May 11, 2010

Via E-Mail

Mr. Sean Sheldrake
U.S. Environmental Protection Agency
1200 Sixth Avenue, ECL-111
Seattle, Washington 98101

Subject: Preliminary CDF Screening Evaluation (PSE)
Final Report and Response to Comments
Arkema Early Action, Arkema Inc. Portland Facility
Administrative Order on Consent (AOC) for Removal Action
U.S. EPA Region 10 Docket No. CERCLA 10-2005-0191

Dear Mr. Sheldrake:

An electronic copy of the above-referenced PSE in support of the Arkema Portland Non Time Critical Removal Action has been placed on an FTP site for submittal; you will receive separate instructions for file retrieval via e-mail. This report was prepared in accordance with the previous agreements between EPA and LSS. LSS agrees with EPA's suggestion in the comment letter dated April 11, 2010 (Comment Letter) that most of what has been requested can and should be completed in the EE/CA. LSS has modified the PSE to include the directed change per the Comment Letter (see PSE and RLSO version attached). Also attached are LSS' responses to EPA's other comments provided in the Comment Letter. A CD will follow by overnight mail.

Please contact me at (610) 594-4430 if you have any questions or comments pertaining to this submittal.

Sincerely,

Legacy Site Services LLC

for

J. Todd Slater
Manager, Environmental Technologies
And Remedial Procurement

Legacy Site Services LLC
468 Thomas Jones Way
Exton, PA 19341-2528
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Attachment
Response to Comments

Enclosure
CD of Preliminary CDF Screening Evaluation Report

cc: (hard copy, CD, and electronic copy) Lance Peterson, CDM; Matt McClincy, Oregon DEQ; Les Williams, Integral-Seattle; Philip Spadaro, Kristi Maitland, and Chris Moody, ARCADIS; David Livermore and Eron Dodak, Integral-Portland.

(hard copy and CD) Rob Neely, NOAA; Erin Madden, Nez Perce Tribe; Lori Cora, EPA.

(hard copy and electronic copy) Brian Cunninghame, Confederated Tribes of the Warm Springs Reservation of Oregon; Larry Patterson, LSS; Doug Loutzenhiser, LSS; Steve Parkinson, Groff Murphy.

(CD and electronic copy) Chip Humphrey, EPA Oregon Ops; Genevieve Angle, NOAA Fisheries; Erik Ipsen, ERM; Cy Young, Oregon Division of State Lands.

(hard copy only) Karen Traeger, LSS.

(CD copy only) Tom Zeilman, Yakama Tribe; Preston Sleeger, US Department of Interior; Sheila Fleming, Ridolfi.

(electronic file only) James M. Anderson, Oregon DEQ; Rick Kepler, Oregon Department of Fish and Wildlife; Jeremy Buck, US Fish and Wildlife; Rose Longoria, Confederated Tribes and Bands of the Yakama Nation; Pete Wakeland, Confederated Tribes of the Grand Ronde Community of Oregon; Tom Downey, Confederated Tribe of the Siletz Indians; Audie Huber, Confederated Tribes of the Umatilla Indian Reservation; Alex Cyril, DEQ; Jennifer Peterson, DEQ; Mike Poulsen, DEQ.

May 11, 2010
Arkema Early Action
Portland, Oregon
Draft Preliminary Confined Disposal Facility (CDF) Screening Evaluation
Response to Comments

