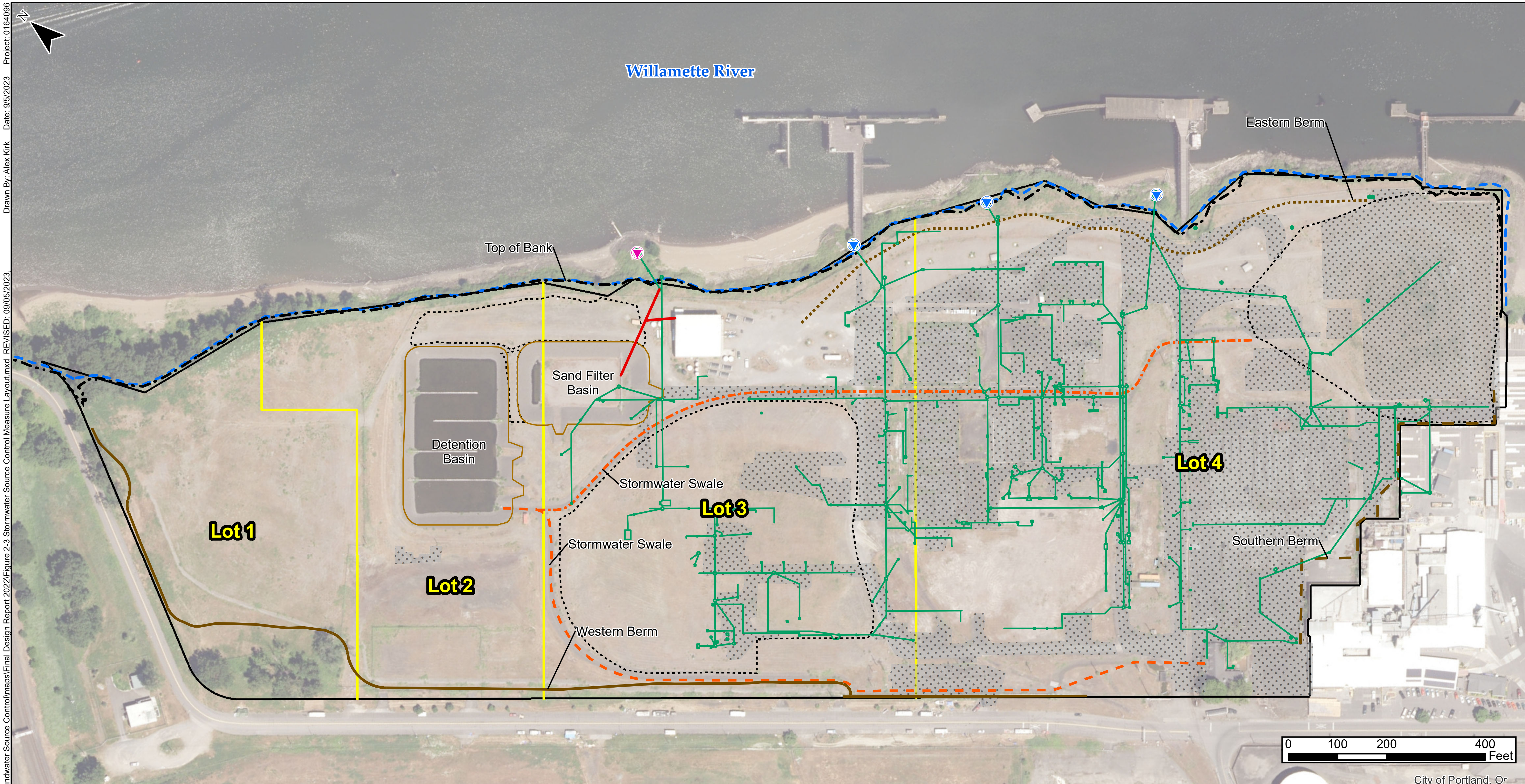
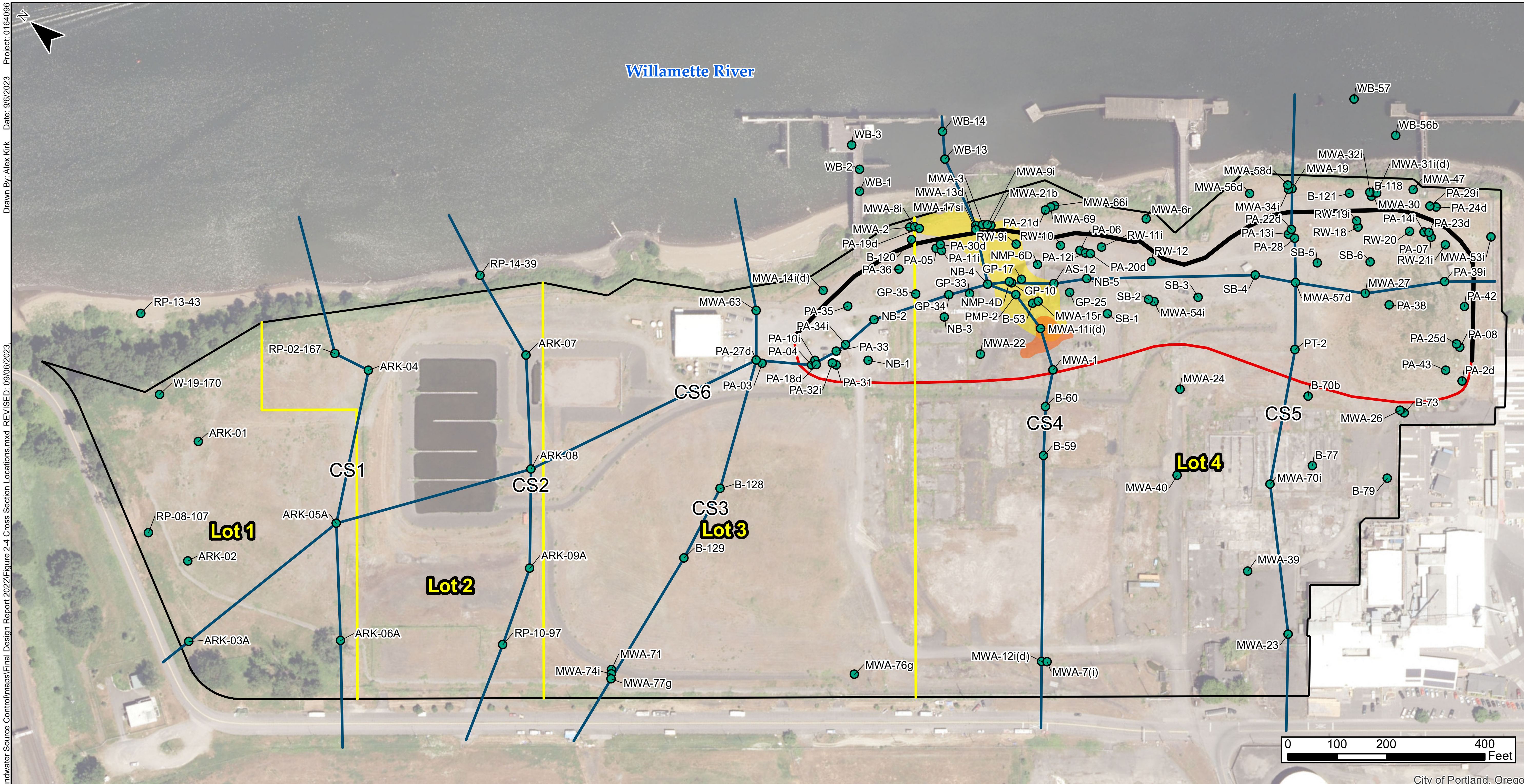


Figure 2-3
Stormwater Source Control Measure Layout
Feasibility Study
Arkema Inc.
Portland, Oregon

Environmental Resources Management
Portland, Oregon 97204
ERM

Source: City of Portland Aerial Imagery, flown Summer 2021; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl

File: M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 2-3 Stormwater Source Control Measure Layout.mxd REVISED: 09/05/2023 Drawn By: Alex Kirk Date: 9/5/2023 Project: 0164096



Legend

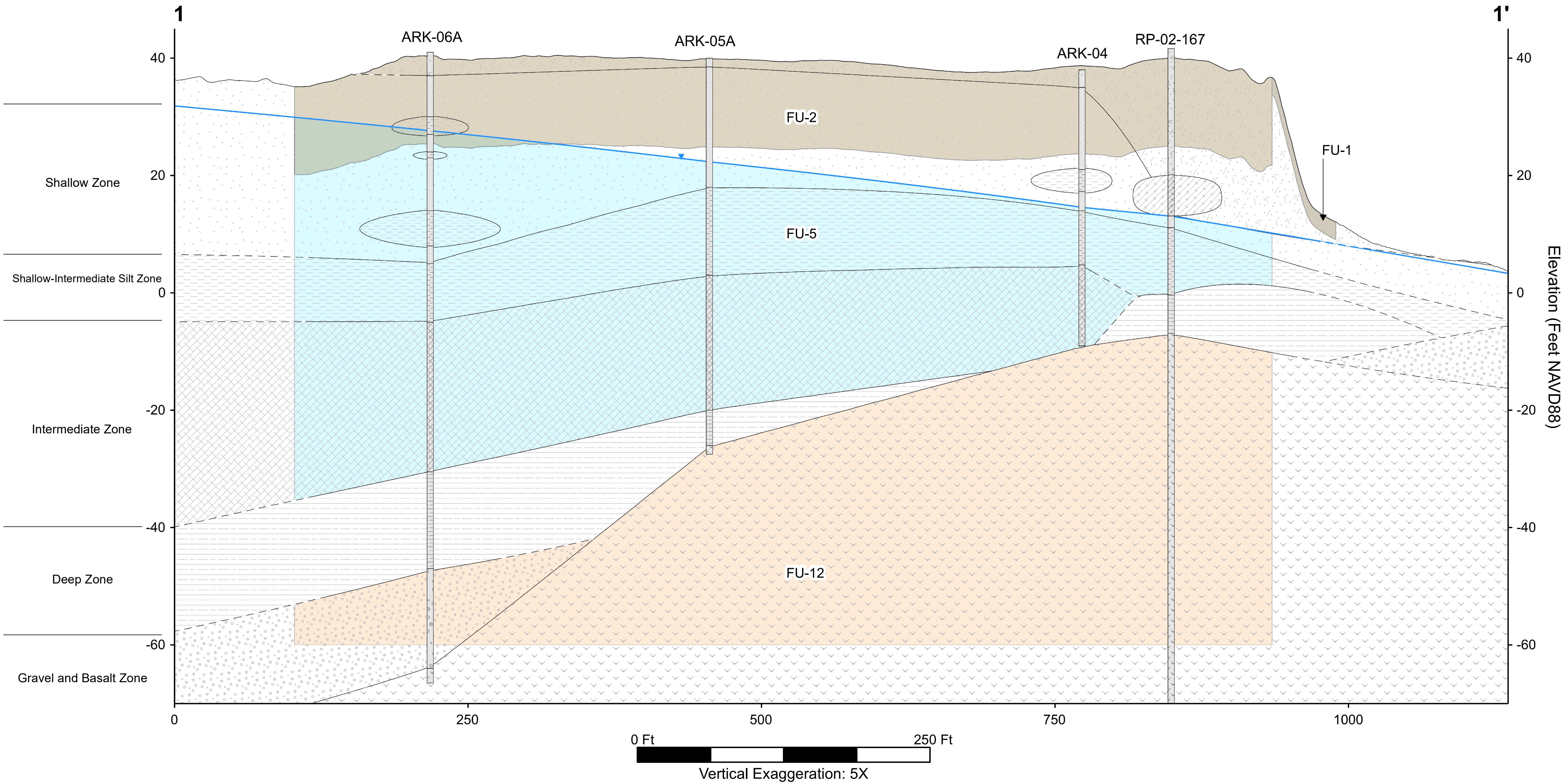
- Arkema Boring Geology in Model
- Cross Sections
- Barrier Wall Alignment
- Target Capture Zone
- Lot Boundaries
- Parcel and Property Boundaries
- Soil DNAPL
- Groundwater DNAPL

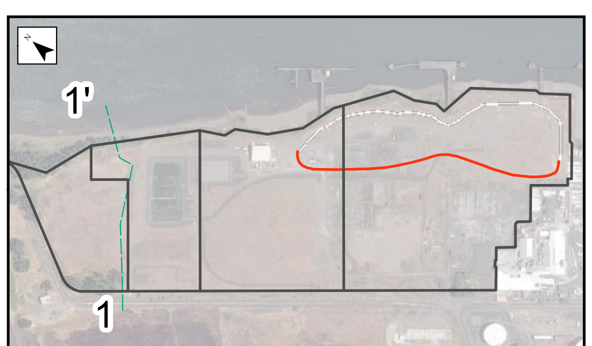
Figure 2-4
Cross Section Locations
Feasibility Study
Arkema Inc.
Portland, Oregon

Environmental Resources Management
Portland, Oregon 97204
ERM

File: M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\Images\Final Design Report 2022\Figure 2-4 Cross Section Locations.mxd REVISED: 09/06/2023. Drawn By: Alex Kirk Date: 9/6/2023 Project: 0164096

Source: City of Portland Aerial Imagery, flown Summer 2021; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl





Legend

- Shallow Zone potentiometric surface (ft NAVD88)
- Inferred soil contact (dashed where uncertain)
- Screened Interval

Functional Units

Soil: 1, 2, 3, 4

Groundwater: 5, 6, 7, 8, 9, 10, 11, 12

Lithology

- Groundwater Barrier Wall
- Fill
- Clay with Silt
- Sandy Silt
- Fine to medium sand with silt and clay
- Interbedded silt and sand
- Fine sand with clay
- Silt with clay
- Gravel
- Basalt

Notes:
Shallow Zone potentiometric surface is representative of averaged groundwater elevations during 2022.
Cross section geology generated from 3D geologic model.

Figure 2-5
Cross Section 1
Feasibilty Study
Former Arkema, Inc. Facility
Portland, Oregon

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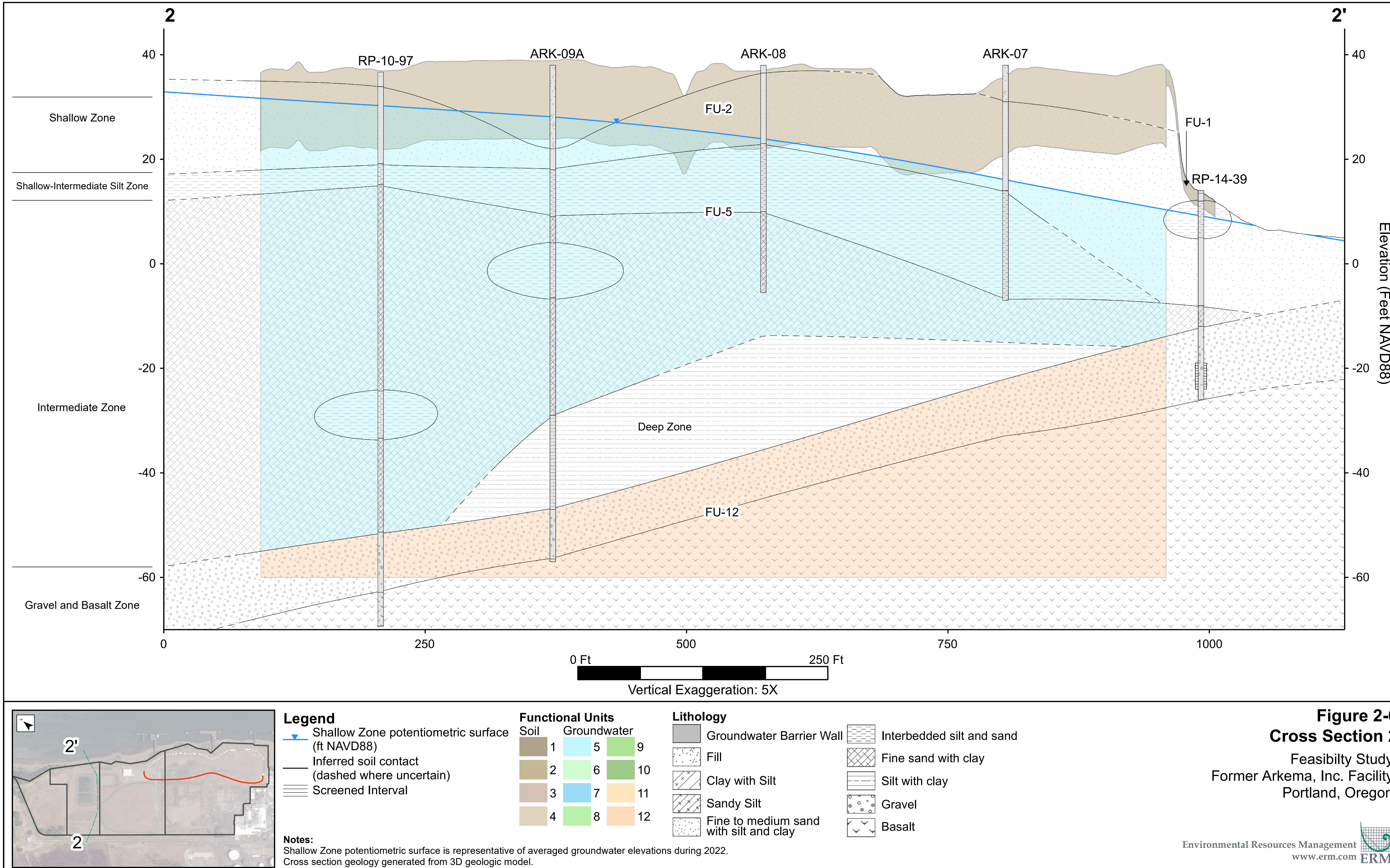
2
2'
40
20
0
-20
-40
-60
Shallow Zone
Shallow-Intermediate Silt Zone
Intermediate Zone
Gravel and Basalt Zone
RP-10-97
ARK-09A
ARK-08
ARK-07
RP-14-39
FU-1
FU-2
FU-5
FU-12
Deep Zone
Elevation (Feet NAVD88)
0
250
500
750
1000
0 Ft
250 Ft
Vertical Exaggeration: 5X
2'
2
Legend
Shallow Zone potentiometric surface (ft NAVD88)
Inferred soil contact (dashed where uncertain)
Screened Interval
Functional Units
Soil
Groundwater
1
2
3
4
5
6
7
8
9
10
11
12
Lithology
Groundwater Barrier Wall
Fill
Clay with Silt
Sandy Silt
Fine to medium sand with silt and clay
Interbedded silt and sand
Fine sand with clay
Silt with clay
Gravel
Basalt
Notes:
Shallow Zone potentiometric surface is representative of averaged groundwater elevations during 2022.
Cross section geology generated from 3D geologic model.
Figure 2-6
Cross Section 2
Feasibilty Study
Former Arkema, Inc. Facility
Portland, Oregon
Environmental Resources Management
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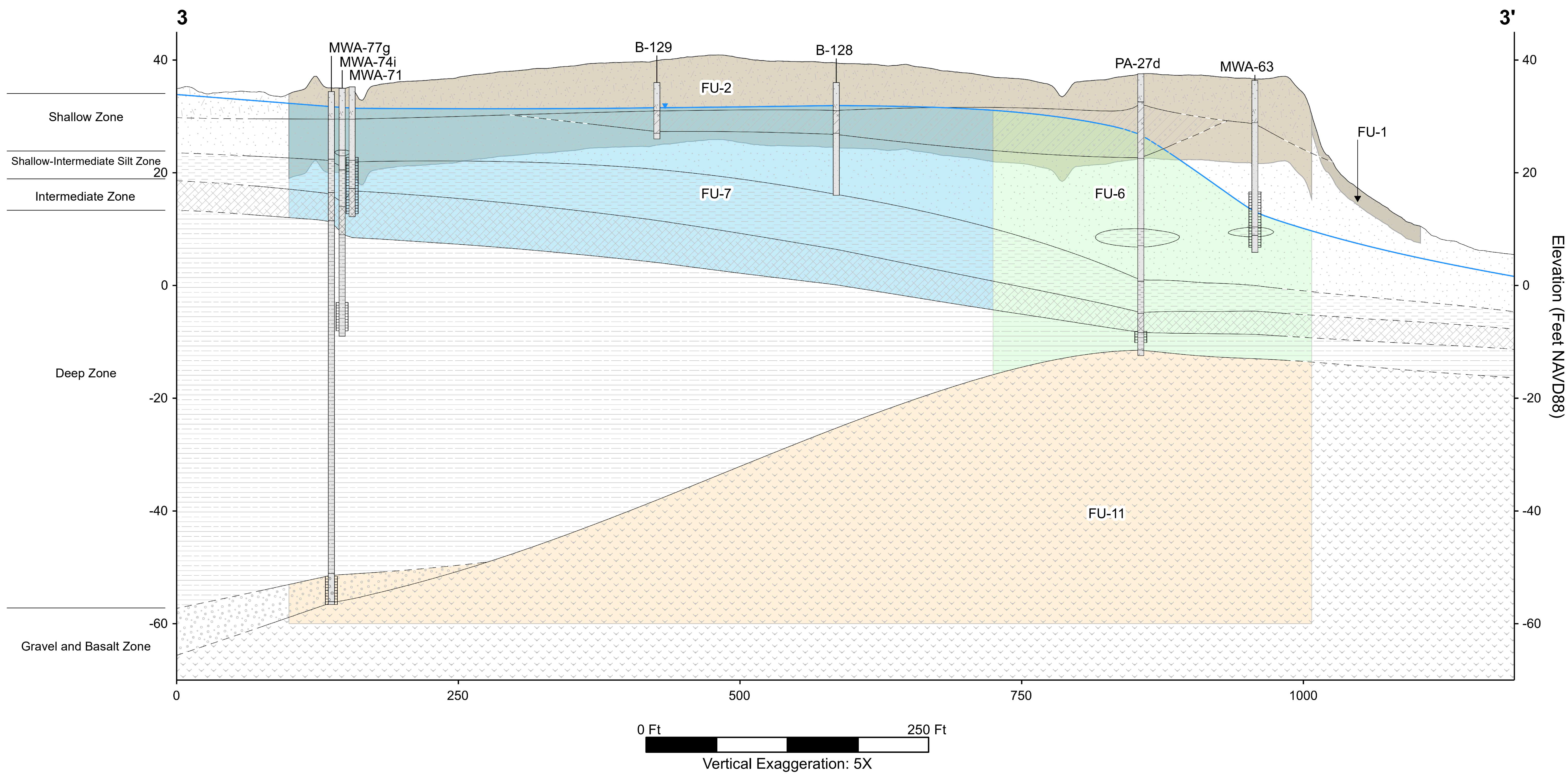

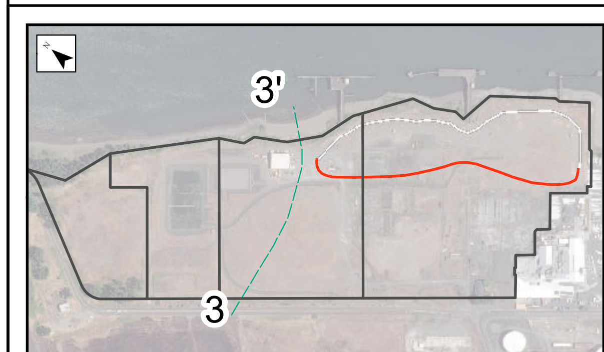

Legend

- Shallow Zone potentiometric surface (ft NAVD88)
- Localized pressure area potentiometric surface (ft NAVD88)
- Inferred soil contact (dashed where uncertain)
- Screened Interval

Functional Units

Soil		Groundwater	
1		5	9
2		6	10
3		7	11
4		8	12

Lithology

- Groundwater Barrier Wall
- Fill
- Clay with Silt
- Sandy Silt
- Fine to medium sand with silt and clay
- Interbedded silt and sand
- Fine sand with clay
- Silt with clay
- Gravel
- Basalt

Notes:
Shallow Zone potentiometric surface is representative of averaged groundwater elevations during 2022.
Cross section geology generated from 3D geologic model.

Figure 2-7
Cross Section 3

Feasibilty Study
Former Arkema, Inc. Facility
Portland, Oregon

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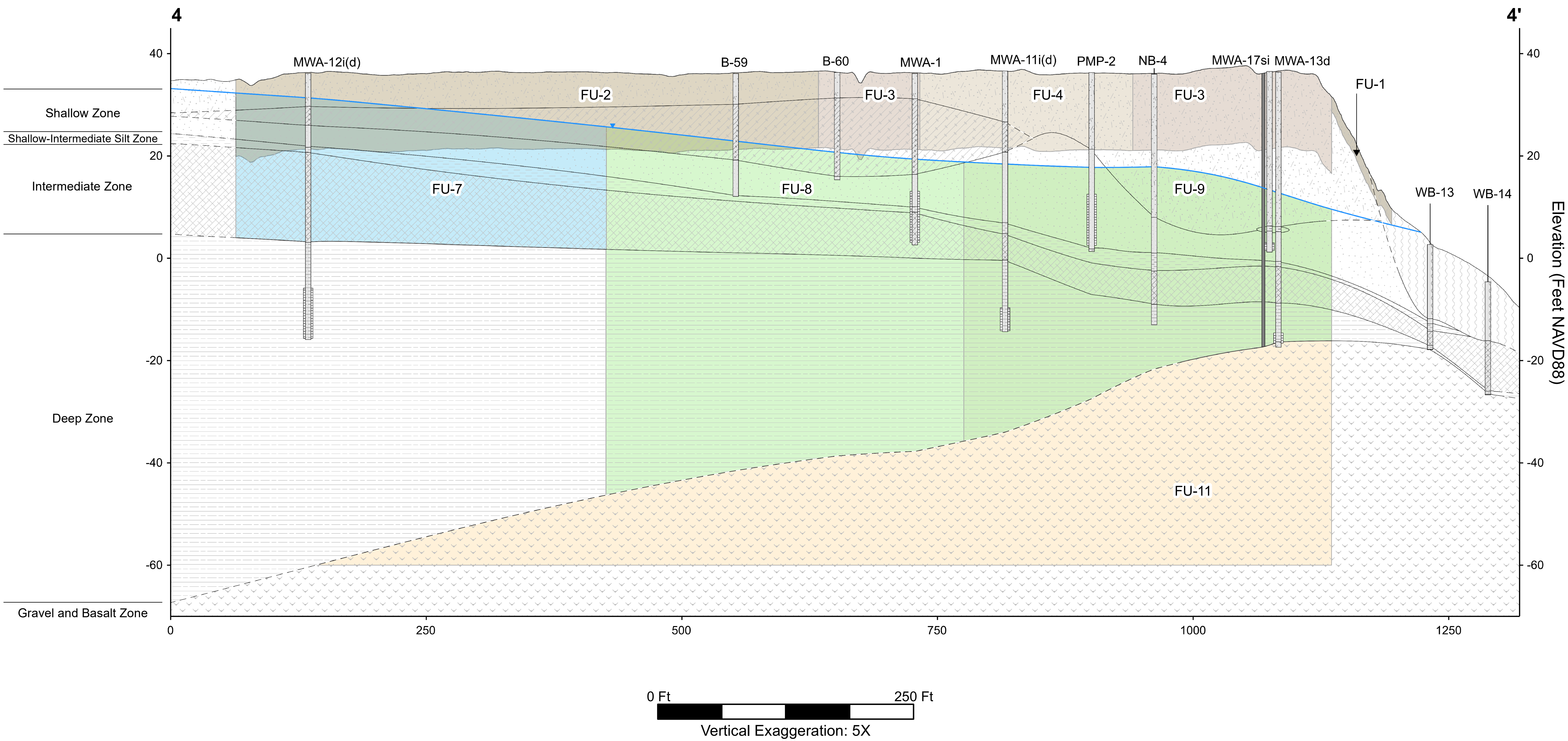

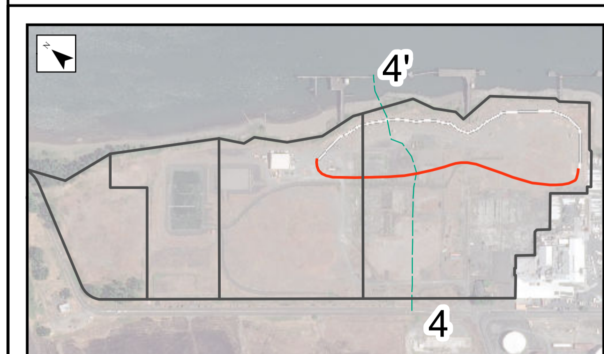

Legend

- Shallow Zone potentiometric surface (ft NAVD88)
- Inferred soil contact (dashed where uncertain)
- Screened Interval

Functional Units

Soil: 1, 2, 3, 4

Groundwater: 5, 6, 7, 8, 9, 10, 11, 12

Lithology

- Groundwater Barrier Wall
- Fill
- Clay with Silt
- Sandy Silt
- Fine to medium sand with silt and clay
- Interbedded silt and sand
- Fine sand with clay
- Silt with clay
- Gravel
- Basalt

Notes:
Shallow Zone potentiometric surface is representative of averaged groundwater elevations during 2022.
Cross section geology generated from 3D geologic model.

Figure 2-8
Cross Section 4
Feasibilty Study
Former Arkema, Inc. Facility
Portland, Oregon

Environmental Resources Management
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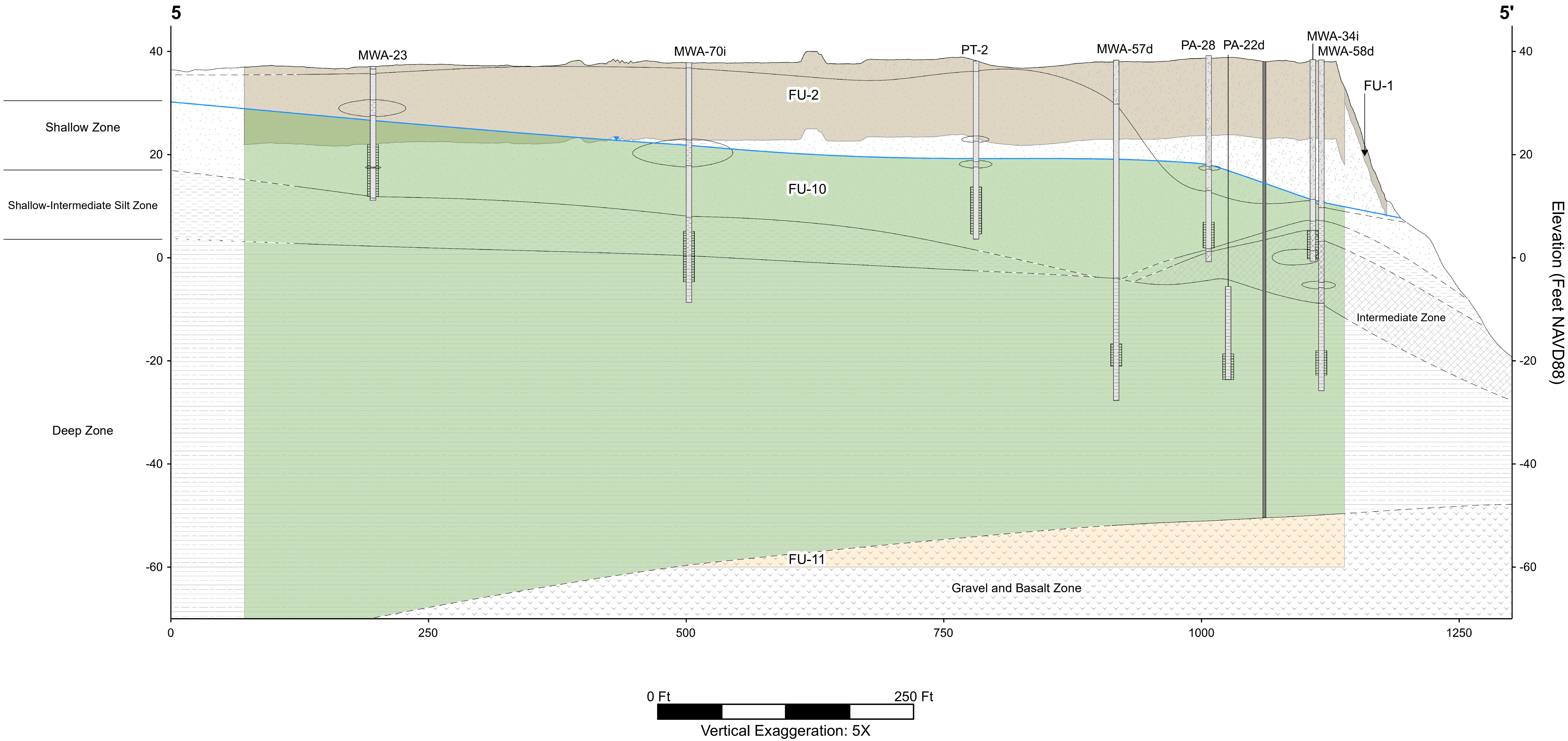

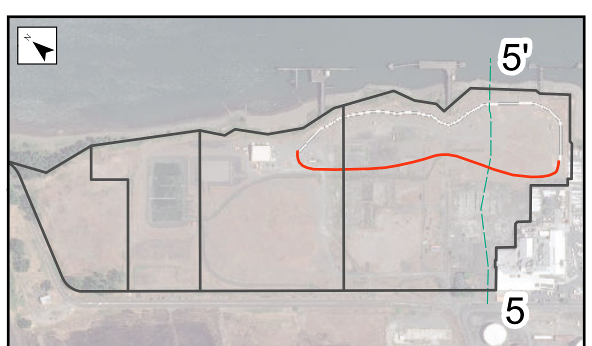

Legend

- Shallow Zone potentiometric surface (ft NAVD88)
- Inferred soil contact (dashed where uncertain)
- Screened Interval

Functional Units

Soil	Groundwater	
1	5	9
2	6	10
3	7	11
4	8	12

Lithology

- Groundwater Barrier Wall
- Fill
- Clay with Silt
- Sandy Silt
- Fine to medium sand with silt and clay
- Interbedded silt and sand
- Fine sand with clay
- Silt with clay
- Gravel
- Basalt

Notes:
Shallow Zone potentiometric surface is representative of averaged groundwater elevations during 2022.
Cross section geology generated from 3D geologic model.

Figure 2-9
Cross Section 5
Feasibilty Study
Former Arkema, Inc. Facility
Portland, Oregon

Environmental Resources Management
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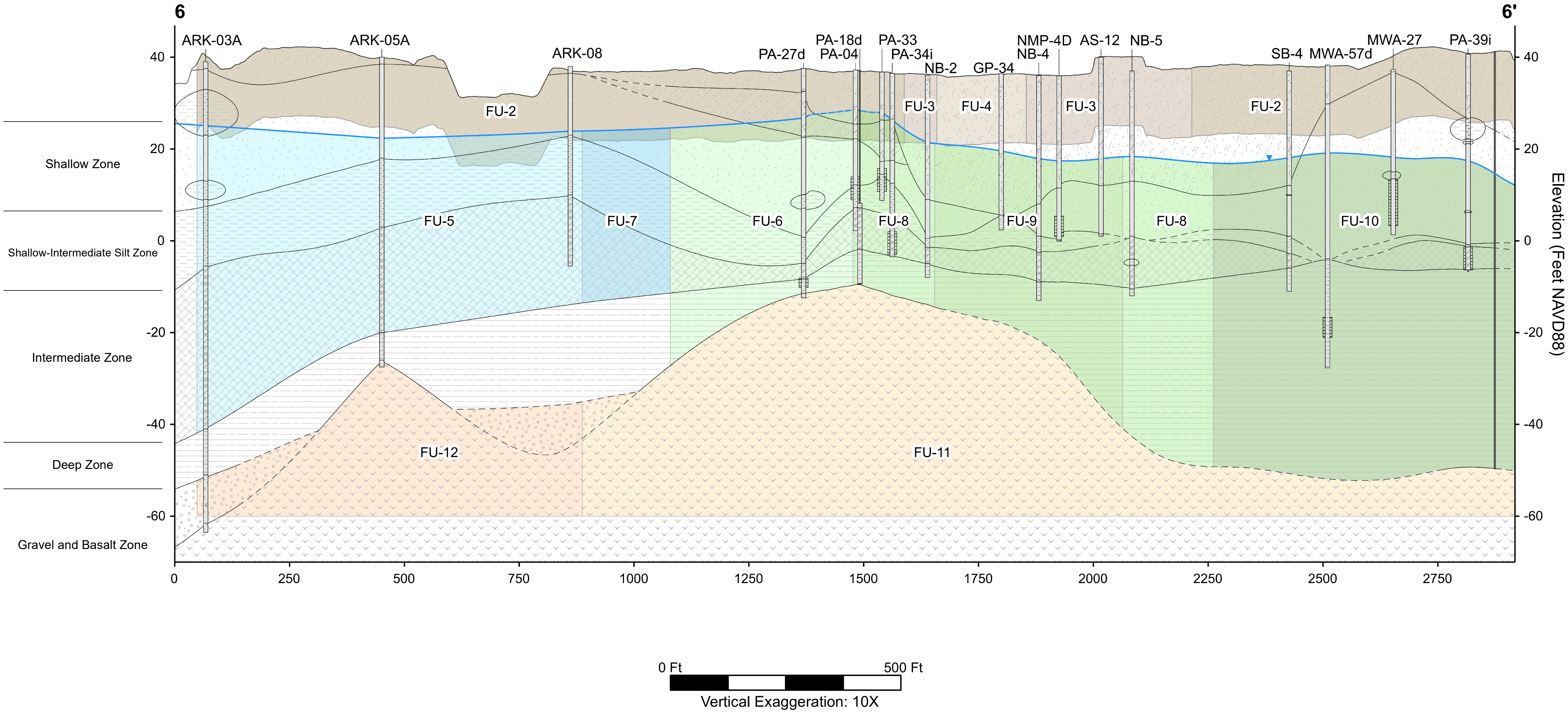

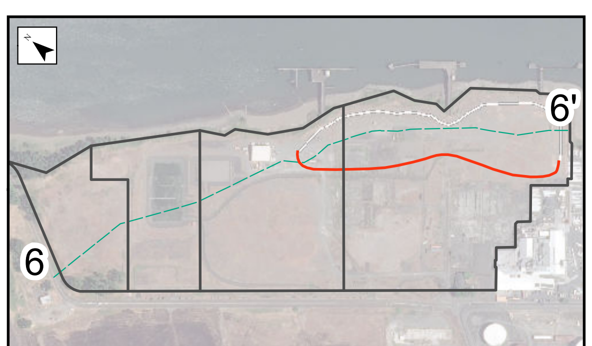

Legend

- Shallow Zone potentiometric surface (ft NAVD88)
- Localized pressure area potentiometric surface (ft NAVD88)
- Inferred soil contact (dashed where uncertain)
- Screened Interval

Functional Units

Soil: 1, 2, 3, 4
Groundwater: 5, 6, 7, 8, 9, 10, 11, 12

Lithology

- Groundwater Barrier Wall
- Fill
- Clay with Silt
- Sandy Silt
- Fine to medium sand with silt and clay
- Interbedded silt and sand
- Fine sand with clay
- Silt with clay
- Gravel
- Basalt

Notes:
Shallow Zone potentiometric surface is representative of averaged groundwater elevations during 2022.
Cross section geology generated from 3D geologic model.

Figure 2-10
Cross Section 6

Feasibilty Study
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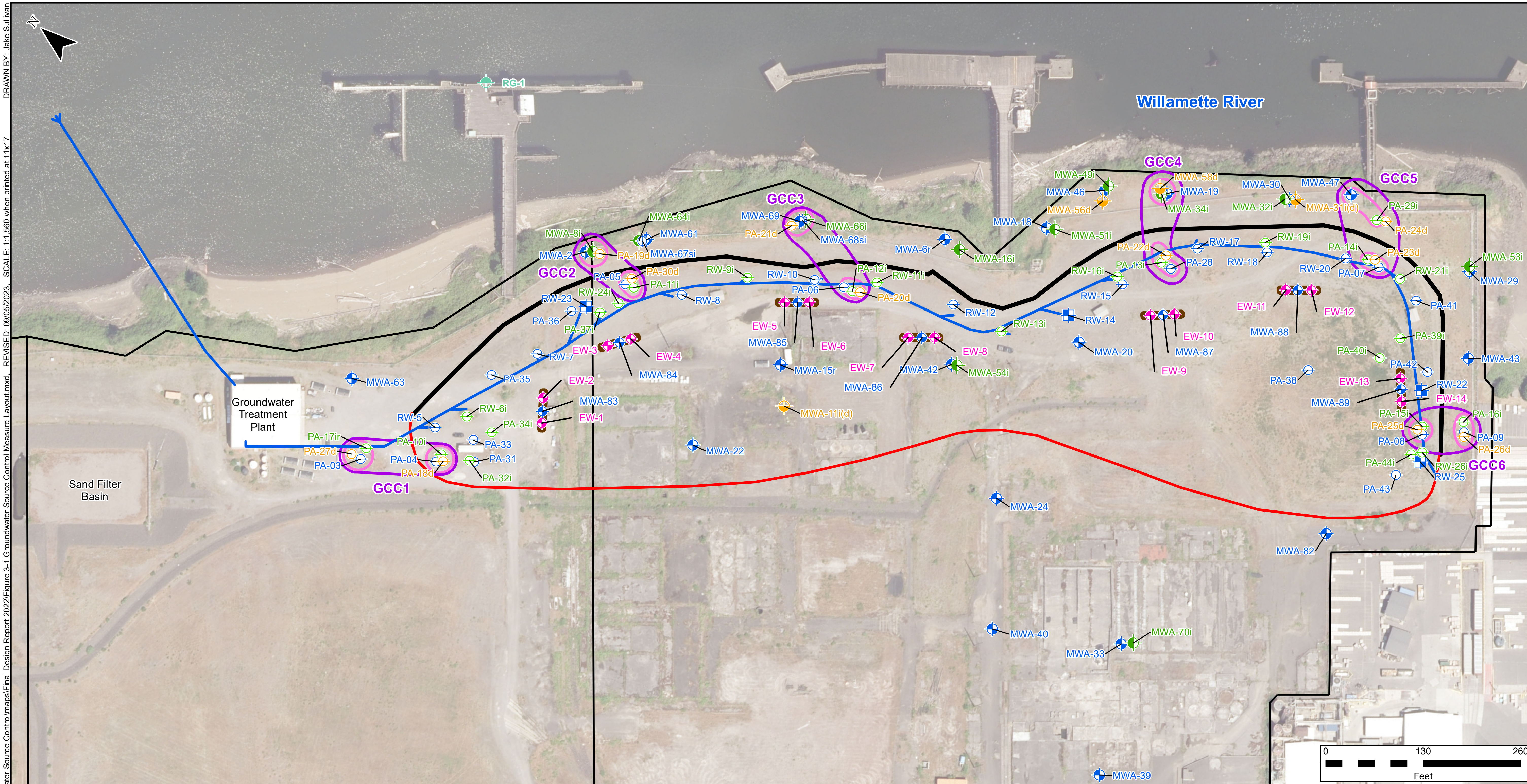

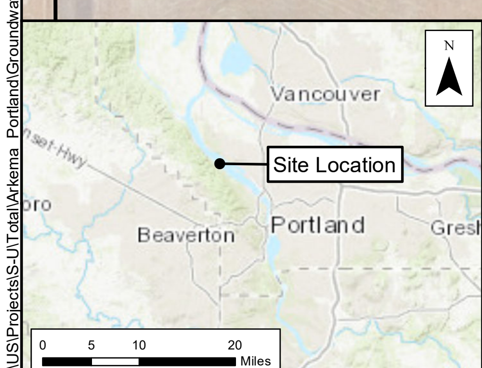

Legend

- Shallow Zone Monitoring Well
- Intermediate Zone Monitoring Well
- Shallow-Intermediate Zone Monitoring Well
- Deep Zone Monitoring Well
- Shallow Zone Piezometer
- Intermediate Zone Piezometer
- Deep Zone Piezometer
- Shallow Zone Recovery Well
- River Gauge
- Trench Extraction Well
- Target Capture Zone
- Barrier Wall Alignment
- Underground Groundwater Conveyance Piping
- Parcel and Property Boundaries
- Extraction Trench

Gradient Clusters

Type

- Gradient Control Cluster
- Vertical Flow Cluster

Figure 3-1

Groundwater Source Control Measure Layout
Feasibility Study
Arkema Inc.
Portland, Oregon

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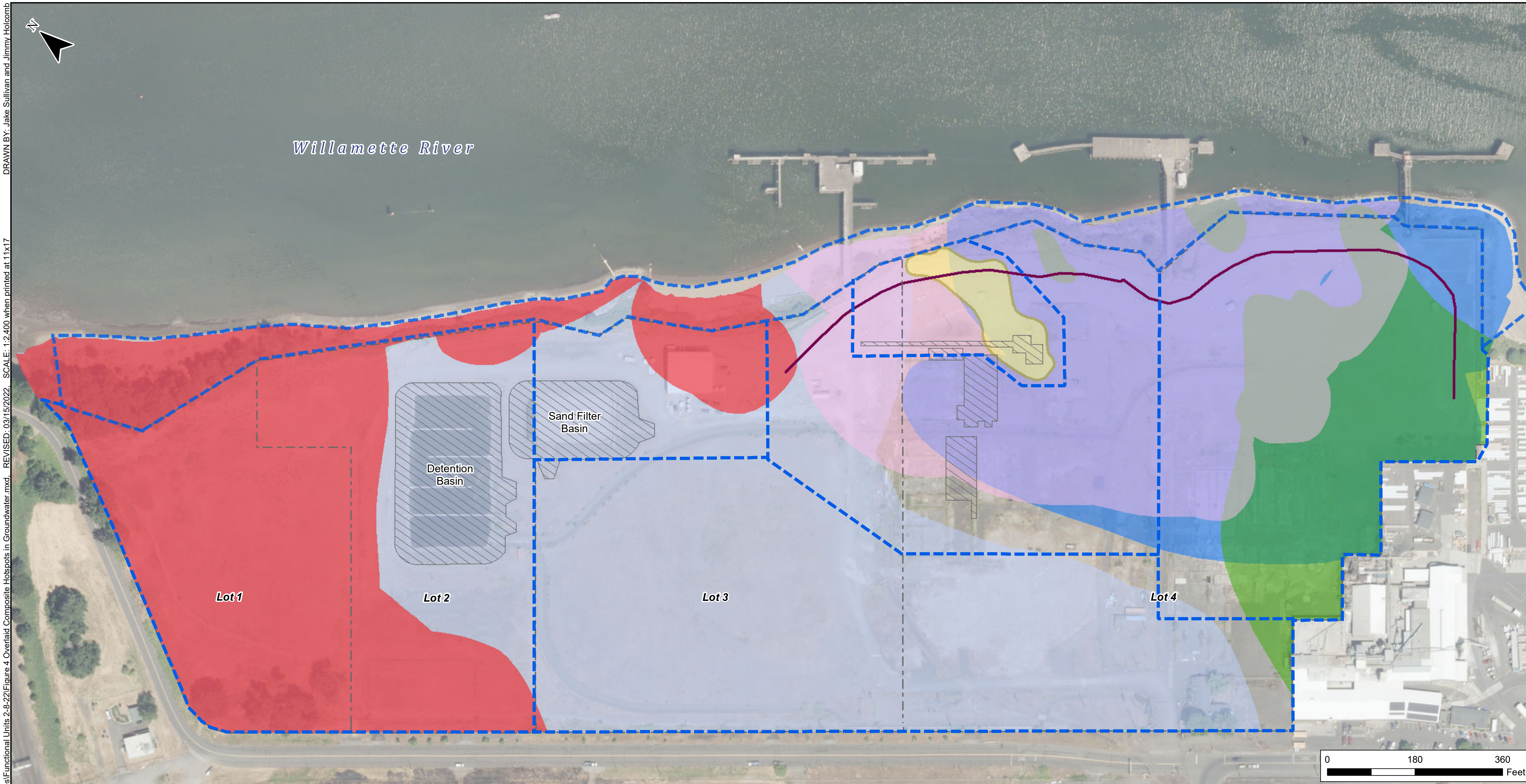
Source: City of Portland Aerial Imagery, flown Summer 2021; NAD 1983 StatePlane Oregon North FIPS 3601 Feet Intl

M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 3-1 Groundwater Source Control Measure Layout.mxd, REVISED: 09/05/2023, SCALE: 1:1,560 when printed at 11x17 DRAWN BY: Jake Sullivan



- Barrier Wall
- Excavated
- Functional Unit
- Parcel and Property Boundaries
- Shallow Aquifer DNAPL
- VOCs in GW
- VOCs in GW - GWET Capture
- Perchlorate in Groundwater
- Metals in Shallow Groundwater
- Chromium in Shallow Groundwater

Figure 4-1
Composite Hotspots in Groundwater
Functional Unit Memorandum
Arkema Inc.
Portland, Oregon

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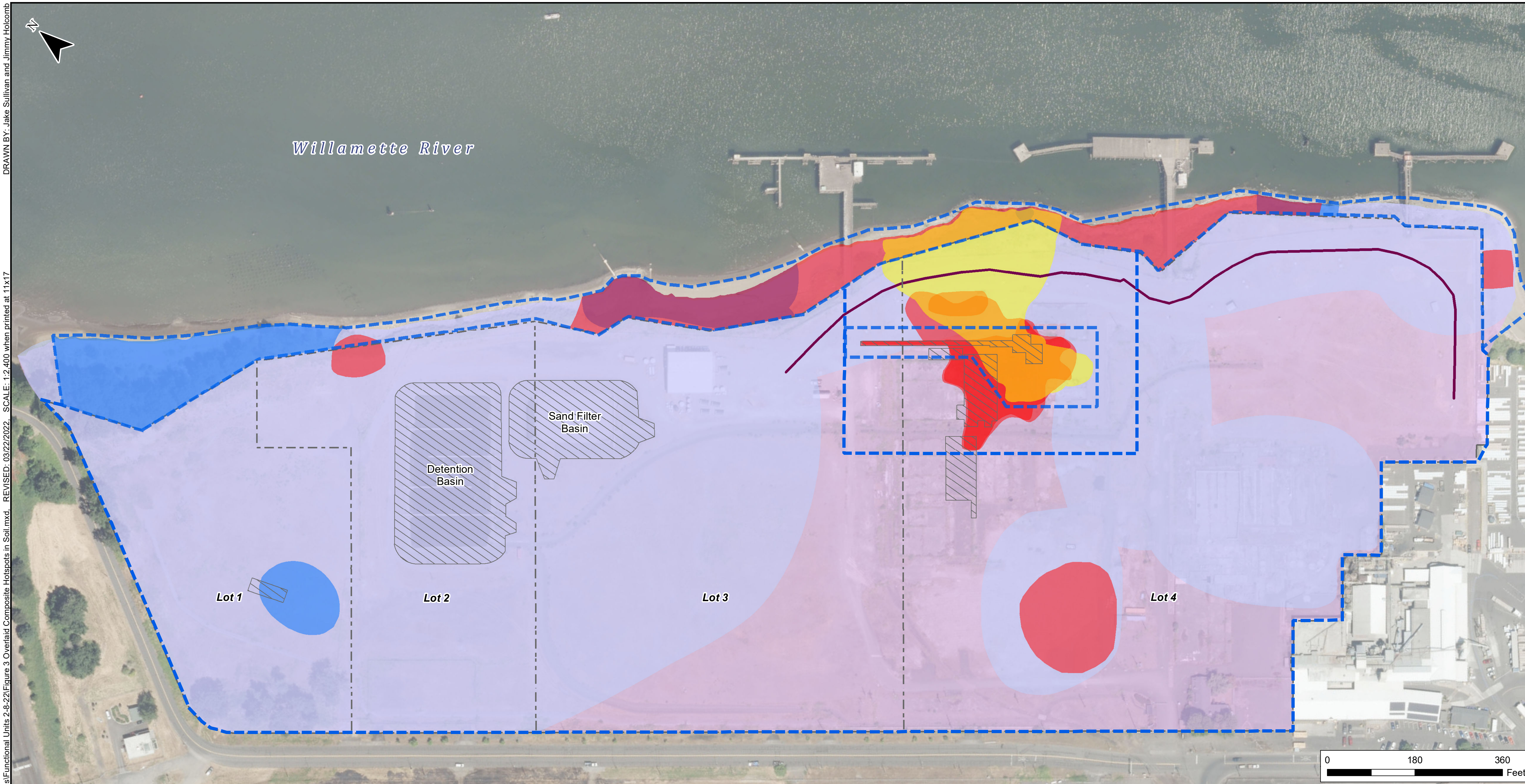
Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl



- Excavated Area
- Functional Unit
- Parcel and Property Boundaries
- Barrier Wall Alignment
- Soil Metals - Direct Exposure
- Soil VOCs -LtGW
- Soil Pest - Direct Exposure
- Soil Metals- LtGW
- Soil Pest - LtGW

Figure 4-2
Composite Hotspots in Soil
Functional Unit Memorandum
Arkema Inc.
Portland, Oregon

Environmental Resources Management
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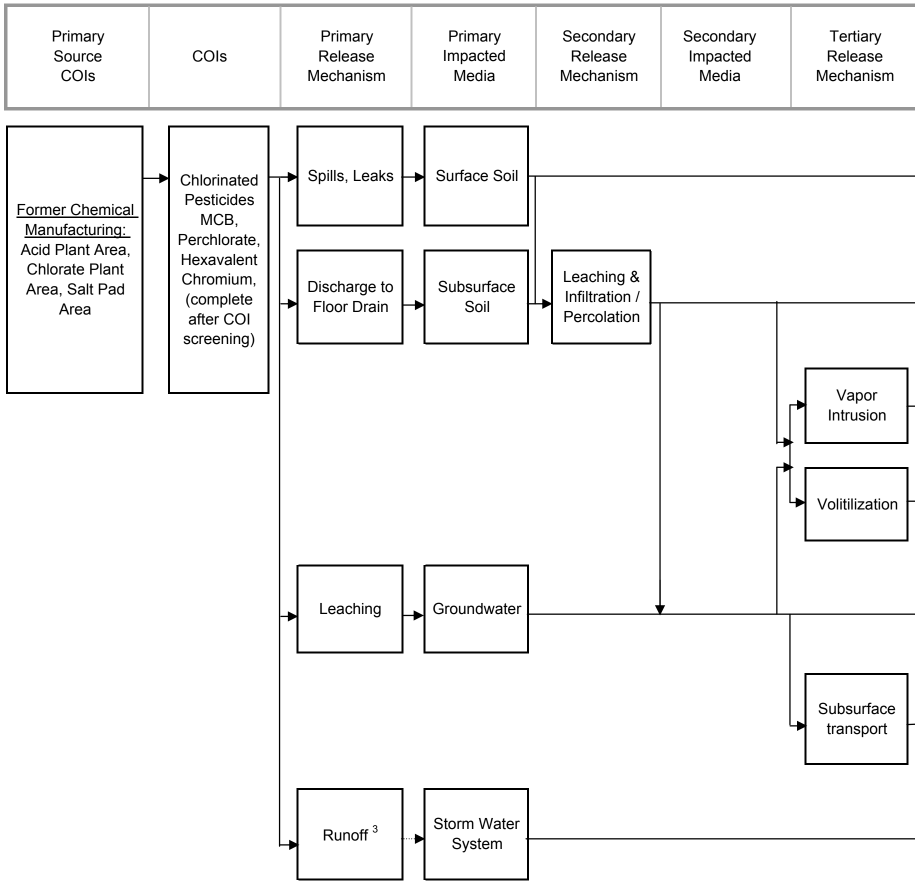
M:\Projects\Arkema Portland\Arkema 2019 HSE\Maps\Functional Units 2-8-22\Figure 3 Overlaid Composite Hotspots in Soil.mxd   REVISED: 03/22/2022   SCALE: 1:2,400 when printed at 11x17   DRAWN BY: Jake Sullivan and Jimmy Holcomb

Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl



Receptors

Contact Medium	Exposure Route	Current / Future Trespasser[1]	Future Excavation Worker	Current / Future Indoor Occupational Worker	Future Construction Worker	Future Outdoor Occupational Worker	Future Outdoor Occupational Worker (Redevelopment Scenario)
Upland & Riverbank Surface Soil (0-3 ft bgs)	Incidental Ingestion	●	AE	--	●	●	AE
	Inhalation	●	AE	--	●	●	AE
	Dermal	●	AE	--	●	●	AE
Subsurface Soil (0-15 ft bgs)	Incidental Ingestion	--	●	--	●	--	●
	Inhalation	--	●	--	●	--	●
	Dermal	--	●	--	●	--	●
Indoor Air	Inhalation	--	--	●	--	--	--
Outdoor Air (incl. trench air)	Inhalation	--	●	--	●	●	●
Groundwater	Incidental Ingestion	--	--	--	--	--	--
	Dermal	--	--	--	--	--	--
Sediment and Aquatic Biota[2]	Incidental Ingestion	C/D	--	--	--	--	--
	Inhalation	C/D	--	--	--	--	--
	Dermal	C/D	--	--	--	--	--
Surface Water[2]	Incidental Ingestion	C/D	--	--	--	--	--
	Inhalation	C/D	--	--	--	--	--
	Dermal	C/D	--	--	--	--	--

KEY:
- O = Potentially complete exposure pathway
- ● = Complete exposure pathway
- -- = Incomplete exposure pathway
- AE = Alternate evaluation = 0 - 15 ft soil horizon evaluated only
- C/D = Potentially complete exposure pathway but deferred to the PH HHRA (Kennedy / Jenks 2004)
- → = Complete chemical migration pathway

NOTES:

* CSM includes potential chemical transport pathways and exposure media for Lots 1, 2, 3, and 4 and Tract A.

* Exposure scenarios not shown include dock workers, in-water workers, and near-shore recreational fishers, Native American fishers, and other river users. All scenarios pertaining to contact with surface water and in-water sediments are being evaluated under the current EE/CA action (Integral 2005) and/or the Portland Harbor In-water Human Health Risk Assessment (Kennedy / Jenks 2004).

1 As discussed in the HHRA, scenario applies to Lots 1 and 2 and the riverbank only.

2 Chemicals in pore water and sediment also may mix with surface water. Uptake of chemicals by biota from sediment, pore water, and surface water also may occur.

3 Stormwater is collected and conveyed to the Willamette River and managed under a NPDES permit issued by DEQ.

Figure 5-1
Human Health Conceptual Site Model
Feasibility Study
Arkema Inc.
Portland, Oregon

Source: Integral Consulting, 2009

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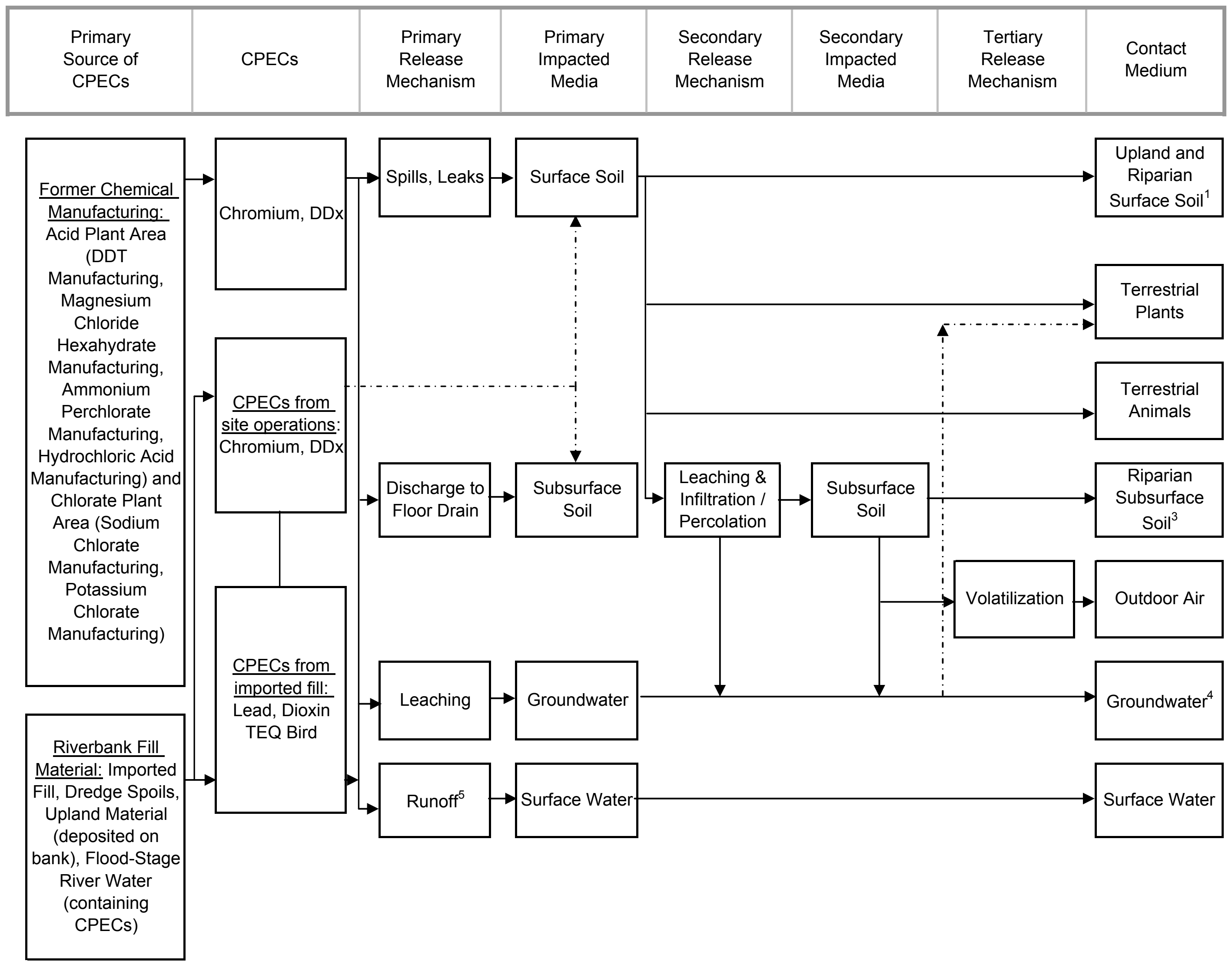


Receptors of Concern

Contact Medium	Exposure Route	Terrestrial Plants	Soil Invertebrates	Terrestrial Birds	Terrestrial Mammals
Upland and Riparian Surface Soil[1]	Ingestion	--	■	■	■
	Inhalation	--	--	i	i
	Contact[2]	■	□	i	i
Terrestrial Plants	Ingestion	--	□	□	□
Terrestrial Animals	Ingestion	--	□	□	□
Riparian Subsurface Soil[3]	Ingestion	--	■	i	■
	Inhalation	--	--	i	□
	Contact	■	□	i	i
Outdoor Air	Inhalation	--	--	□	□
Groundwater[4]	Ingestion	--	--	--	--
	Inhalation	--	--	--	--
	Contact	--	--	--	--
Surface Water	Ingestion	--	--	--	--
	Inhalation	--	--	--	--
	Contact	--	--	--	--

Key:

■ = Complete and significant exposure pathway.
□ = Potentially complete exposure pathway, not quantified in ERA.
i = Complete and insignificant exposure pathway.
-- = Incomplete exposure pathway.

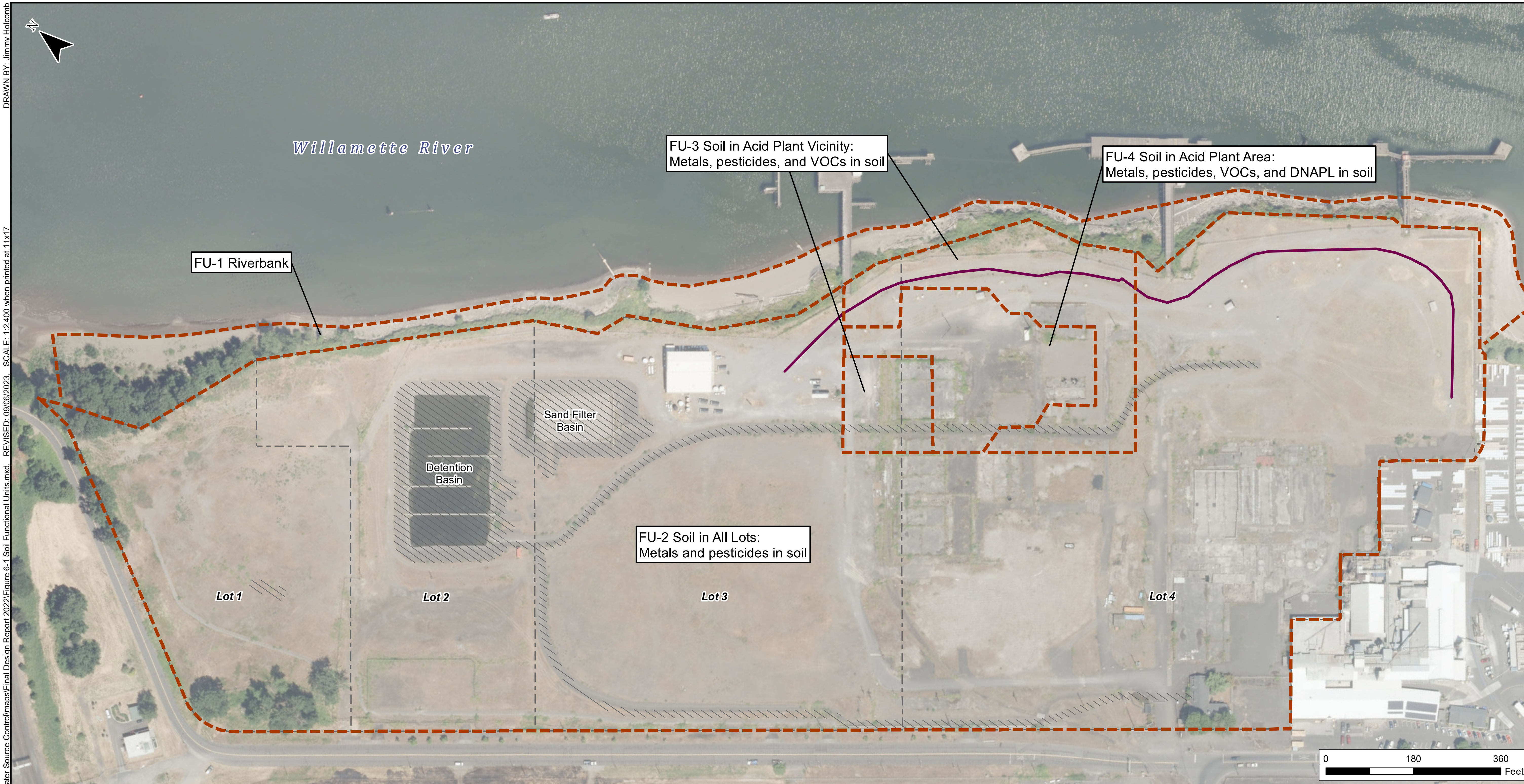
Notes:

CSM includes potential chemical transport pathways and exposure media for ecological habitat in Lots 1 and 2 (upland habitat) and the riverbank (riparian habitat).
In-water transport pathways, exposure media, and exposure pathways are discussed in Section 4 of the Arkema EE/CA Work Plan (Integral 2006).
Dashed lines are employed for resolving arrow paths especially where arrows intersect.
2,4'- and 4,4'-DDD, DDE, and DDT are expressed as DDx.

[1] For the purposes of this ERA, surface soil is defined as soil between the ground surface and 0.5 ft below ground surface (bgs), except for the upland where surface soil samples from 0 to 1.0 ft bgs were used.
[2] Contact route for plants is via root uptake and for animals is via direct dermal exposure and assimilation.
[3] For the purposes of this ERA, subsurface soil is defined as extending between 0.5 ft bgs and 3.0 ft bgs. No data is available for upland subsurface soil, as samples extend to a maximum of 1 ft bgs and were therefore classified with surface soils.
[4] Groundwater at the site is deeper than accessible by the plant root zone and to wildlife receptors (>1m); therefore, groundwater pathway is not expected to be a source of contaminants for terrestrial plants or animals.
[5] Stormwater is collected and conveyed to the Willamette River and managed under a NPDES permit issued by DEQ. No overland run-off is expected.

Figure 5-2
Ecological Conceptual Site Model
Feasibility Study
Arkema Inc.
Portland, Oregon

Source: Integral Consulting, 2009



Legend

- Soil Functional Unit
- Parcel and Property Boundaries
- Previously Excavated Area
- Barrier Wall Alignment

Figure 6-1
Soil Functional Units
Feasibility Study
Arkema Inc.
Portland, Oregon

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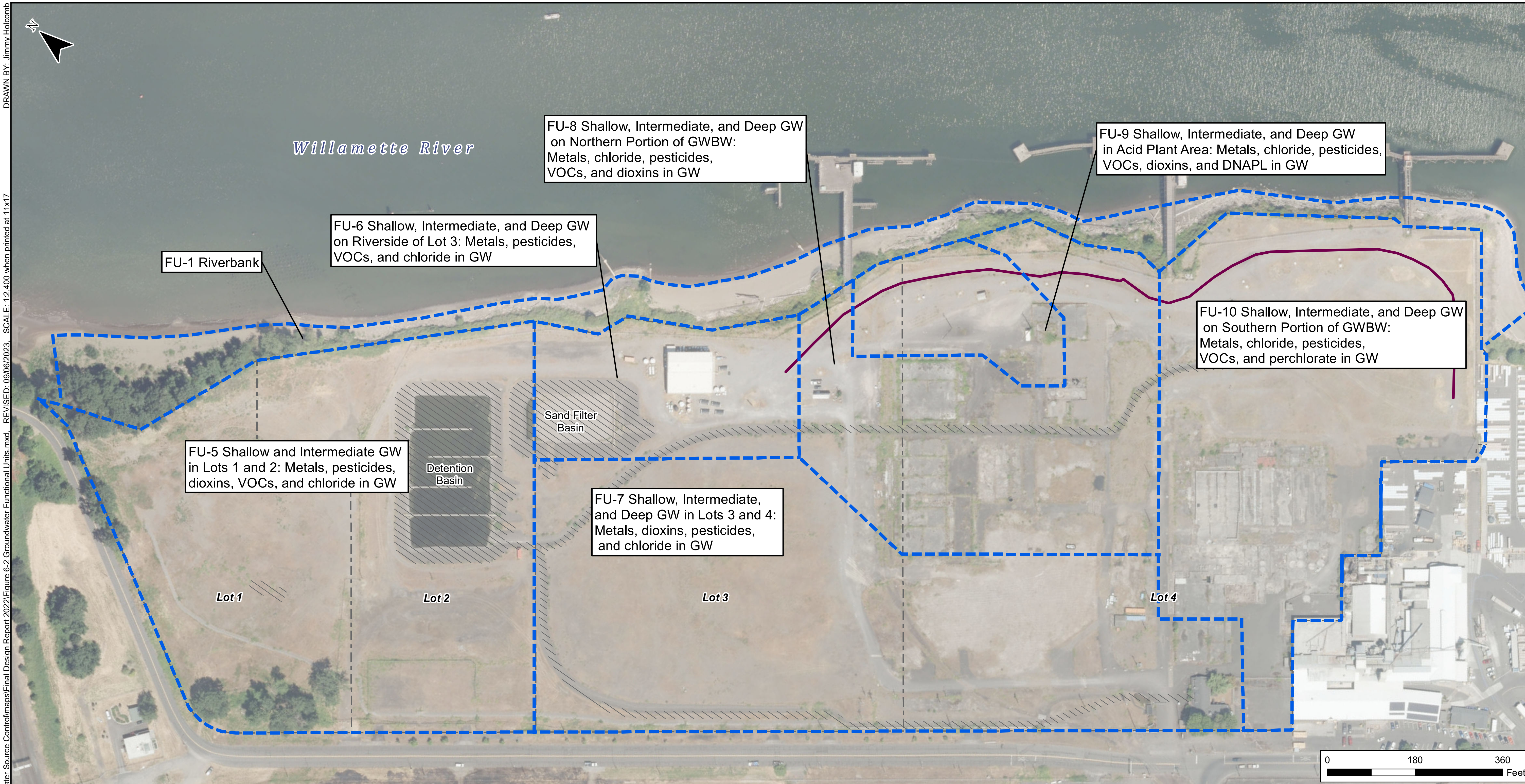
Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl

M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 6-1 Soil Functional Units.mxd, REVISED: 09/06/2023, SCALE: 1:2,400 when printed at 11x17 DRAWN BY: Jimmy Holcomb



Legend

- Groundwater Functional Unit
- Parcel and Property Boundaries
- Previously Excavated Area
- Barrier Wall Alignment

Notes:
FU-11 Gravel/Basalt Zone - Lots 3 and 4; not shown on figures
FU-12: Deep and Gravel/Basalt Zone - Lots 1 and 2; not shown on figures

Figure 6-2
Groundwater Functional Units
Feasibility Study
Arkema Inc.
Portland, Oregon

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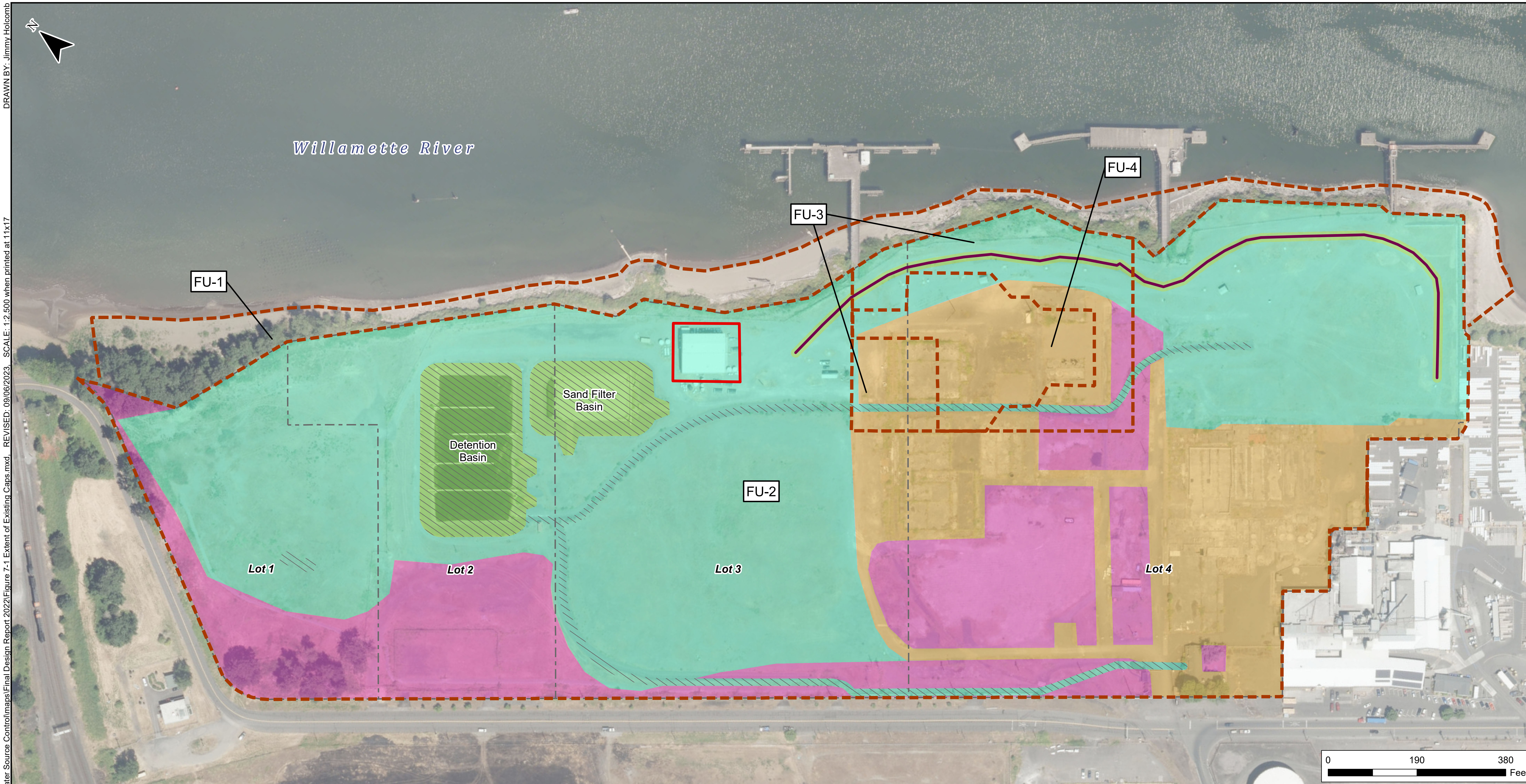
DRAWN BY: Jimmy Holcomb
M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 6-2 Groundwater Functional Units.mxd, REVISED: 09/06/2023, SCALE: 1:2,400 when printed at 11x17

Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl



DRAWN BY: Jimmy Holcomb

M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 7-1 Extent of Existing Caps.mxd, REVISED: 09/06/2023, SCALE: 1:2,500 when printed at 11x17

Legend

- Functional Unit
- Previously Excavated Area
- GWET Area (excluded from capping remedy)
- Groundwater Barrier Wall
- Parcel and Property Boundaries
- Gravel Cap
- Lined Cap
- Paved and/or Foundation
- No Existing Cap

Notes:
Cap areas are approximate.
Need for expanded or engineered caps to be determined during remedial design.

Source: December 2013 and July 2014 Google Earth Images
Erosion and Sediment Control Plan,
Integral, 2013

Figure 7-1
Extent of Existing Caps
Feasibility Study
Arkema Inc.
Portland, Oregon

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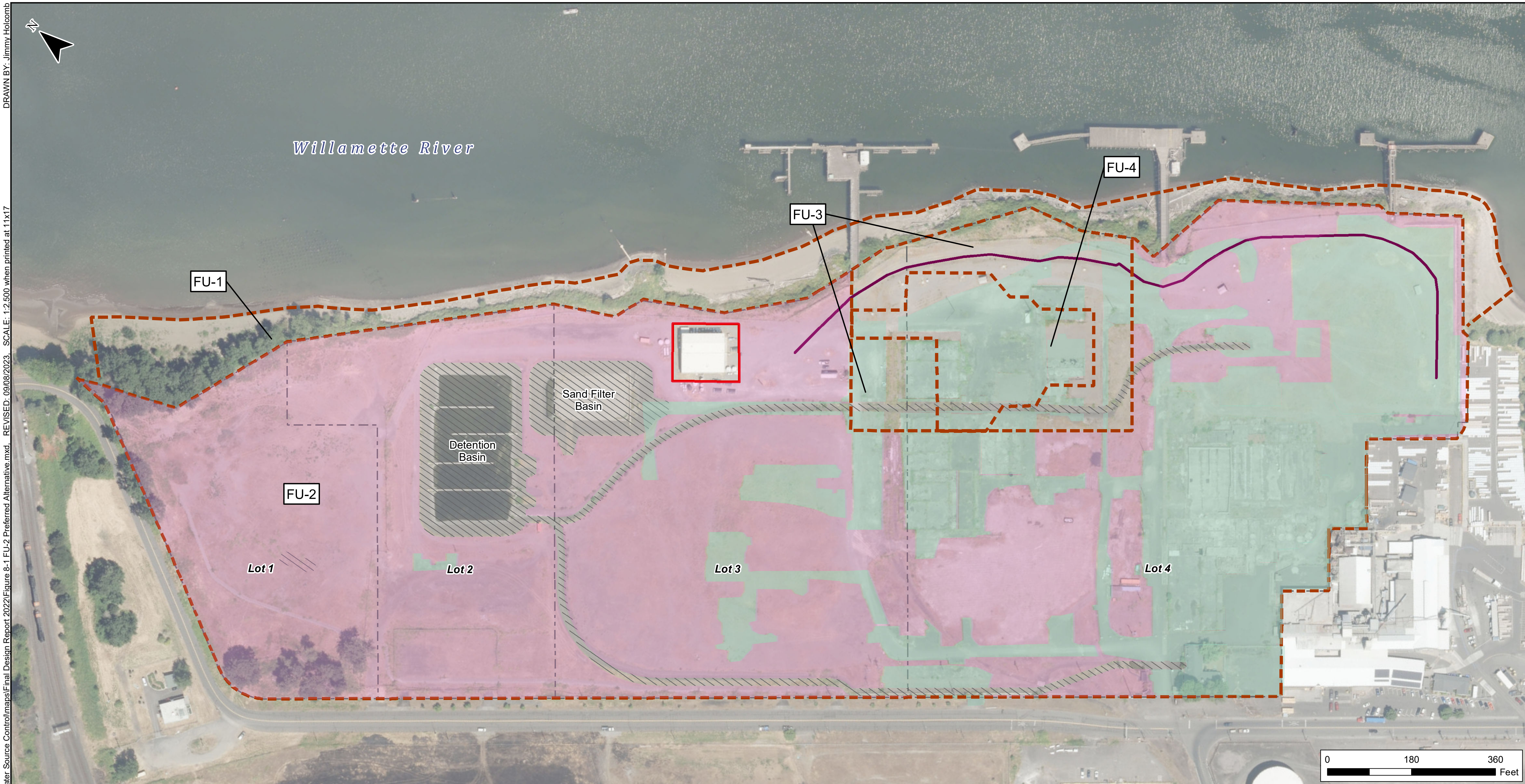
Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl



Legend

- Functional Unit
- Parcel and Property Boundaries
- Existing Paved or Lined Capped Area
- Previously Excavated Area
- Barrier Wall Alignment
- Proposed Engineered Cap
- GWET Area (excluded from capping remedy)

Notes:
The alternative layout is conceptual for FS cost estimates only. Actual remedial actions will be based on pre-design investigation and analysis.

Figure 8-1
FU-2 Preferred Alternative
Feasibility Study
Arkema Inc.
Portland, Oregon

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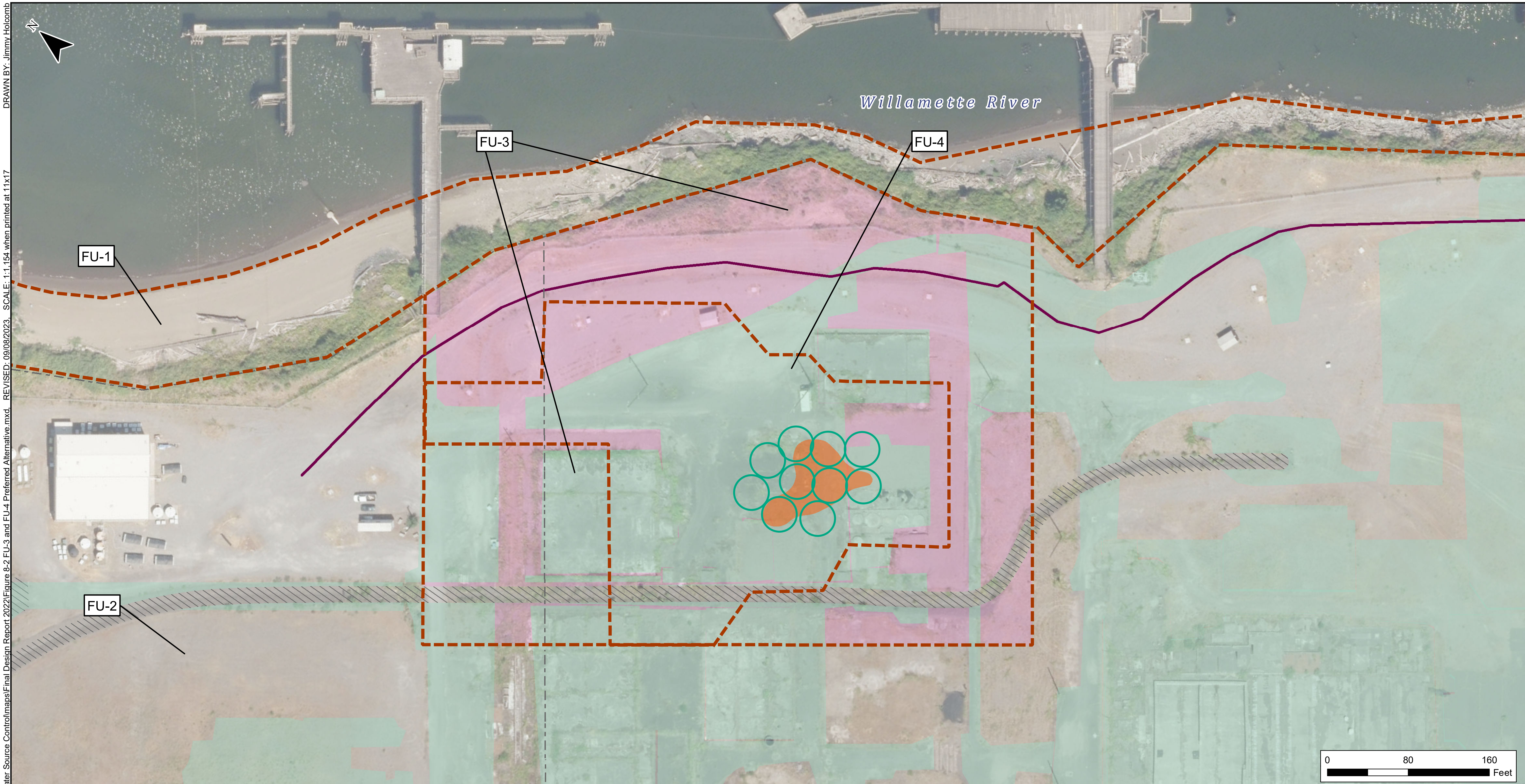
M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 8-1 FU-2 Preferred Alternative.mxd, REVISED: 09/08/2023, SCALE: 1:2,500 when printed at 11x17 DRAWN BY: Jimmy Holcomb

Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl



Legend

- Functional Unit
- Parcel and Property Boundaries
- Existing Paved or Lined Capped Area
- Previously Excavated Area
- Barrier Wall Alignment
- Proposed Engineered Cap
- Soil DNAPL
- ISCR/ISS Points and Radii of Influence

Notes:
The alternative layout is conceptual for FS cost estimates only. Actual remedial actions will be based on pre-design investigation and analysis.

Figure 8-2
FU-3 and FU-4 Preferred Alternative
Feasibility Study
Arkema Inc.
Portland, Oregon

Environmental Resources Management
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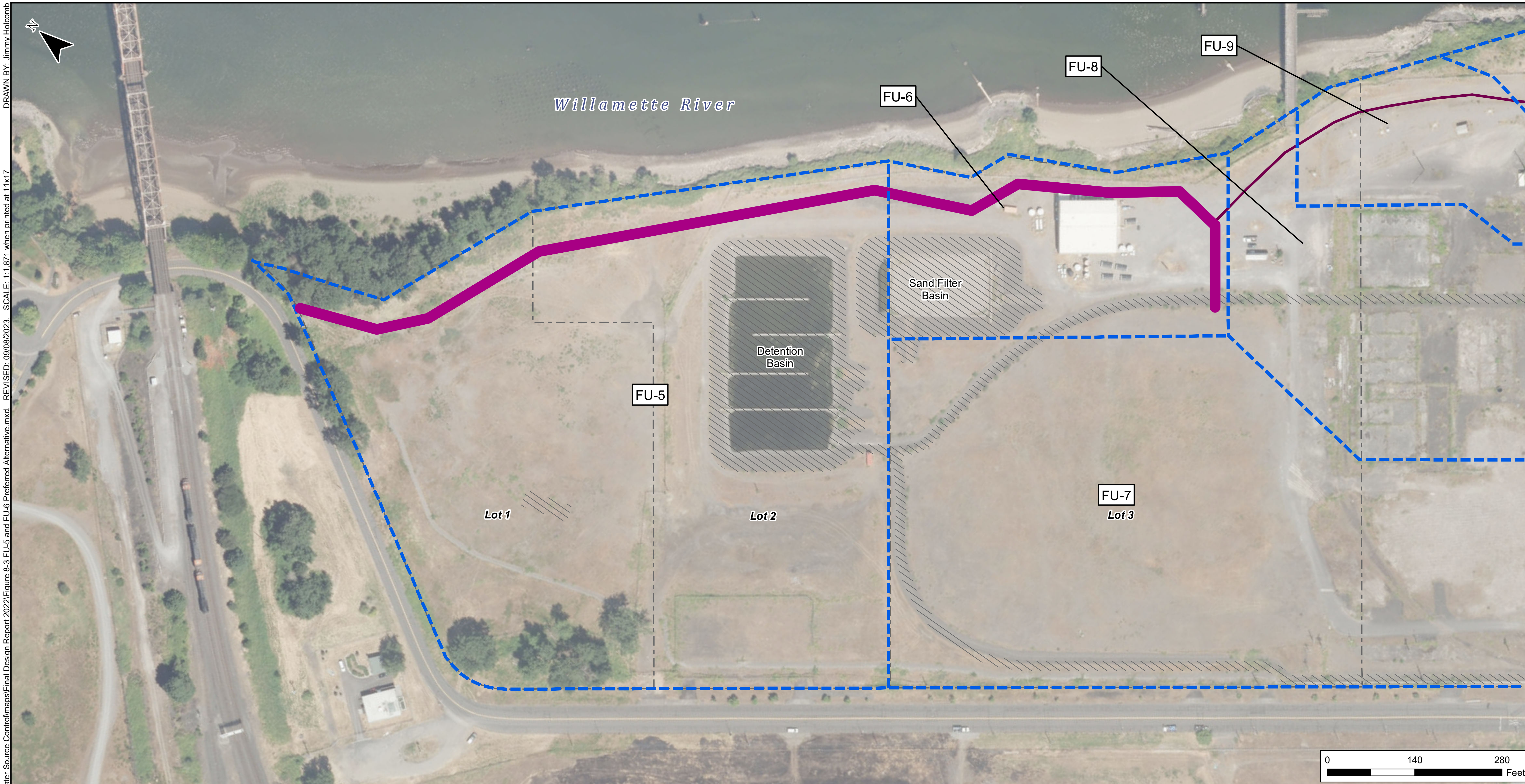
M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 8-2 FU-3 and FU-4 Preferred Alternative.mxd, REVISED: 09/08/2023, SCALE: 1:1,154 when printed at 11x17 DRAWN BY: Jimmy Holcomb

Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl



Legend

- Functional Unit
- Parcel and Property Boundaries
- Previously Excavated Area
- Barrier Wall Alignment
- Conceptual Injected ISCR PRB*

Notes:
The alternative layout is conceptual for FS cost estimates only. Actual remedial actions will be based on pre-design investigation and analysis.

FU-11 Gravel/Basalt Zone - Lots 3 and 4; not shown on figures.
FU-12: Deep and Gravel/Basalt Zone - Lots 1 and 2; not shown on figures.
* ISCR PRB connected at southern end to the barrier wall

Figure 8-3
FU-5 and FU-6 Preferred Alternative
Feasibility Study
Arkema Inc.
Portland, Oregon

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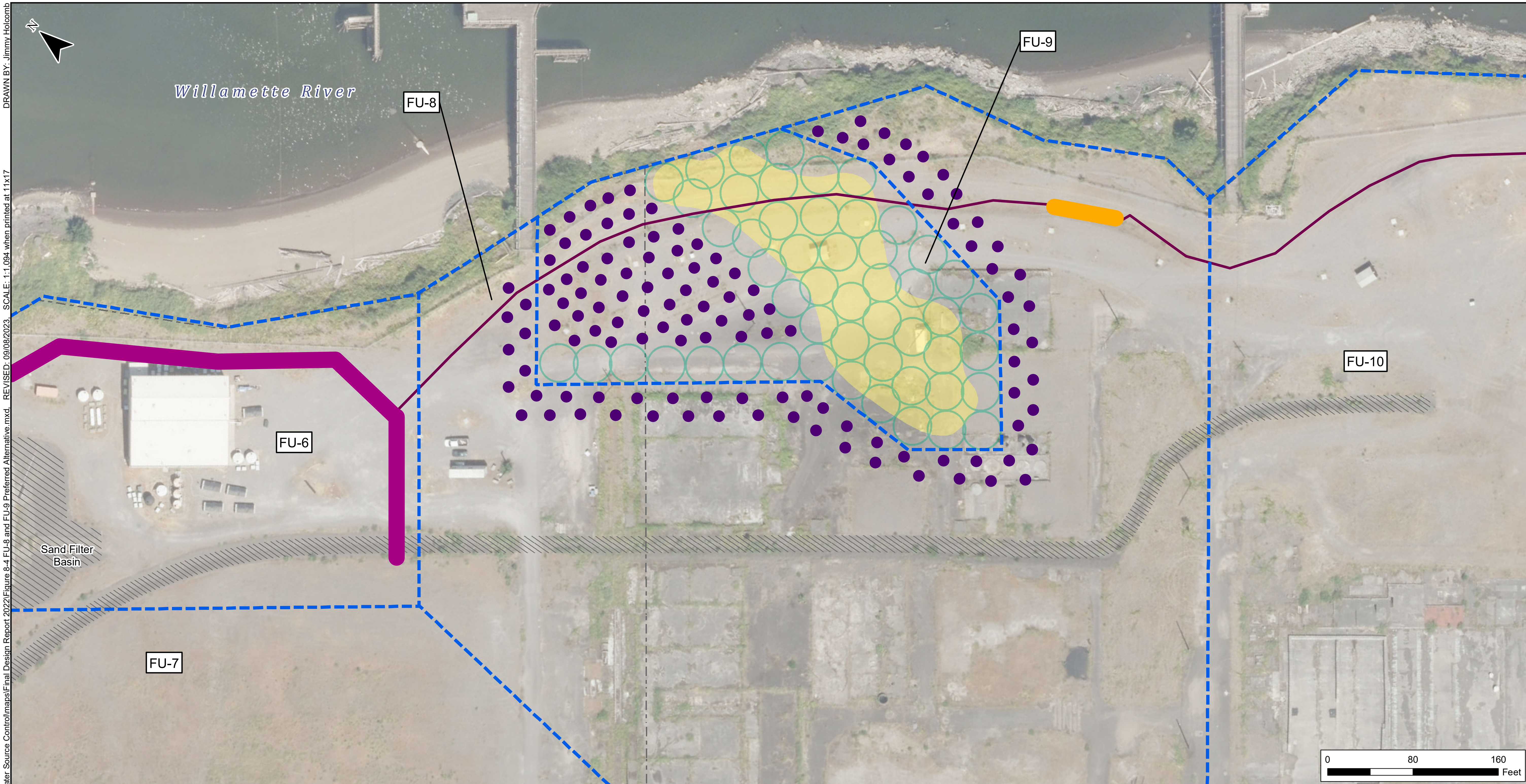
Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl

M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 8-3 FU-5 and FU-6 Preferred Alternative.mxd, REVISED: 09/08/2023, SCALE: 1:1,871 when printed at 11x17 DRAWN BY: Jimmy Holcomb



Legend

- Functional Unit
- Parcel and Property Boundaries
- Previously Excavated Area
- Barrier Wall Alignment
- Conceptual Injected ISCR PRB*
- Excavated ISCR PRB**
- Supplemental ISCR Injection Points
- ISCR/ISS Focus Zone
- ISCR/ISS Points and Radii of Influence

Notes:
The alternative layout is conceptual for FS cost estimates only. Actual remedial actions will be based on pre-design investigation and analysis.

FU-11 Gravel/Basalt Zone - Lots 3 and 4; not shown on figures.
FU-12: Deep and Gravel/Basalt Zone - Lots 1 and 2; not shown on figures.
* ISCR PRB connected at southern end to the barrier wall.
** Not shown to scale

Figure 8-4
FU-8 and FU-9 Preferred Alternative
Feasibility Study
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Portland, Oregon

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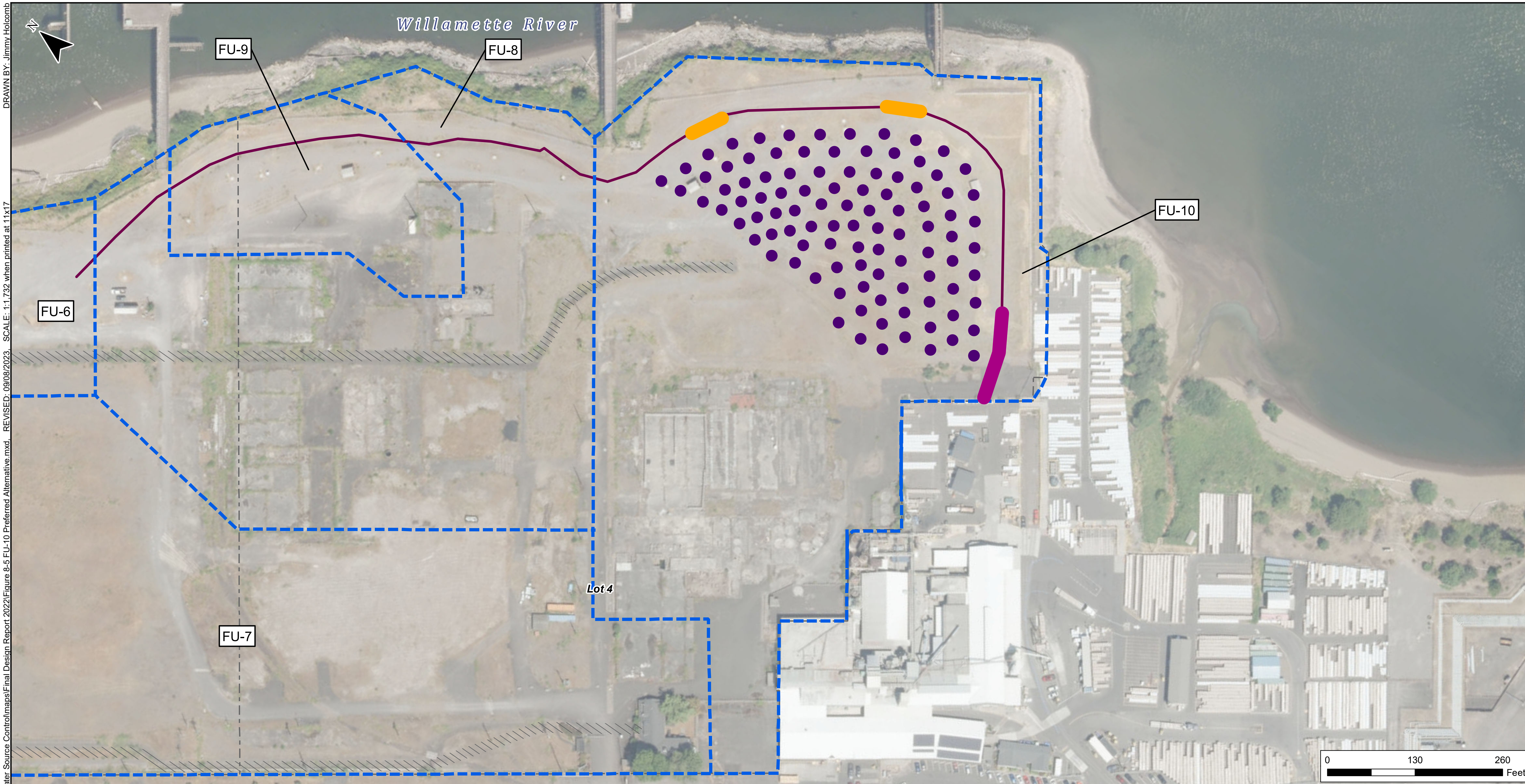
Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl

M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 8-4 FU-8 and FU-9 Preferred Alternative.mxd REVISED: 09/08/2023 SCALE: 1:1,094 when printed at 11x17 DRAWN BY: Jimmy Holcomb



Legend

- Parcel and Property Boundaries
- Previously Excavated Area
- Barrier Wall Alignment
- Injected ISCR PRB*
- Excavated ISCR PRB**
- Supplemental ISCR Injection Points

Notes:
The alternative layout is conceptual for FS cost estimates only. Actual remedial actions will be based on pre-design investigation and analysis.

FU-11 Gravel/Basalt Zone - Lots 3 and 4; not shown on figures.
FU-12: Deep and Gravel/Basalt Zone - Lots 1 and 2; not shown on figures.
* ISCR PRB connected at southern end to the barrier wall.
** Not shown to scale

Figure 8-5
FU-10 Preferred Alternative
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M:\US\Projects\S-U\Total\Arkema_Portland\Groundwater Source Control\maps\Final Design Report 2022\Figure 8-5 FU-10 Preferred Alternative.mxd, REVISED: 09/08/2023, SCALE: 1:1,732 when printed at 11x17 DRAWN BY: Jimmy Holcomb

Source: City of Portland Aerial Imagery, Flow 7/2018 at 6in per pixel; NAD 1983 HARN StatePlane Oregon North FIPS 3601 Feet Intl

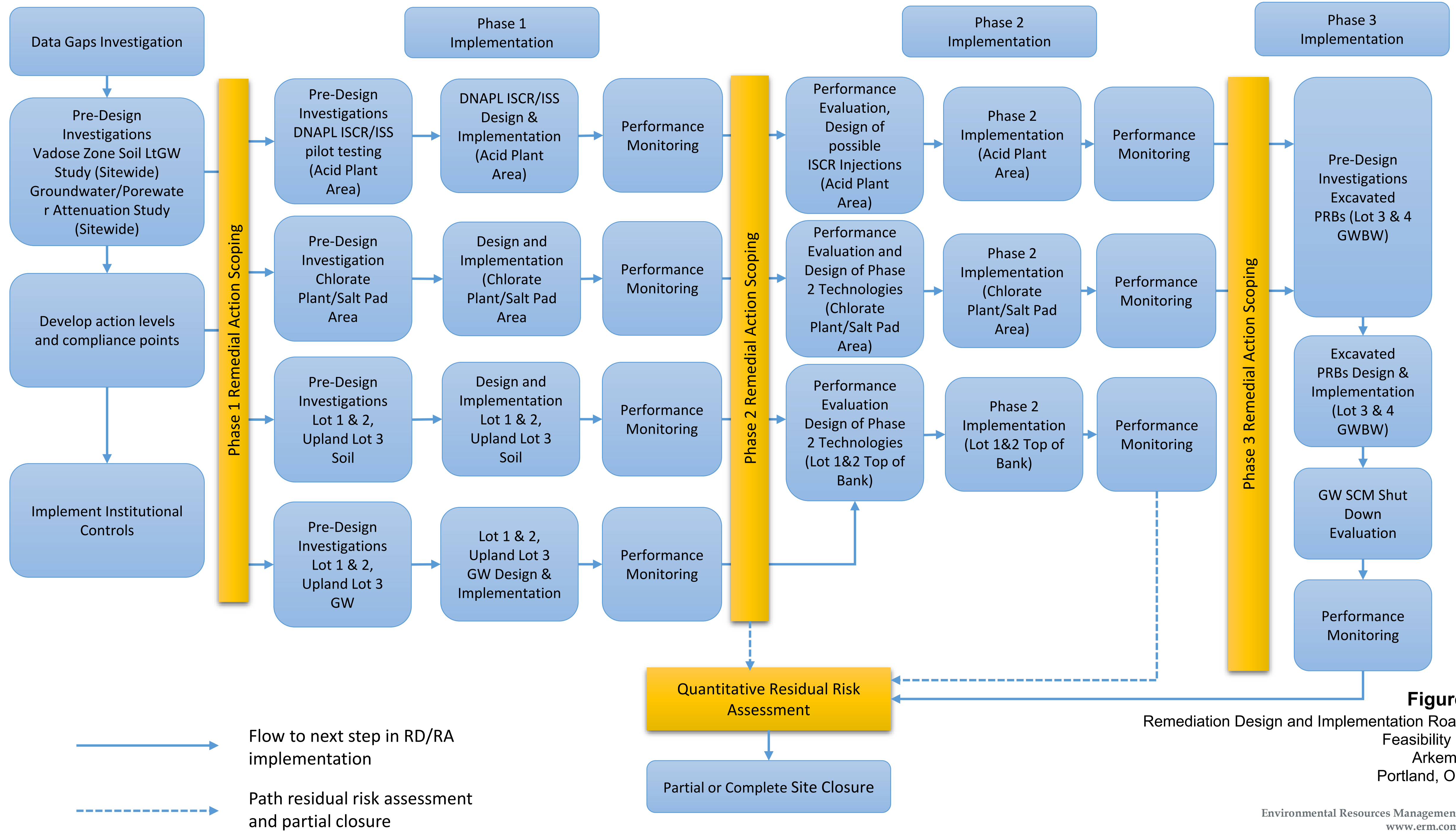

Figure 9-1

Remediation Design and Implementation Roadmap
Feasibility Study
Arkema Inc.
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APPENDIX A COSTING SHEETS

A-1: FU-2 Costing Summary
A-2: FU-3 Costing Summary
A-3: FU-4 Costing Summary
A-4: FU-5 Costing Summary
A-5: FU-6 Costing Summary
A-6: FU-7 Costing Summary
A-7: FU-8 Costing Summary
A-8: FU-9 Costing Summary
A-9: FU-10 Costing Summary
A-10: FU-11 Costing Summary
A-11: FU-12 Costing Summary
A-12: Alternatives Costing Summary

Table A-1
FU-2 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative				
	3			4a	4b
	Low	Medium	High		
Alternative Description	Cap Maintenance	Gravel Cap	Engineered Cap	Focused Excavation with Offsite Disposal and Capping	Focused Excavation with Onsite Disposal and Capping
Capital Costs					
Evaluation, Testing, Design	$150,000	$150,000	$150,000	$300,000	$300,000
Construction	$0	$1,561,000	$3,706,000	$9,808,000	$3,710,000
PM, H&S, Reporting (5% on capital costs)	$8,000	$86,000	$193,000	$505,000	$201,000
Subtotal Capital Costs	$158,000	$1,797,000	$4,049,000	$10,613,000	$4,211,000
Recurring and Future Costs					
Operation and Maintenance	$400,000	$400,000	$400,000	$721,000	$721,000
Monitoring and Reporting	N/A	N/A	N/A	N/A	N/A
Replacement and Upgrades	N/A	N/A	N/A	N/A	N/A
PM, H&S, Reporting (5% on capital costs)	$20,000	$20,000	$20,000	$36,000	$36,000
Subtotal Recurring and Future Costs	$420,000	$420,000	$420,000	$757,000	$757,000
Total Alternative Cost	$578,000	$2,217,000	$4,469,000	$11,370,000	$4,968,000

Notes:
*Alternative 1 = No action**
*Alternative 2a = Excavation and Offsite Disposal**
*Alternative 2b = Excavation and Onsite Treatment and Backfill**
Alternative 3 (L) = Maintenance of Current Cap
Alternative 3 (M) = Gravel Cap
Alternative 3 (H) = Engineered Cap
Alternative 4a = Focused Excavation with Offsite Disposal and Capping
Alternative 4b = Focused Excavation with Onsite Disposal and Capping
*Alternative 5 = Focused Excavation, ISCR**
H&S = Health and safety
N/A = Not Applicable
PM = Project management
** = alternative not costed*
Future and recurring costs are net-present value at a discount rate of 7.5 percent.

Table A-2
FU-3 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative			
	3	5		
		Low	Medium	High
Alternative Description	ISCR and ISS	Cap Maintenance	Gravel Cap	Engineered Cap
Capital Costs				
Evaluation, Testing, Design	$250,000	$150,000	$150,000	$150,000
Construction	$3,435,000	$0	$176,000	$364,000
PM, H&S, Reporting (5% on capital costs)	$184,000	$8,000	$16,000	$26,000
Subtotal Capital Costs	$3,869,000	$158,000	$342,000	$540,000
Recurring and Future Costs				
Operation and Maintenance	$721,000	$400,000	$400,000	$400,000
Monitoring and Reporting	N/A	N/A	N/A	N/A
Replacement and Upgrades	N/A	N/A	N/A	N/A
PM, H&S, Reporting (5% on future costs)	$36,000	$20,000	$20,000	$0
Subtotal Recurring and Future Costs	$757,000	$420,000	$420,000	$400,000
Total Alternative Cost	$4,626,000	$578,000	$762,000	$940,000

Notes:
*Alternative 1 = No action**
*Alternative 2a = Excavation, Backfill, and Offsite Disposal**
*Alternative 2b = Excavation, Backfill, and Onsite Treatment**
Alternative 3 = ISCO or ISCR and ISS
*Alternative 4 = Thermal and Capping**
Alternative 5 (L) = Maintenance of Existing Cap
Alternative 5 (H) = Engineered Cap
H&S = Health and safety
ISCR = Insitu chemical reduction
ISS = Insitu solidification and stabilization
N/A = Not Applicable
PM = Project management
** = alternative not costed*
Future and recurring costs are net-present value at a discount rate of 7.5 percent.

Table A-3
FU-4 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative		
	3	5	7
Alernative Description	**Focused Excavation, Backfill, and Offsite Disposal, Capping**	**ISCO or ISCR and ISS**	**Capping**
Capital Costs			
Evaluation, Testing, Design	$250,000	$250,000	$125,000
Construction	$2,506,000	$1,408,100	$309,000
PM, H&S, Reporting (5% on capital costs)	$138,000	$83,000	$22,000
Subtotal Capital (W/ Haz Waste) Costs	$6,677,000	N/A	N/A
Subtotal Capital Costs	$2,894,000	$1,741,000	$456,000
Recurring and Future Costs			
Operation and Maintenance	$721,000	$400,000	$721,000
Monitoring and Reporting	N/A	N/A	N/A
Replacement and Upgrades	N/A	N/A	N/A
PM, H&S, Reporting (5% on future costs)	$36,000	$20,000	$36,000
Subtotal Recurring and Future Costs	$757,000	$420,000	$757,000
Total Alternative (w/ Haz Waste) Cost	$7,434,000	N/A	N/A
Total Alternative Cost	$3,651,000	$2,161,000	$1,213,000

Notes:
*Alternative 1 = No action**
*Alternative 2a = Excavation, Backfill, and Offsite Disposal**
*Alternative 2b = Excavation, Backfill, and Onsite Treatment**
Alternative 3 = Focused Excavation, Backfill, and Offsite Disposal, Capping
*Alternative 4 = Shallow Excavation, Backfill, and Offsite Disposal**
Alternative 5 = ISCO or ISCR and ISS
*Alternative 6 =Thermal and Capping**
Alternative 7 = Capping
H&S = Health and safety
ISCO = Insitu chemical oxidation
ISCR = Insitu chemical reduction
ISS = Insitu solidification and stabilization
N/A = Not Applicable
PM = Project management
** = alternative not costed*
Future and recurring costs are net-present value at a discount rate of 1.5 percent.

Table A-4
FU-5 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative				
	2			3	6
	Low	Medium	High		
Alernative Description	Monitored Natural Attenuation	Injected ISCR PRB (w/ GAC) - Short	Injected ISCR PRB (w/ GAC)	Excavated ISCR PRB	ISCR Injections
Capital Costs					
Evaluation, Testing, Design	$120,000	$220,000	$250,000	$250,000	$250,000
Construction	$86,600	$639,800	$3,219,000	$9,148,700	$5,258,600
PM, H&S, Reporting (5% on capital costs)	$10,000	$43,000	$172,000	$470,000	$275,000
Subtotal Capital Costs	$217,000	$903,000	$3,641,000	$9,869,000	$5,784,000
Recurring and Future Costs					
Operation and Maintenance	N/A	N/A	N/A	N/A	N/A
Monitoring and Reporting	$353,000	$353,000	$353,000	$867,000	$867,000
Replacement and Upgrades	N/A	N/A	N/A	N/A	N/A
PM, H&S, Reporting (5% on future costs)	$18,000	$18,000	$18,000	$43,000	$43,000
Subtotal Recurring and Future Costs	$371,000	$371,000	$371,000	$910,000	$910,000
Total Alternative Cost	$588,000	$1,274,000	$4,012,000	$10,779,000	$6,694,000

Notes:
*Alternative 1 = No action**
Alternative 2 (L) = MNA
Alternative 2 (M) = Injected ISCR PRB (w/ GAC) - Smaller PRB
Alternative 2 (H) = Injected ISCR PRB (w/ GAC) - North-south length of
Alternative 3 = Excavated ISCR PRB (w/ GAC)
Alternative 4 = Enhanced Biodegradation and Monitored Natural
*Alternative 5 = ISCO Injections**
Alternative 6 = ISCR Injections
*Alternative 7 = Hydraulic Control**
GAC = Granular activated carbon
H&S = Health and safety
ISCR = Insitu chemical reduction
N/A = Not Applicable
PM = Project management
PRB = Permeable reactive barrier
** = alternative not costed*
Future and recurring costs are net-present value at a discount rate of 1.5 percent.

Table A-5
FU-6 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative				
	2			3	6
	Low	Medium	High		
	Monitored Natural Attenuation	Injected ISCR PRB (w/ GAC) - Short	Injected ISCR PRB (w/ GAC)	Excavated ISCR PRB	ISCR Injections
Capital Costs					
Evaluation, Testing, Design	$50,000	$130,000	$150,000	$150,000	$150,000
Construction	$0	$346,400	$912,200	$4,707,200	$1,474,400
PM, H&S, Reporting (5% on capital costs)	$10,000	$24,000	$53,000	$243,000	$81,000
Subtotal Capital Costs	$60,000	$500,000	$1,115,000	$5,100,000	$1,705,000
Recurring and Future Costs					
Operation and Maintenance	N/A	N/A	N/A	N/A	N/A
Monitoring and Reporting	$395,000	$395,000	$395,000	$537,000	$537,000
Replacement and Upgrades	N/A	N/A	N/A	N/A	N/A
PM, H&S, Reporting (5% on future costs)	$20,000	$20,000	$20,000	$27,000	$27,000
Subtotal Recurring and Future Costs	$415,000	$415,000	$415,000	$564,000	$564,000
Total Alternative Cost	$475,000	$915,000	$1,530,000	$5,664,000	$2,269,000

Notes:
*Alternative 1 = No action**
Alternative 2 (L) = MNA
Alternative 2 (M) = Injected ISCR PRB (w/ GAC) - Smaller PRB
Alternative 2 (H) = Injected ISCR PRB (w/ GAC) - North-south length of FU
Alternative 3 = Excavated ISCR PRB (w/ GAC)
*Alternative 4 = Enhanced Biodegradation and Monitored Natural Attenuation **
*Alternative 5 = ISCO Injections**
Alternative 6 = ISCR Injections
*Alternative 7 = Hydraulic Control**
GAC = Granular activated carbon
H&S = Health and safety
ISCR = Insitu chemical reduction
N/A = Not Applicable
PM = Project management
PRB = Permeable reactive barrier
** = alternative not costed*
Future and recurring costs are net-present value at a discount rate of 1.5 percent.

Table A-6
FU-7 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative		
	2	3	4
Alternative Description	Institutional Controls and MNA	ISCO Injections	ISCR Injections
Capital Costs			
Evaluation, Testing, Design	$120,000	$300,000	$300,000
Construction	$217,500	$5,064,600	$3,876,700
PM, H&S, Reporting (5% on capital costs)	$17,000	$268,000	$209,000
Subtotal Capital Costs	$355,000	$5,633,000	$4,386,000
Recurring and Future Costs			
Operation and Maintenance	N/A	N/A	N/A
Monitoring and Reporting	$771,000	$341,000	$341,000
Replacement and Upgrades	N/A	N/A	N/A
PM, H&S, Reporting (5% on future costs)	$39,000	$17,000	$17,000
Subtotal Recurring and Future Costs	$810,000	$358,000	$358,000
Total Alternative Cost	$1,165,000	$5,991,000	$4,744,000

Notes:
*Alternative 1 = No action**
Alternative 2 = Institutional Controls and Monitored Natural Attenuation
Alternative 3 = ISCO Injections
Alternative 4 = ISCR Injections
H&S = Health and safety
ISCO = Insitu chemical oxidation
ISCR = Insitu chemical reduction
MNA = Monitored natural attenuation
N/A = Not Applicable
PM = Project management
** = alternative not costed*
Future and recurring costs are net-present value at a discount rate of 1.5 percent.

Table A-7
FU-8 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative					
	1	4	5	7		
				Low	Medium	High
Alternative Description	No Action	ISCR Injections	ISCR PRB (w/ GAC)	ISCR PRB (w/ GAC)	Smaller Focused ISCR Injections and ISCR PRB (w/ GAC)	Focused ISCR Injections and ISCR PRB (w/ GAC)
Capital Costs						
Evaluation, Testing, Design	$0	$200,000	$200,000	$125,000	$170,000	$200,000
Construction	$0	$5,415,300	$1,957,700	$1,957,700	$2,290,000	$2,616,400
PM, H&S, Reporting (5% on capital costs)	$0	$281,000	$108,000	$104,000	$123,000	$141,000
Subtotal Capital Costs	$0	$5,896,000	$2,266,000	$2,187,000	$2,583,000	$2,957,000
Recurring and Future Costs						
Operation and Maintenance (GWET NPV)	$28,561,500	$5,449,000	$5,449,000	$5,449,000	$5,449,000	$5,449,000
Monitoring and Reporting	$0	$395,000	$428,000	$428,000	$428,000	$428,000
Replacement and Upgrades	$0	N/A	N/A	N/A	N/A	N/A
PM, H&S, Reporting (5% on future costs)	$0	$20,000	$294,000	$21,000	$21,000	$21,000
Subtotal Recurring and Future Costs	$28,562,000	$5,864,000	$6,171,000	$5,898,000	$5,898,000	$5,898,000
Total Alternative Cost	$28,562,000	$11,760,000	$8,437,000	$8,085,000	$8,481,000	$8,855,000

Notes:
Alternative 1 = No action (Includes Cost to operate GWET for 30 years). Costs split equally between FU-8 and FU-10
*Alternative 2 = ISCO Injections**
*Alternative 3 = ISCO and ISS**
Alternative 4 = ISCR Injections
Alternative 5 = ISCR PRB (w/ GAC)
*Alternative 6 = Enhanced Biodegradation**
Alternative 7 (L) = ISCR PRB (w/ GAC)
Alternative 7 (M) = Half of Focused ISCR Injections and ISCR PRB (w/ GAC)
Alternative 7 (H) = Focused ISCR Injections and ISCR PRB (w/ GAC)
GAC = Granular activated carbon
H&S = Health and safety
ISCR = Insitu chemical reduction
N/A = Not Applicable
PM = Project management
PRB = Permeable reactive barrier
** - alternative not costed*
Future and recurring costs are net-present value at a discount rate of 1.5 percent.

Table A-8
FU-9 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative		
	2b	3a	3b
Alternative Description	ISCO & ISS	Enhanced ISCR & ISS	ISCR & ISS
Capital Costs			
Evaluation, Testing, Design	$250,000	$250,000	$250,000
Construction	$7,412,200	$7,273,800	$7,261,900
PM, H&S, Reporting (5% on capital costs)	$383,000	$376,000	$376,000
Subtotal Capital Costs	$8,045,000	$7,900,000	$7,888,000
Recurring and Future Costs			
Operation and Maintenance	N/A	N/A	N/A
Monitoring and Reporting	$222,000	$222,000	$179,000
Replacement and Upgrades	N/A	N/A	N/A
PM, H&S, Reporting (5% on future costs)	$11,000	$11,000	$9,000
Subtotal Recurring and Future Costs	$233,000	$233,000	$188,000
Total Alternative Cost	$8,278,000	$8,133,000	$8,076,000

Notes:
*Alternative 1 = No action**
*Alternative 2a = ISCO Injection Program**
Alternative 2b = ISCO & ISS
Alternative 3a = Enhanced ISCR & ISS
Alternative 3b = ISCR & ISS
*Alternative 4 = Enhanced Aerobic/Anaerobic Biodegradation**
H&S = Health and safety
ISCR = Insitu chemical reduction
ISS = Insitu solidification and stabilization
N/A = Not Applicable
PM = Project management
** = alternative not costed*
Future and recurring costs are net-present value at a discount rate of 1.5 percent.

Table A-9
FU-10 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative					
	1	2	4	5		
				Low	Medium	High
Alternative Description	No Action	Focused ISCO Injections, ISCR Injections, Anaerobic Biodegradation	ISCR PRB	ISCR PRB (w/ GAC)	Smaller Focused ISCR Injections and ISCR PRB (w/ GAC)	Focused ISCR Injections and ISCR PRB (w/ GAC)
Capital Costs						
Evaluation, Testing, Design	$0	$180,000	$180,000	$140,000	$164,000	$180,000
Construction	$0	$15,299,800	$3,767,200	$3,759,000	$5,385,000	$7,004,400
PM, H&S, Reporting (5% on capital cos	$0	$774,000	$197,000	$195,000	$277,000	$359,000
Subtotal Capital Costs	$0	$16,254,000	$4,144,000	$4,094,000	$5,826,000	$7,543,000
Recurring and Future Costs						
Operation and Maintenance (GWET NF	$28,561,500	N/A	$5,449,000	$5,449,000	$5,449,000	$5,449,000
Monitoring and Reporting	$0	$509,000	$509,000	$509,000	$509,000	$509,000
Replacement and Upgrades	$0	N/A	N/A	N/A	N/A	N/A
PM, H&S, Reporting (5% on capital cos	$0	$25,000	$298,000	$25,000	$25,000	$25,000
Subtotal Recurring and Future Costs	$28,562,000	$534,000	$6,256,000	$5,983,000	$5,983,000	$5,983,000
Total Alternative Cost	$28,562,000	$16,788,000	$10,400,000	$10,077,000	$11,809,000	$13,526,000

Notes:
Alternative 1 = No action (Includes Cost to operate GWET for 30 years). Costs split equally between FU-8 and FU-10.
Alternative 2 = Focused ISCO Injections, ISCR Injections, Anaerobic Biodegradation
*Alternative 3 = Enhanced ISCR Injections**
Alternative 4 = ISCR PRB
Alternative 5 = Focused ISCR Injections and ISCR (w GAC) PRB
GAC = Granular activated carbon
H&S = Health and safety
ISCO = Insitu chemical oxidation
ISCR = Insitu chemical reduction
N/A = Not Applicable
PM = Project management
PRB = Permeable reactive barrier
** = alternative not costed*
Future and recurring costs are net-present value at a discount rate of 1.5 percent.

Table A-10
FU-11 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative 2
Alternative Description	Institutional Controls & MNA
Capital Costs	
Evaluation, Testing, Design	$120,000
Construction	$313,800
PM, H&S, Reporting (5% on capital costs)	$22,000
Subtotal Capital Costs	$456,000
Recurring and Future Costs	
Operation and Maintenance	N/A
Monitoring and Reporting	$282,000
Replacement and Upgrades	N/A
PM, H&S, Reporting (5% on capital costs)	$14,000
Subtotal Recurring and Future Costs	$296,000
Total Alternative Cost	$752,000

Notes:
*Alternative 1 = No action**
Alternative 2 = Institutional Controls and Monitored Natural Attenuation
MNA = Monitored natural attenuation
** = alternative not costed*
Future and recurring costs are net-present value at a discount rate of 1.5 percent.

Table A-11
FU-12 Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Item	Alternative 2
Alternative Description	Institutional Controls & MNA
Capital Costs	
Evaluation, Testing, Design	$120,000
Construction	$575,000
PM, H&S, Reporting (5% on capital costs)	$35,000
Subtotal Capital Costs	$730,000
Recurring and Future Costs	
Operation and Maintenance	N/A
Monitoring and Reporting	$767,000
Replacement and Upgrades	N/A
PM, H&S, Reporting (5% on future costs)	$38,000
Subtotal Recurring and Future Costs	$805,000
Total Alternative Cost	$1,535,000

Notes:
*Alternative 1 = No action**
Alternative 2 = Institutional Controls and Monitored Natural Attenuation
MNA = Monitored natural attenuation
** = alternative not costed*
Future and recurring costs are net-present value at a discount rate of 1.5 percent.

Table A-12
Alternatives Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Functional Unit	FU-2			FU-3			FU-4
Recommended Alternative	3			5			5
	Low	Medium	High	Low	Medium	High	
Alternative Description	Cap Maintenance	Gravel Cap	Engineered Cap	Cap Maintenance	Gravel Cap	Engineered Cap	ISCO or ISCR and ISS
Pre-Design Investigation, Remedy Design	$150,000	$150,000	$150,000	$150,000	$150,000	$150,000	$250,000
Construction	$0	$1,561,000	$3,706,000	$0	$176,000	$364,000	$1,408,100
PM, H&S, Reporting (5% on capital costs)	$8,000	$86,000	$193,000	$8,000	$16,000	$26,000	$83,000
Subtotal Capital Costs	**$158,000**	**$1,797,000**	**$4,049,000**	**$158,000**	**$342,000**	**$540,000**	**$1,741,000**
GWET O&M	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Future & Recurring Monitoring, Maintenance, Reporting	$420,000	$420,000	$420,000	$420,000	$420,000	$400,000	$20,000
Subtotal Recurring and Future Costs	**$420,000**	**$420,000**	**$420,000**	**$420,000**	**$420,000**	**$400,000**	**$20,000**
Total NPV Costs	**$578,000**	**$2,217,000**	**$4,469,000**	**$578,000**	**$762,000**	**$940,000**	**$1,761,000**

Notes:
GAC = Granular activated carbon
GWET = Groundwater extraction and treatment
H&S = Health and safety
ISCO = Insitu chemical oxidation
ISCR = Insitu chemical reduction
NPV = Net present value
O&M = Operations and maintenance
PM = Project management
PRB = Permeable reactive barrier
ISS = Insitu solidification and stabilization
N/A = Not Applicable

Table A-12
Alternatives Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Functional Unit	Soil Remedy Subtotal		FU-5			FU-6		
Recommended Alternative			2			2		
			Low	Medium	High	Low	Medium	High
Alternative Description	Low	High	Monitored Natural Attenuation	Injected ISCR PRB (w/ GAC) - Short	Injected ISCR PRB (w/ GAC)	Monitored Natural Attenuation	Injected ISCR PRB (w/ GAC) - Short	Injected ISCR PRB (w/ GAC)
Pre-Design Investigation, Remedy Design	**$550,000**	**$550,000**	$120,000	$220,000	$250,000	$50,000	$130,000	$150,000
Construction	**$1,408,100**	**$5,478,100**	$86,600	$639,800	$3,219,000	$0	$346,400	$912,200
PM, H&S, Reporting (5% on capital costs)	**$99,000**	**$302,000**	$10,000	$43,000	$172,000	$10,000	$24,000	$53,000
Subtotal Capital Costs	**$2,057,000**	**$6,330,000**	**$217,000**	**$903,000**	**$3,641,000**	**$60,000**	**$500,000**	**$1,115,000**
GWET O&M	**$0**	**$0**	N/A	N/A	N/A	N/A	N/A	N/A
Future & Recurring Monitoring, Maintenance, Reporting	**$860,000**	**$840,000**	$371,000	$371,000	$371,000	$415,000	$415,000	$415,000
Subtotal Recurring and Future Costs	**$860,000**	**$840,000**	**$371,000**	**$371,000**	**$371,000**	**$415,000**	**$415,000**	**$415,000**
Total NPV Costs	**$2,917,000**	**$7,170,000**	**$588,000**	**$1,274,000**	**$4,012,000**	**$475,000**	**$915,000**	**$1,530,000**

Notes:
GAC = Granular activated carbon
GWET = Groundwater extraction and treatment
H&S = Health and safety
ISCO = Insitu chemical oxidation
ISCR = Insitu chemical reduction
NPV = Net present value
O&M = Operations and maintenance
PM = Project management
PRB = Permeable reactive barrier
ISS = Insitu solidification and stabilization
N/A = Not Applicable

Table A-12
Alternatives Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Functional Unit	FU-7	FU-8			FU-9	FU-10		
Recommended Alternative	2	7			3a	5		
		Low	Medium	High		Low	Medium	High
Alternative Description	Monitored Natural Attenuation	ISCR PRB (w/ GAC)	Smaller Focused ISCR Injections and ISCR PRB (w/ GAC)	Focused ISCR Injections and ISCR PRB (w/ GAC)	Enhanced ISCR & ISS	ISCR PRB (w/ GAC)	Smaller Focused ISCR Injections and ISCR PRB (w/ GAC)	Focused ISCR Injections and ISCR PRB (w/ GAC)
Pre-Design Investigation, Remedy Design	$120,000	$125,000	$170,000	$200,000	$250,000	$140,000	$164,000	$180,000
Construction	$217,500	$1,957,700	$2,290,000	$2,616,400	$7,273,800	$3,759,000	$5,385,000	$7,004,400
PM, H&S, Reporting (5% on capital costs)	$17,000	$104,000	$123,000	$141,000	$376,000	$195,000	$277,000	$359,000
Subtotal Capital Costs	**$355,000**	**$2,187,000**	**$2,583,000**	**$2,957,000**	**$7,900,000**	**$4,094,000**	**$5,826,000**	**$7,543,000**
GWET O&M	N/A	$5,449,000	$5,449,000	$5,449,000	N/A	$5,449,000	$5,449,000	$5,449,000
Future & Recurring Monitoring, Maintenance, Reporting	$810,000	$449,000	$449,000	$449,000	$233,000	$534,000	$534,000	$534,000
Subtotal Recurring and Future Costs	**$810,000**	**$5,898,000**	**$5,898,000**	**$5,898,000**	**$233,000**	**$5,983,000**	**$5,983,000**	**$5,983,000**
Total NPV Costs	**$1,165,000**	**$8,085,000**	**$8,481,000**	**$8,855,000**	**$8,133,000**	**$10,077,000**	**$11,809,000**	**$13,526,000**

Notes:
GAC = Granular activated carbon
GWET = Groundwater extraction and treatment
H&S = Health and safety
ISCO = Insitu chemical oxidation
ISCR = Insitu chemical reduction
NPV = Net present value
O&M = Operations and maintenance
PM = Project management
PRB = Permeable reactive barrier
ISS = Insitu solidification and stabilization
N/A = Not Applicable

Table A-12
Alternatives Costing Summary
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Functional Unit	FU-11	FU-12	Groundwater Remedy Subtotal		Site Wide Total	
Recommended Alternative	2	2				
Alternative Description	Monitored Natural Attenuation	Monitored Natural Attenuation	Low	High	Low	High
Pre-Design Investigation, Remedy Design	$120,000	$120,000	**$1,045,000**	**$1,390,000**	**$1,595,000**	**$1,940,000**
Construction	$313,800	$575,000	**$14,183,400**	**$22,132,100**	**$15,591,500**	**$27,610,200**
PM, H&S, Reporting (5% on capital costs)	$22,000	$35,000	**$769,000**	**$1,175,000**	**$868,000**	**$1,477,000**
Subtotal Capital Costs	**$456,000**	**$730,000**	**$15,997,000**	**$24,697,000**	**$18,054,000**	**$31,027,000**
GWET O&M	N/A	N/A	**$10,898,000**	**$10,898,000**	**$10,898,000**	**$10,898,000**
Future & Recurring Monitoring, Maintenance, Reporting	$296,000	$805,000	**$3,913,000**	**$3,913,000**	**$4,773,000**	**$4,753,000**
Subtotal Recurring and Future Costs	**$296,000**	**$805,000**	**$14,811,000**	**$14,811,000**	**$15,671,000**	**$15,651,000**
Total NPV Costs	**$752,000**	**$1,535,000**	**$30,808,000**	**$39,508,000**	**$33,725,000**	**$46,678,000**

Notes:
GAC = Granular activated carbon
GWET = Groundwater extraction and treatment
H&S = Health and safety
ISCO = Insitu chemical oxidation
ISCR = Insitu chemical reduction
NPV = Net present value
O&M = Operations and maintenance
PM = Project management
PRB = Permeable reactive barrier
ISS = Insitu solidification and stabilization
N/A = Not Applicable

APPENDIX B TABLE 7-2: TECHNOLOGY SCREENING

Table 7-2
Technology Screening
Arkema Feasibility Study
Arkema Inc.
Portland, Oregon

Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
Functional Unit 1 – Riverbank Soil									
• Metals, pesticides, VOCs, dioxins	TBD by others	TBD by others	N/A	N/A	N/A	N/A	N/A	The Riverbank FU will be addressed in accordance with ASAOC for River Mile 7 West.	Yes
Functional Unit 2 – Site-wide Surface and Near-Surface Soil									
• Metals and pesticides; LtGW • Metals (Arsenic) and pesticides; Direct exposure. • Depth interval: surface to 15 feet bgs.	Excavation	Removal, treatment, and disposal	high	high	low	medium	low	Excavation is effective and implementable to minimize potential worker exposure and LtGW. Excavation for FU-2 assumes excavation of the entire FU as a stand-alone alternative. Excavation of the entire FU-2 would require substantial backfill and may not be cost effective. Presence of site infrastructure (i.e., GWET system) reduces implementability on Lots 3 and 4. Focused excavation of source areas, in combination with other technologies, may be implementable and cost effective. Health and safety hazards of excavation and offsite disposal constitute implementation risk. The RD will apply current data to identify the limits of excavation.	Yes
	Capping	Engineering controls	high	high	high	medium	low-medium	Capping is highly effective at preventing direct exposure and LtGW, depending on the capping material. Sampling and analysis conducted during RD would identify relevant materials, pathways, construction, and extent of a cap. Capping is reliable with proper maintenance and implementable. A cap is consistent with likely future site development for industrial use and is less expensive than active treatment technologies. Caps installed as interim remedies cover portions of the site. The low-medium cost effectiveness reflects the high cost of a cap expanded site-wide relative to the benefits. The RD will evaluate retention of existing caps and/or expanding the caps as a final remedial technology.	Yes
	Insitu phytoremediation	Removal, treatment, and disposal	low	low	low	low	medium	Phytoremediation is of uncertain effectiveness for arsenic and pesticides. Implementability may be low due to requirements of the City Portland Willamette Greenway Plan and preference for maintaining industrial land use of the site. Implementation risk is high due to exposures during implementation and possible release and spread of colonizing plants. Phytoremediation is not retained for consideration in the FS due to low effectiveness resulting from the complex mix of COCs and limited demonstrated effectiveness at similar sites.	No
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	medium	medium	low-medium	medium	medium	The COCs in soil at FU-2 present challenges to both aerobic and anaerobic biological treatment. Pesticides and some VOCs may be amenable to anaerobic biological treatment. Aerobic biological treatment may be appropriate for some VOCs and the dechlorinated intermediates from anaerobic degradation. For these reasons, a two-step process may be necessary for a biodegradation remedy to be effective. Insitu mixing/tilling may enhance amendment distribution and contact and improve effectiveness. Enhanced biodegradation requires adequate moisture, nutrient balance, and pH. These complex requirements could lower effectiveness and complicate technical implementability.	Yes
	ISCO	Removal, treatment, and disposal	high	medium	low-medium	medium	low	ISCO can be effective to treat VOCs and pesticides in soil and stabilize dissolved metals (e.g., arsenic) through precipitation. The substantial field operations and high capital cost of implementing ISCO site wide reduces its implementability and cost effectiveness, but rapid treatment eliminates long-term O&M costs of other technologies. ISCO can be combined simultaneously or sequentially with ISCR, ISCS, and ISS by tilling or otherwise mixing amendments into the soil to the target depth.	Yes

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Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
	ISCR	Removal, treatment, and disposal	medium	medium	low-medium	medium	low	ISCR may be only marginally effective to immobilize arsenic because arsenic sulfide minerals formed by ISCR are soluble and mobile. The substantial field operations and high capital cost of implementing ISCR site wide reduces its implementability and cost effectiveness.	Yes
	ISCS	Removal, treatment, and disposal	medium	medium	low-medium	medium	medium	ISCS using chemical precipitation for metals or activated carbon for metals and pesticides can be effective to reduce the mobility (leachability) of the COCs in FU-2. ISCS can be combined simultaneously or sequentially with ISCO or ISCR by tilling or otherwise mixing amendments into the near-surface soil. ISCS may be less effectives or reliable for pesticides. Relevance depends on potential for mobility. Medium reliability and implementability reflect the need for reliable mixing to the target depth to be effective.	Yes
	ISS	Removal, treatment, and disposal	high	medium	low-medium	high	medium	ISS using Portland cement or other additive minimizes COC mobility and provides geotechnical stability. ISS can be combined simultaneously or sequentially with ISCO or ISCR by tilling or otherwise mixing amendments into the near-surface soil. The low-medium implementability ranking reflects the large area of the FU and challenges of uniform mixing at depth. Implementation risk is low (high ranking) due to low risk of Portland cement and immediate solidification of COCs in concrete.	Yes
Functional Unit 3 – Acid Plant Vicinity Surface and Near-Surface Soil									
• Metals, pesticides, and VOCs in soil; LtGW. • Depth interval: surface to 15 feet bgs.	Excavation	Removal, treatment, and disposal	high	high	medium	medium	medium	Excavation would be effective and reliable to minimize potential LtGW in the Acid Plant areas. The RD would identify the appropriate depth and extent of excavation. Capping (or combination of other technologies) may be necessary to prevent infiltration and LtGW of residual contamination below 3 feet bgs in the areas where further excavation is not feasible. Presence of site infrastructure (i.e., the GWET system) reduces implementability on Lots 3 and 4. Excavation of surface soil and other focused areas within an FU may be cost effective to remove mass.	Yes
	Capping	Engineering controls	medium	medium	high	high	high	Capping is effective at preventing direct exposure and LtGW, but the high concentrations of COCs in soil may limit effectiveness and long-term reliability. FU-3 would be capped with a low permeability cap to limit infiltration and/or prevent direct contact with soil. Sampling and analysis conducted during RD would identify relevant pathways, construction, and extent of a cap. Capping is reliable with proper maintenance and easy to implement. A cap is consistent with likely future site development for industrial use and is inexpensive, as compared to other active treatment technologies. A cap for FU-3 has higher cost-effectiveness ranking than for FU-2 due to its smaller area. An existing cap, constructed as an interim remedy, covers portions of the site. The RD will evaluate retention of existing caps and/or expanding the caps as a final remedial technology.	Yes
	Insitu soil flushing	Removal, treatment, and disposal	low	low	medium	low	medium	Effectiveness of soil flushing relies on uniform application of water, an amendment applicable to the range of COC properties to induce mobility. Achieving uniform mobility of COCs in FU-3 would be difficult, making effectiveness and long-term reliability low. A cap, if constructed, would be incompatible with insitu soil flushing. Implementation risk of insitu soil flushing includes mobilization of COCs to groundwater without adequate capture. Soil flushing is not retained for FU-3.	No

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Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
	Insitu thermal treatment	Removal, treatment, and disposal	medium	high	medium	medium	low	Thermal treatment is common, effective, and reliable on VOCs and pesticides in soil, but not for metals. When effective, long-term reliability is high because COCs are volatilized and extracted. High temperatures and possible uncontrolled mobility of vapor are implementation risks. Thermal treatment is complex and expensive to implement (low cost-effectiveness), but the short duration of thermal treatment can be cost effective if treatment removes the source and achieves RAOs, while significantly reducing long-term O&M costs.	Yes
	SVE	Removal, treatment, and disposal	low	medium	medium	low	low	SVE in FU-3 would be effective only on VOCs. SVE would not be effective on pesticides or metals. Heterogeneity of fill and presence of silts and clays could result in short-circuiting or poor penetration of subsurface airflow, resulting in low effectiveness and low reliability of SVE. Previous SVE interim remedial action had limited effectiveness for treating VOCs in soil. Because SVE would not be effective to treat metals and high boiling point pesticides, and because the SVE interim action was only minimally effective on VOCs, SVE is not retained for FU-3.	No
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	low	low	medium	low	low	Bioremediation is likely redundant to or incompatible with remedies for DNAPL in FU-3. Enhanced biodegradation would not be effective as primary treatment for FU-3, but it is retained as a possible polishing step after source mass is treated. Low cost-effectiveness as an initial technology reflects the low effectiveness of bioremediation as primary treatment of high COC concentrations in the source area.	Yes
	ISCO	Removal, treatment, and disposal	high	medium	medium	medium	medium	ISCO is generally effective on the COCs in FU-3. Testing during RD would determine the effective reagent(s). The implementation depth interval would be determined by sampling and analysis during RD. ISCO may be implemented by direct injection or by mechanical or hydraulic mixing of amendments throughout the soil volume. The medium long-term reliability and implementability reflect uncertain reagent longevity of reagents and need to attain adequate mixing at depth. Use of ISCO reagent constitutes implementation risk. The RD will evaluate delivery and mixing methods.	Yes
	ISCR	Removal, treatment, and disposal	high	medium	medium	medium	medium	ISCR is generally effective on the COCs in FU-3. ISCR rankings for FU-3 are the same as those for ISCO.	Yes
	ISCS	Removal, treatment, and disposal	low-medium	medium	low-medium	medium	medium	ISCS including activated carbon can be effective to reduce the mobility (leachability) of the metals, pesticides, and VOCs in FU-2. The low-medium rankings reflect challenges to develop regent blends to react with the suite of COCs and challenges to attain adequate mixing and contact.	Yes
	ISS	Removal, treatment, and disposal	high	medium	high-medium	medium	medium	ISS using Portland cement or other additive minimizes COC mobility and provides geotechnical stability. ISS can be combined simultaneously or sequentially with ISCO or ISCR by tilling or otherwise mixing amendments into the near-surface soil. The high-medium ranking (as compared to FU-2) reflects the smaller area of FU-3. Implementation risk is low (high ranking) due to low risk of Portland cement and immediate solidification of COCs in concrete.	Yes

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Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
Functional Unit 4 – Acid Plant Area Surface and Near-Surface Soil									
• Metals, pesticides, VOCs, and DNAPL in soil; LtGW • Pesticides; Direct exposure • Depth interval: surface to 15 feet bgs.	Excavation	Removal, treatment, and disposal	high	high	high	medium	medium	Excavation depth for FU-4 would be up to 15 feet (excavation worker), or to the water table. The RD would refine the excavation depth. Excavation would be effective and reliable to minimize potential worker exposure and LtGW. Medium implementation risk reflects excavation and transportation risks. Medium cost effectiveness reflects the high transportation and disposal costs.	Yes
	Capping	Engineering controls	medium- high	high	high	high	high	A cap is easy to implement and is highly effective and reliable at preventing direct exposure and LtGW. A cap is consistent with likely future site development for industrial use and is inexpensive, as compared to other active treatment technologies. The higher cost-effectiveness of a cap over FU-4, as compared to FU-2, reflects the smaller area of FU-4. A gravel cap, plastic liner, and concrete pads from former building foundations left in place, constitute an interim remedy over portions of the site, including FU-4. The RD will evaluate retention of existing caps and/or expanding the caps as a final remedial technology.	Yes
	Insitu soil flushing	Removal, treatment, and disposal	low	low	high	low	medium	Effectiveness of soil flushing relies on uniform application of water, an amendment applicable to the range of COC properties to induce mobility. Achieving uniform mobility of COCs in FU-4 would be difficult, making effectiveness and long-term reliability low. A cap, if constructed, would be incompatible with insitu soil flushing. Implementation risk of insitu soil flushing includes mobilization of COCs to groundwater without adequate capture. Soil flushing is not retained for FU-4.	No
	Insitu thermal treatment	Removal, treatment, and disposal	high	high	high	medium	medium	Thermal treatment is common, effective, and reliable on VOCs and pesticides in soil, but not for metals. Thermal treatment is effective on VOC DNAPLs. When effective, long-term reliability is high. High temperatures and possible uncontrolled mobility of vapors constitute implementation risk. Thermal treatment is complex and expensive to implement (low cost-effectiveness), but the short duration of thermal treatment can be cost effective if treatment removes the source and achieves RAOs, while significantly reducing long-term O&M costs.	Yes
	SVE	Removal, treatment, and disposal	low	low	medium	low	low	SVE is not effective or reliable on DNAPL, high-boiling-point pesticides, or metals. Previous SVE interim remedial action had limited effectiveness on VOCs in soil. Since effectiveness is low on DNAPL, cost-effectiveness is also low for FU-4. Because of low effectiveness, and because the SVE interim action was minimally effective, SVE is not retained for FU-4.	No
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	low	medium	medium	low	medium	The COCs in soil at FU-4 present challenges to both aerobic and anaerobic biological treatment. Bioremediation is not effective on DNAPL. Enhanced biodegradation would not be effective as primary treatment for FU-3, but it is retained as a possible polishing step after source mass is depleted.	Yes
	ISCO	Removal, treatment, and disposal	high	high	high	medium	medium	ISCO and combined technologies can be effective to treat VOCs, including DNAPL and metals including arsenic with modifications to the soil to prevent leaching of COCs to groundwater. Application of ISCO in FU-4 would likely include mixing of amendments by mechanical or hydraulic methods in possible combination with ISS. High ISCO effectiveness for FU-4 that includes DNAPL presumes effective mixing.	Yes
	ISCR	Removal, treatment, and disposal	high	medium	medium	medium	medium	ISCR is generally effective on the COCs in FU-3. ISCR rankings for FU-3 are the same as those for ISCO, except that implementation would likely require more intense mixing of ISC reagents to assure contact. High ISCO effectiveness for FU-4 that includes DNAPL presumes effective mixing.	Yes

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Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
	ISCS	Removal, treatment, and disposal	low-medium	medium	low-medium	medium	medium	ISCS including activated carbon can be effective to reduce the mobility (leachability) of the metals, pesticides, and VOCs in FU-3. The low-medium rankings reflect the possible presence of DNAPL and the challenges to develop regent blends to react with the suite of COCs and challenges to attain adequate mixing and contact.	Yes
	ISS	Removal, treatment, and disposal	high	medium	medium	medium	medium	ISS using Portland cement or other additive minimizes COC mobility and provides geotechnical stability. ISS can be combined simultaneously or sequentially with ISCO or ISCR by tilling or otherwise mixing amendments into the near-surface soil. The high-medium ranking (as compared to FU-2) reflects the smaller area of FU-4. Implementation risk is low (high ranking) due to low risk of Portland cement and immediate solidification of COCs in concrete.	Yes
Functional Unit 5 – Lots 1 and 2 Shallow and Intermediate Groundwater Zones									
• Metals, pesticides, dioxins, VOCs, and chloride in shallow and intermediate zones • Depth interval: water table to top of deep zone	Natural attenuation	Removal, treatment, and disposal	medium	medium	high	medium	high	Natural attenuation (See Note 4) is an effective remediation technology if monitoring demonstrates that concentrations are trending toward cleanup goals or the remedy is otherwise achieving RAOs. MNA may be combined with active treatment, capping, or other technologies to achieve RAOs. Upland groundwater remedies interface with the in-water remedy, such as an expected in-water reactive sediment cap. MNA is easy to implement and cost effective. MNA is a likely cost-effective polish component of long-term implementation under a comprehensive management approach. Certain constituents in FU-5 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	Permeable reactive barrier	Removal, treatment, and disposal	high	high	high	medium	high	A permeable reactive barrier installed upslope of the riverbank would be easy to construct and would be effective and reliable to intercept and treat COCs in groundwater that flows through the barrier. The COCs in groundwater beneath Lots 1 and 2 are amenable to sorption and ISCR media in a barrier. ZVI could produce divalent iron at concentrations above hotspot criteria. Bench testing during RD would assess effectiveness and possible adverse effects of barrier media. Possible breakthrough of COCs constitutes implementation risk. Lots 1 and 2 span the northwest end of the site, where groundwater is shallow, making installation of reactive barrier simple and cost effective. Certain constituents in FU-5 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	Insitu thermal treatment	Removal, treatment, and disposal	low-medium	medium	low	medium	low	Thermal treatment can be effective for treating VOCs, dioxins, and pesticides. Because the FU is a groundwater zone and because some of the COCs require temperatures above the boiling point of water, either dewatering or intense energy would be necessary for effective thermal treatment in groundwater. Thermal treatment is not effective for metals. Due to the high cost in comparison to other relevant technologies, thermal treatment is not retained for FU-5. Certain constituents in FU-5 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	No
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	low-medium	medium	low-medium	medium	medium	The COCs in FU-5 present challenges to both aerobic and anaerobic biological treatment. Some pesticides and some VOCs may be amenable to anaerobic biological treatment. Aerobic biological treatment may be appropriate for some VOCs and the dechlorinated intermediates from anaerobic degradation. Therefore, a two-step process is may be effective. Maintaining proper conditions to support biological processes makes implementability in FU-5 complex. Possible slow degradation that may allow migration during implementation constitutes implementation risk. Lab or field-scale testing may be necessary to demonstrate enhanced biodegradation. Certain constituents in FU-5 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes

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Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
	ISCO	Removal, treatment, and disposal	high	high	high	medium	medium	ISCO and possible combined technologies (see below) can be effective to treat VOCs and metals including arsenic with possible modifications to the formation to prevent transport of COCs in groundwater. ISCO execution would be similar for soil and groundwater FUs. Sampling and analysis during RD would determine the target depth interval and applicable amendments. Application in groundwater would likely include mixing of amendments by mechanical (auger) or hydraulic (e.g., jet grouting) methods throughout the impacted soil and groundwater volume. The RD will evaluate oxidants, delivery, and mixing methods. Certain constituents in FU-5 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	ISCR	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISCR may be effective to treat COCs in FU-5. See FU-5 ISCO (above) for additional description. ISCR may be less effective than ISCO due to reaction kinetics for site COCs. Certain constituents in FU-5 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	ISCS	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISCS using reagents that cause a chemical reactions, formation of complexes, or sorption to activated carbon can be effective to reduce the mobility of the metals, pesticides, dioxins, and VOCs in groundwater in FU-5. See FU-5 ISCO (above) for additional explanation. Certain constituents in FU-5 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	ISS	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISS using Portland cement or other additive could be effective to entrain the COCs. Inadequate mixing in groundwater may lower effectiveness of ISS. See FU-5 ISCO (above) for additional explanation and description of process options. Certain constituents in FU-5 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	Hydraulic control	Engineering control	medium	medium	high	medium	low	Hydraulic control is an engineering control that minimizes transport of COCs, but it is not considered treatment under Oregon's hot spot rule. Hydraulic control (the GWET system) is retained as an interim remedial measure in shallow and intermediate groundwater. FU-5 is not bounded by the GWET system. If hydraulic control were implemented in FU-5, a new extraction system would be required. Low cost effectiveness reflects the high cost of designing, constructing, and operating a new extraction and treatment system. Certain constituents in FU-5 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes

Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
Functional Unit 6 – Southern Riverside Portion of Lot 3 Shallow and Intermediate Groundwater Zones									
• VOCs and pesticides in shallow groundwater, chloride, and metals in shallow and intermediate groundwater • Depth interval: water table to top of deep zone	Natural attenuation	Removal, treatment, and disposal	low	medium	high	medium	high	Natural attenuation is an effective remediation technology if monitoring demonstrates that concentrations are trending toward cleanup goals or the remedy is otherwise achieving RAOs. The FU-6 natural attenuation effectiveness ranking is low (as an independent technology) due to higher concentrations, proximity to the river, and shorter flow-path length and time of travel for natural attenuation processes (as compared to FU-5). Natural attenuation is a likely cost-effective polish component of long-term implementation under a comprehensive management approach.	Yes
	Permeable reactive barrier	Removal, treatment, and disposal	high	medium-high	medium	medium	high	A permeable reactive barrier installed upslope of the riverbank would be effective and reliable to intercept and treat COCs in groundwater that flows through the barrier. A permeable reactive barrier may be more difficult to implement in FU-6, as compared to FU-5, due to the presence of the GWET treatment system and deeper groundwater.	Yes
	Insitu thermal treatment	Removal, treatment, and disposal	low-medium	medium	low	medium	low	Because FU-6 is a groundwater zone and because some of the COCs require temperatures above the boiling point of water, either dewatering or intense energy would be necessary for effective thermal treatment in groundwater. Thermal treatment is not effective for metals. Due to the high cost in comparison to other relevant technologies, thermal treatment is not retained for FU-6.	No
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	medium	medium	low-medium	medium	medium	The COCs in FU-6 present challenges to both aerobic and anaerobic biological treatment. Effectiveness may decrease with increasing depth due to challenges of amendment delivery. Soil and groundwater conditions downgradient of ISCO or soil stabilization may enhance biodegradation in FU-6. Enhanced aerobic biological treatment can be expensive due to difficulty in delivering sufficient electron acceptor. Conversely, sources of electron donor that enhance anaerobic biological treatment are abundant. Lab or field-scale testing may be necessary to demonstrate enhanced biodegradation.	Yes
	ISCO	Removal, treatment, and disposal	high	high	high	medium	medium	ISCO and possible combined technologies (see below) can be effective to treat the VOCs and metals in FU-6 with possible modifications to the groundwater formation to prevent transport of recalcitrant or residual or residual COCs in groundwater. The injection interval for FU-6 would be determined by sampling and analysis during RD. The effectiveness of ISCO and similar technologies via injections rely on distribution and contact with the reactive reagents, which can be difficult in deeper aquifers. The RD will evaluate delivery and mixing methods.	Yes
	ISCR	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISCR may be effective to treat COCs in FU-6. See FU-6 ISCO (above) for additional explanation and description of process options. Relative effectiveness of ISCO and ISCR may require testing to assess reaction kinetics for site COCs.	Yes
	ISCS	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISCS using reagents that cause a chemical reactions, formation of complexes, or sorption can be effective to reduce the mobility of the VOCs, metals, and pesticides in groundwater in FU-6. See FU-6 ISCO (above) for additional explanation.	Yes
	ISS	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISS using Portland cement or other additive could be effective to entrain the COCs in FU-6 groundwater into a low-strength concrete monolith. Adequate mixing in groundwater may lower effectiveness of ISS. See FU-6 ISCO (above) for additional explanation and description of process options.	Yes
	Hydraulic control	Engineering control	low	low	high	high	high	Hydraulic control is an engineering control that minimizes transport of COCs, but it is not effective treatment of hot spots. See FU-5 for discussion. FU-6 is not bounded by the existing GWET system. The reliability of hydraulic control in deeper groundwater is uncertain.	Yes

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			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
Functional Unit 7 – Uplands Portion of Lots 3 and 4 Shallow, Intermediate, and Deep Groundwater Zones									
• Metals, dioxins, and pesticides in shallow intermediate, and deep groundwater and chloride in shallow and intermediate groundwater • Depth interval: water table to top of basalt	Natural attenuation	Removal, treatment, and disposal	medium	medium	high	medium	high	Natural attenuation is an effective remediation technology if monitoring demonstrates that concentrations are trending toward cleanup goals, or the remedy is otherwise achieving RAOs by specific attenuation mechanisms. Natural attenuation is easy to implement and cost effective. The medium effectiveness and reliability rankings reflect the longer flow path to the river to allow attenuation. Possible ongoing transport and exposure during natural attenuation may constitute implementation risk. Natural attenuation is a likely polish component of long-term implementation under a comprehensive management approach.	Yes
	Permeable reactive barrier (GAC)	Removal, treatment, and disposal	high	high	high	high	medium	A permeable reactive barrier installed near the border of FU-6 would be effective and reliable to intercept and treat COCs in groundwater that flows through the barrier. Testing during RD would assess the effectiveness of alternative barrier media. A PRB installed to address the deep zone would be more expensive, as compared to shallow groundwater (e.g., FU-5).	Yes
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	low-medium	medium	low-medium	medium	medium	The COCs in FU-7 present challenges to both aerobic and anaerobic biological treatment. Metals, dioxins, and pesticides do not readily biodegrade. A two-step biological treatment process may be effective. Effectiveness may decrease with increasing depth due to challenges of amendment delivery. Enhanced aerobic biological treatment can be expensive due to difficulty in delivering sufficient electron acceptor. Conversely, sources of electron donor (for anaerobic biological treatment) are abundant. Field-scale testing may be necessary to demonstrate the two-step process is possible.	Yes
	ISCO	Removal, treatment, and disposal	high	high	high	medium	medium	ISCO and possible combined technologies (see below) can be effective to treat VOCs and metals with possible modifications to the groundwater formation to prevent transport of recalcitrant or residual COCs in groundwater. Sampling and analysis during RD would determine the injection interval. The effectiveness of ISCO and similar technologies via injections rely on distribution and contact with the reactive reagents, which can be difficult in deeper aquifers. The RD will evaluate delivery and mixing methods.	Yes
	ISCR	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISCR may be effective to treat the COCs in FU-7. See FU-7 ISCO (above) for additional explanation and description of process options. Relative effectiveness of ISCO and ISCR may require testing to assess reaction kinetics for site COCs.	Yes
	ISCS	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISCS using reagents that cause chemical reactions, formation of complexes, or sorption can be effective on the metals, dioxins, and pesticides in FU-7 to reduce their mobility in groundwater. See FU-7 ISCO (above) for additional explanation.	Yes
	ISS	Removal, treatment, and disposal	high	medium	high	medium	medium	ISS using Portland cement or other additive could be effective to entrain the COCs in FU-7 groundwater into a low-strength concrete monolith. Adequate mixing in groundwater may lower effectiveness of ISS. See FU-7 ISCO (above) for additional explanation.	Yes
	Hydraulic control	Engineering controls	medium	medium	low	medium	low	Hydraulic control is an engineering control that minimizes transport of COCs, but it is not effective treatment of hot spots. Portions of FU-7 are not bounded by the existing GWET system. Hydraulic control may be less reliable in the deeper heterogeneous groundwater zones. If hydraulic control were implemented in FU-7, a new extraction system would be required. Low cost effectiveness reflects the high cost of designing, constructing, and operating a new extraction and expanded treatment system.	Yes

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			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
Functional Unit 8 – Northern Riverside Portion of Lots 3 and 4 Shallow, Intermediate, and Deep Groundwater Zones									
• Metals, chloride, pesticides, and VOCs in shallow, intermediate, and deep groundwater, and dioxins in the shallow zone • Depth interval: water table to top of basalt	Natural attenuation	Removal, treatment, and disposal	low	medium	high	low-medium	high	Natural attenuation is an effective remediation technology if monitoring demonstrates that concentrations are trending toward cleanup goals or the remedy is otherwise achieving RAOs. The FU-8 natural attenuation effectiveness ranking is lower than for FU-5 due to higher concentrations, proximity to the river, and shorter flow-path length and time of travel for natural attenuation processes.	Yes
	Insitu thermal treatment	Removal, treatment, and disposal	medium	medium-high	medium	medium	low	Thermal treatment can be effective for removing VOCs, dioxins, and pesticides. Because the FU is a groundwater zone and because some of the COCs require temperatures above the boiling point of water, either dewatering or intense energy would be necessary for effective thermal treatment in groundwater. Thermal treatment is not effective for metals. High temperatures and possible uncontrolled mobility of vapor are implementation risks. Due to the high cost in comparison to other relevant technologies, thermal treatment is not retained for FU-8.	No
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	low-medium	medium	low-medium	medium	medium	The COCs in FU-5 present challenges to both aerobic and anaerobic biological treatment. Some pesticides and some VOCs may be amenable to anaerobic biological treatment. Aerobic biological treatment may be appropriate for some VOCs and the dechlorinated intermediates from anaerobic degradation. Therefore, a two-step process is may be effective. Maintaining proper conditions to support biological processes makes implementability in FU-5 complex. Possible slow degradation that may allow migration during implementation constitutes implementation risk. Lab or field-scale testing may be necessary to demonstrate the effectiveness of enhanced biodegradation.	Yes
	ISCO	Removal, treatment, and disposal	high	high	high	medium	medium	ISCO and possible combined technologies (see below) can be effective to treat VOCs and metals including arsenic with possible modifications to the groundwater formation to prevent transport of COCs in groundwater. ISCO execution would be similar for soil and groundwater FUs. Sampling and analysis during RD would determine the target depth interval. Application in groundwater would likely include mixing of amendments by mechanical (auger) or hydraulic (jet grouting) methods throughout the impacted soil and groundwater volume. The RD will evaluate oxidants and delivery and mixing methods.	Yes
	ISCR	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISCR may be effective to treat COCs in FU-8. See FU-8 ISCO (above) for additional explanation and description of process options. Relative effectiveness of ISCO and ISCR may require testing to assess reaction kinetics for site COCs.	Yes

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Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
Functional Unit 9 – Acid Plant Area Shallow, Intermediate, and Deep Groundwater Zones									
• Metals, chloride, pesticides, and VOCs in shallow, intermediate, and deep groundwater. Dioxins and DNAPL in shallow groundwater • Depth interval: water table to top of basalt	Natural attenuation	Removal, treatment, and disposal	low-medium	low	high	medium	high	Natural attenuation would be used in combination with other technologies in shallow groundwater and is a likely polish treatment under a comprehensive management approach. Natural attenuation is not effective on DNAPL as a stand-alone alternative. Some of the COCs are not easily degraded or transformed by the intrinsic bacteria and will remain in groundwater for many years. The low-medium effectiveness ranking reflects the possibly long timeframe to naturally attenuate VOCs, pesticides, and dioxins. Natural attenuation is a likely polish component of long-term implementation under a comprehensive management approach.	Yes
	Insitu thermal treatment	Removal, treatment, and disposal	medium	medium-high	medium	medium	low	Thermal treatment can be effective for removing VOCs, dioxins, and pesticides, including DNAPL. Because some of the COCs would require temperatures above the boiling point of water, either dewatering or intense energy would be necessary. Thermal treatment is not effective for metals. Due to the high cost in comparison to other relevant technologies, thermal treatment is not retained for FU-9.	No
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	low	medium	low-medium	medium	medium	The COCs in FU-9 present challenges to both aerobic and anaerobic biological treatment. Some pesticides and some VOCs may be amenable to anaerobic biological treatment. Bioremediation is not effective on DNAPL as a stand-alone alternative. Aerobic biological treatment may be appropriate for some VOCs and the dechlorinated intermediates from anaerobic degradation. Therefore, a two-step process may be effective. Maintaining proper conditions to support biological processes makes implementability in FU-9 complex. Possible slow degradation that may allow migration during implementation constitutes implementation risk. Lab or field-scale testing may be necessary to demonstrate enhanced biodegradation.	Yes
	ISCO	Removal, treatment, and disposal	high	high	high	medium	medium	ISCO and possible combined technologies (see below) can be effective to treat VOCs and metals with possible modifications to the groundwater formation to prevent transport of recalcitrant or residual COCs in groundwater. Sampling and analysis during RD would determine the injection interval. The effectiveness of ISCO and similar technologies via injections relies on distribution and contact with the reactive reagents, which can be difficult in deeper aquifers. Delivery and mixing of adequate reagent may be problematic for DNAPL zones The RD will evaluate delivery and mixing methods.	Yes
	ISCR	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISCR may be effective to treat COCs in FU-9. See FU-9 ISCO (above) for additional explanation and description of process options. Relative effectiveness of ISCO and ISCR may require testing to assess reaction kinetics for site COCs.	Yes
	ISCS	Removal, treatment, and disposal	low-medium	medium	medium	medium	low-medium	ISCS using reagents that cause a chemical reactions, formation of complexes, or sorption can be effective on the metals, pesticides, VOCs, and dioxins in FU-9 to reduce their mobility in groundwater. See FU-9 ISCO (above) for additional explanation. Low-medium effectiveness and cost effectiveness reflect presence of DNAPL.	Yes
	ISS	Removal, treatment, and disposal	medium	medium	high	medium	medium	ISS using Portland cement or other additive could be effective to entrain the COCs in FU-9 groundwater into a low-strength concrete monolith. Inadequate mixing in groundwater may lower effectiveness of ISS. See FU-9 ISCO (above) for additional explanation.	Yes
	Hydraulic control	Engineering controls	high	medium	high	medium	high	Hydraulic control is an engineering control that minimizes transport of COCs, but it is not effective treatment of hot spots. Hydraulic control (the GWET system) is retained as an interim remedial measure in shallow, intermediate, and deep groundwater. FU-9 is bounded by the existing GWET system, but capture of deeper groundwater is uncertain. High effectiveness, implementability, and cost effectiveness reflect the existing GWET system. The GWET system is not a viable long-term alternative due to high costs of O&M, as compared to passive treatment technologies.	Yes

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Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
Functional Unit 10 – Southern Riverside Portion of Lot 4 Shallow, Intermediate, and Deep Groundwater Zones									
• Metals, chloride, pesticides, VOCs, and perchlorate in shallow, intermediate, and deep groundwater • Depth interval: water table to top of basalt	Natural attenuation	Removal, treatment, and disposal	low-medium	medium	high	medium	high	Natural attenuation is an effective remediation technology if monitoring demonstrates that concentrations are trending toward cleanup goals or the remedy is otherwise achieving RAOs. The low-medium effectiveness ranking reflects the possibly long timeframe to naturally attenuate VOCs and pesticides. The FU-10 natural attenuation effectiveness ranking is low-medium due to proximity to the river, and the shorter flow-path length and shorter time of travel for natural attenuation processes.	Yes
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	low-medium	medium	low-medium	medium	medium	Aerobic biodegradation is effective on perchlorate. Biodegradation is not effective on metals, chloride, and pesticides. It may be possible to implement a two-step biological treatment process in the saturated zone, but effectiveness may decrease with increasing depth to challenges of amendment delivery. Soil and groundwater conditions downgradient of ISCO or insitu stabilization may enhance natural attenuation. Enhanced aerobic biological treatment can be expensive due to difficulty in delivering sufficient electron acceptor. Conversely, sources of electron donor (for anaerobic biological treatment) are abundant. Field-scale testing may be necessary to demonstrate the two-step process is viable.	Yes
	ISCO	Removal, treatment, and disposal	high	high	high	medium	medium	ISCO and possible combined technologies (see below) can be effective to treat VOCs and metals with possible modifications to the groundwater formation to prevent transport of recalcitrant or residual COCs in groundwater. Sampling and analysis during RD would determine the injection interval. The effectiveness of ISCO and similar technologies via injections rely on distribution and contact with the reactive reagents, which can be difficult in deeper aquifers. The RD will evaluate delivery and mixing methods.	Yes
	ISCR	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISCR may be effective to treat COCs in FU-10. See FU-10 ISCO (above) for additional description. ISCR may be less effective than ISCO due to reaction kinetics for site COCs.	Yes
	ISCS	Removal, treatment, and disposal	medium	medium	medium	medium	medium	ISCS using reagents that cause chemical reactions, formation of complexes, or sorption can be effective to reduce the mobility of the metals pesticides, VOCs, and perchlorate in groundwater in FU-7. See FU-7 ISCO (above) for additional description.	Yes
	ISS	Removal, treatment, and disposal	high	medium	low-medium	medium	medium	ISS using Portland cement or other additive could be effective to entrain the COCs in FU-7 groundwater into a low-strength concrete monolith. Adequate mixing in groundwater may lower effectiveness of ISS. See FU-7 ISCO (above) for additional description.	Yes
	Hydraulic control	Engineering controls	Medium-high	medium	high	medium	high	Hydraulic control is an engineering control that minimizes transport of COCs, but it is not effective treatment of hot spots. Hydraulic control (the GWET system) is retained as an interim remedial measure in shallow and intermediate groundwater. FU-10 is bounded by the GWET system, but the extent of hydraulic control in deeper groundwater is not known. High effectiveness, implementability, and cost effectiveness reflect the existing GWET system. The GWET system is not a viable long-term alternative, due to high costs of O&M, as compared to passive treatment technologies like a PRB. If other insitu treatments are implemented near the existing GWET, the resultant geochemistry of the extracted groundwater may affect the GWET treatment.	Yes

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Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
Functional Unit 11 – Gravel/Basalt Zone Groundwater on Lots 3 and 4									
• Metals, chloride, pesticides, dioxins, and VOCs • Depth interval: Gravel/ Basalt Zones	Natural attenuation	Removal, treatment, and disposal	medium-high	medium	high	medium	high	Natural attenuation is a likely treatment in deep groundwater zones with low COC concentrations under a comprehensive management approach. Medium to high effectiveness reflects likely low hydraulic flux in deep groundwater and decreasing concentrations after source treatment upgradient. Absent an ongoing source, COCs in deep groundwater zones would naturally attenuation by physical and biological pathways. Testing and analysis during RD would verify assumptions. Certain constituents in FU-11 are likely a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	low	medium	low-medium	medium	medium	Other than VOCs, COCs in FU-11 are not readily amenable to biodegradation. Delivery Field-scale testing may be necessary to demonstrate the two-step process is viable. Certain constituents in FU-11 are likely a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	ISCO	Removal, treatment, and disposal	medium	medium	low	medium	low	ISCO and possible combined technologies (see below) can be effective to treat VOCs and metals. Sampling and analysis during RD would determine the injection interval. ISCO and similar technologies via injections rely on distribution and contact with the reactive reagents, which can be difficult in deeper aquifers. Accordingly, the rankings are lower for the gravel/basalt zone than for the shallower water-bearing zones. Low cost-effectiveness reflects high cost to treat low COC concentrations. The RD will evaluate delivery and mixing methods. Certain constituents in FU-11 are likely a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	ISCR	Removal, treatment, and disposal	medium	medium	low	medium	low	ISCR may be effective to treat COCs in FU-11. See FU-11 ISCO (above) for additional explanation and description of process options. ISCR may be less effective than ISCO due to reaction kinetics for site COCs. Low cost-effectiveness reflects high cost to treat low COC concentrations in deep groundwater zones. Certain constituents in FU-11 are likely a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	ISCS	Removal, treatment, and disposal	medium	medium	low	medium	low	ISCS using reagents that cause a chemical reactions, formation of complexes, or sorption can be effective to reduce the mobility of the metals pesticides, dioxins, and VOCs in groundwater in FU-11. See FU-11 ISCO (above) for additional explanation and description. Low cost-effectiveness reflects high cost to treat low COC concentrations in deep groundwater zones. Certain constituents in FU-11 are likely a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	ISS	Removal, treatment, and disposal	low-medium	medium	low	medium	low	ISS using Portland cement or other additive could be effective to entrain the COCs in FU-11 groundwater into a low-strength concrete monolith. Adequate mixing in groundwater may lower effectiveness of ISS. See FU-11 ISCO (above) for additional explanation and description of process options. Low cost-effectiveness reflects high cost to treat low COC concentrations in deep groundwater zones Certain constituents in FU-11 are likely a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes

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Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
Functional Unit 12 – Deep and Gravel/Basalt Zone Groundwater on Lots 1 and 2									
• Metals, chloride, pesticides, dioxins, and VOCs • Depth interval: Deep and Gravel/Basalt Zones	Natural attenuation	Removal, treatment, and disposal	medium - high	medium	high	medium	high	Natural attenuation is a likely technology in deep groundwater zones with low COC concentrations under a comprehensive management approach. Medium to high effectiveness reflects likely low hydraulic flux in deep groundwater and decreasing concentrations after source treatment upgradient, allowing for effective natural attenuation. Absent an ongoing source, COCs in deep groundwater zones would naturally attenuation by physical and biological pathways. Testing and analysis during RD would verify assumptions. Certain constituents in FU-12 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	PRB to top of Gravel/Basalt zone	Removal, treatment, and disposal	medium- high	high	medium - high	medium	medium	A PRB in FU-12 would be a deeper version of that on Lots 1 and 2 for FU-5. A PRB installed to address groundwater in the Deep Zone would be more expensive, as compared to shallow groundwater (e.g., FU-5). The conceptual PRB would not intercept COCs in the Gravel/Basalt zone, which would be allowed to naturally attenuate. Medium-high effectiveness, reliability, and implementability reflect industry experience with sorptive media and PRBs for the FU-12 COCs. The medium cost effectiveness reflects the more expensive construction of a deeper barrier, as compared to FU-5. Certain constituents in FU-12 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	Enhanced aerobic/ anaerobic biodegradation	Removal, treatment, and disposal	low-medium	medium	medium	medium	medium	Metals, dioxins, and pesticides present in FU-12 are not readily amenable to biodegradation. Soil and groundwater conditions downgradient of ISCO or insitu stabilization may enhanced biodegradation. Absent an ongoing source, lower concentrations of COCs in deep groundwater zones would be more amenable to biodegradation or natural attenuation. Lab or field-scale testing may be necessary to demonstrate enhanced biodegradation. Certain constituents in FU-12 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	ISCO	Removal, treatment, and disposal	medium	high	low-medium	medium	low	ISCO and possible combined technologies (see below) can be effective to treat VOCs and metals in the deep zone. Sampling and analysis during RD would determine the injection interval. ISCO and similar technologies via injections rely on distribution and contact with the reactive reagents, which can be difficult in deeper aquifers. Accordingly, the rankings are lower for the gravel/basalt zone than for the shallower water-bearing zones. Injection technologies are not easily implementable in the gravel-basalt, which would be allowed to naturally attenuate. Low cost-effectiveness reflects high cost to treat low COC concentrations. The RD will evaluate delivery and mixing methods. Certain constituents in FU-12 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	ISCR	Removal, treatment, and disposal	low-medium	medium	low-medium	medium	low	ISCR may be effective to treat COCs in FU-12. See FU-12 ISCO (above) for additional explanation and description of process options. ISCR may be less effective than ISCO due to reaction kinetics for site COCs. Low cost-effectiveness reflects high cost to treat low COC concentrations in deep groundwater zones. Injection technologies are not easily implementable in the gravel-basalt, which would be allowed to naturally attenuate. Certain constituents in FU-12 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes

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Functional Unit	Technology (1)	General Response Action	Preliminary Remedy Selection Balancing Factors Ranking (2)					Comments (4)	Retained (Yes/No)
			Effectiveness	Long term Reliability	Implementability	Implementation Risk	Cost (3)		
	ISCS	Removal, treatment, and disposal	low-medium	medium	low-medium	medium	low	ISCS using reagents that cause a chemical reactions, formation of complexes, or sorption can be effective to reduce the mobility of the metals, pesticides, dioxins, and VOCs in groundwater in FU-12. See FU-12 ISCO (above) for additional explanation and description. Low cost-effectiveness reflects high cost to treat low COC concentrations in deep groundwater zones. Injection technologies are not easily implementable in the gravel-basalt, which would be allowed to naturally attenuate. Certain constituents in FU-12 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes
	ISS	Removal, treatment, and disposal	low-medium	medium	low-medium	medium	low	ISS using Portland cement or other additive could be effective to entrain the COCs in FU-12 groundwater into a low-strength concrete monolith. Adequate mixing in groundwater may lower effectiveness of ISS. See FU-12 ISCO (above) for additional explanation and description of process options. Injection technologies are not easily implementable in the gravel-basalt, which would be allowed to naturally attenuate. Low cost-effectiveness reflects high cost to treat low COC concentrations in deep groundwater zones. Certain constituents in FU-12 are a trespass plume and the responsibility of others, subject to negotiation with the DEQ and responsible parties.	Yes

Notes:
(1) Technologies considered are those deemed relevant to the FU due to COCs or FU characteristics. Therefore, most technologies are retained, but not all technologies are considered for each of the soil or groundwater FUs.
(2) DEQ 1998, Guidance for Conducting Feasibility Studies. High, medium, low are rankings indicating relative performance against criterion.
(3) Cost ranking indicates cost effectiveness. Low ranking indicates high cost relative to effectiveness.
(4) Natural attenuation is not considered treatment for hot spots but natural attenuation but is a likely polish treatment for FU and other FUs under a comprehensive management approach.
AC = activated carbon
ASAOC = Administrative settlement agreement and order on consent
bgs = below ground surface
COCs = contaminants of concern
cost = cost effectiveness
Cr-VI = chromium VI
DNAPL = dense nonaqueous-phase liquid
ESIB = enhanced insitu biological treatment
FU = functional unit
GAC = granular activated carbon
GWET = groundwater extraction and treatment (system)
ISCO = insitu chemical oxidation
ISCR = insitu chemical reduction
ISS = insitu stabilization
ISCS = insitu chemical stabilization (including both insitu chemical stabilization and insitu solidification)
LtGW = leaching to groundwater
MCB = monochlorobenzene
MNA = monitored natural attenuation
N/A = not applicable
O&M = operation and maintenance
PRB = permeable reactive barrier
RAOs = remedial action objectives
RD = remedial design
SVE = soil vapor extraction
VOCs = volatile organic compounds
ZVI = zero valent iron

REFERENCES:
ERM (ERM-West, Inc.). 2009. 2009 Response to Public Comments on the Groundwater Source Control Measure Interim Remedial Measure Focused Feasibility Study Arkema Inc. Facility, Portland, Oregon. April 2009.

Not included in the Interim deliverable

Table 3

Technology Screening Table Summary

Arkema Feasibility Study

Arkema Inc.

Portland, Oregon

Functional Unit	Soil Technologies					Technologies Applicable to Soil and Groundwater						Groundwater Technologies				
	Technology #1 – Excavation, Capping, and Stabilization	Technology #2 – Excavation	Technology #3 – Capping	Technology #4 – In-situ Soil Flushing	Technology #5 – Soil Vapor Extraction	Technology #6 – Institutional Controls	Technology #7 – In-situ phytoremediation	Technology #8 – ISCO	Technology #9 – ISCR	Technology #10 – ISCS	Technology #11 – ISS	Technology #12 – Enhanced Aerobic/ Anaerobic Biodegradation	Technology #13 – Thermal	Technology #14 – Monitored Natural Attenuation	Technology #15 – Permeable Reactive Barrier	Technology #16 – Hydraulic Control
FU-1	X															
FU-2		X	X			X	O	X	X	X	X	X				
FU-3		X	X	O	O	X		X	X	X	X	O	X			
FU-4		X	X	O	O	X		X	X	X	X	O	X			
FU-5						X		X	X	X	X	X	O	X	X	X
FU-6						X		X	X	X	X	X	O	X	X	X
FU-7						X		X	X	X	X	X		X	X	X
FU-8						X		X	X	X	X	X	O	X		X
FU-9						X		X	X	X	X	X	O	X		X
FU-10						X		X	X	X	X	X		X		X
FU-11						X		X	X	X	X			X		
FU-12								X	X	X	X			X	X	

Notes:

X = Retained

O = Not retained

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Australia
Belgium
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France
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