Master Comment Number	Comment	Response
Comment Overview		
1	Based on EPA and stakeholder review, there is insufficient information presented in the Draft PSE concerning floodway impacts, short-term contaminant transport and habitat impacts to make a determination that these issues will not be "fatal flaws." Federal Emergency Management Agency (FEMA) requirements, the Clean Water Act Section 404 analysis requirements and Endangered Species Act (ESA) are significant applicable and relevant and appropriate requirements that any CDF will need to comply with to be selected as a remedial action component. Significant additional information and analysis under these laws plus others has not been accomplished and there is no basis at this time to indicate that there are no fatal flaws related to the feasibility of the conceptual CDF Arkema is proposing. EPA and stakeholders have also identified other issues that need further valuation/clarification in the EE/CA.	LSS understands that additional information and analysis will be required for these items in the EE/CA. LSS believes that it complied with the expectations outlined within the multiple letters from EPA and responses from LSS on the subject. The Preliminary CDF Screening Evaluation (PSE) was never intended to take the place of the EE/CA and the issues raised in this comment cannot be addressed until a final Removal Action Area (RAA) boundary is selected and a CDF footprint based on this RAA boundary is evaluated in the EE/CA. This is also consistent with EPA's initial correspondence regarding the CDF screening evaluation. In the June 19, 2008 letter, EPA states that this is a screening level evaluation and that …"if the CDF is found to be feasible by Arkema's site specific analysis, these factors would be evaluated in further detail for the EE/CA…." In accordance with EPA's request, LSS will provide additional analysis in the EE/CA on the issues raised in this letter.
2	As indicated in the LSS letter to EPA dated July 25, 2008, the intended scope and schedule of this Draft PSE is "*to keep pace with the overall EE/CA process*". EPA has previously expressed concerns that further evaluation of a CDF alternative will possibly delay development and review of potentially more viable removal alternatives (EPA 2008d). Additionally, given that the draft Portland Harbor Feasibility Study will be submitted to EPA as early as Fall of 2010, any further analysis of a CDF for Arkema dredged materials will need to be accomplished within the FS' schedule at the latest. At a minimum, the issues presented in this letter concerning a CDF will need to be addressed in either the EE/CA or the FS, whichever is submitted first. EPA is concerned that the designation of the PSE as "draft" indicates a process of multiple iterations for screening evaluation of a CDF prior to the EE/CA and will continue to delay the schedule.	The May 11, 2010 version of the PSE is intended to be a final version. However, performing many of the tasks identified in the letter, as EPA points out in this comment, should be addressed in the EE/CA. LSS is preparing to respond to these new/additional requests in the EE/CA. As there was only one directed change identified in the letter (evaluating ex-situ soil mixing treatment technologies), the focus of the revised PSE is based on addressing that directed change. The other issues identified in the letter will be addressed as suggested by the EPA team in the EE/CA. None of the additional analysis or requests from EPA will delay the EE/CA schedule.
FLOODWAY IMPACTS ANALYSIS		
3	A specific methodology based on the above-referenced regulatory requirements was provided in the June 19, 2008 letter from the EPA to LSS for analyzing potential floodway impacts from the proposed siting of the CDF within the Willamette River channel and floodway. This analysis is based on FEMA procedures for assessing floodway impacts and includes the following steps: 1. Obtain, review and correct the FEMA regulatory floodplain model to reflect current conditions. 2. Utilize the corrected, effective model to predict CDF impacts on regulatory base flood elevations. The information presented in the Draft PSE does not support this requirement. ARCADIS states in Section 4 that they developed two models to predict current and proposed conditions, but only the output table from one model is presented in Appendix B. Section 4.3 indicates that this model may be based on current conditions. However, the model output contained in Appendix B is not identified as current or proposed, nor is it clear if the model is based on the FEMA regulatory model.	LSS believes the methodology used in the PSE was appropriate for assessing floodway impacts from a conceptual CDF and is generally consistent with EPA's June 19, 2008 letter. A HEC-RAS model was set up with all current bathymetric survey information for the river and flow data in the area of interest. Since this information was more recent than the FEMA model, the FEMA model was not used. Sensitivity to tidal influence was also assessed by changing water surface elevation of the downstream boundary of the model. The model was run for existing and proposed scenarios (i.e., including the CDF footprint/volume within the appropriate cross sections) to determine the associated impact of the facility on water elevations through this section of river. The procedure described in your letter is typically used for projects that are nearing completion from a design standpoint and may affect the BFEs on the associated FIRM map. Prior to construction, FEMA requires an evaluation of the potential for changes in the BFEs so they may communicate that to local agencies. This requires a completion of a Conditional Letter of Map Revision (CLOMR). For the EE/CA, FEMA will be contacted to obtain the hydraulic model (thought to be HEC-RAS or earlier version) developed as part of the Portland, Oregon Flood Insurance Study (FIS). This model will be updated as necessary to include the more current survey data which was used in the modeling for the PSE. Results for the existing model will then be compared with results from the FIS. A proposed model will then be developed by inputting data from the proposed CDF into the HEC-RAS model. The results of a comparison

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		between the existing and proposed situations will then be discussed with FEMA if there was any net increase in BFEs. As discussed in our July 25, 2008 letter "As long as the HEC modeling and analysis shows "no net rise" and is conducted by a registered professional engineer, the additional FEMA consultation steps outlined by EPA in its June 19th letter are not required".
4	EPA presumes that the model is not based on the FEMA regulatory model since the model cross-sections described in the Appendix do not appear to reflect FEMA Flood Insurance Rate Map (FIRM) cross-sections.	As detailed above, the existing FEMA model of the area will be obtained and used to make the comparison between existing and proposed conditions. The model presented in the PSE was constructed using recent survey data for the river in the vicinity of the proposed CDF. It is anticipated that the FEMA model would need to be updated with this same data in order to perform the floodway analysis, using a similar approach to that presented in the PSE.
5	ARCADIS references a 100-year flow of 375,000 cubic feet per second (cfs), obtained from the Terminal 4 Early Action EE/CA (BBL 2005). The statement is made in the Draft PSE that this flow was originally obtained from the Flood Insurance Study (FIS), but ARCADIS could not identify such a flow in the study. ARCADIS should reference the FIS in the Draft PSE.	The Portland FIS does not explicitly state the 100-year flood flow for the Willamette River; however, as detailed above, the existing FEMA model of the area will be obtained and used to make the comparison between existing and proposed conditions. The flood flows entered in the FEMA model will be utilized in the analysis. The Technical Memo by Parsons Brinckerhoff on Floodway and Flood Storage Technical Explanation and Analysis for the Terminal 4 project was developed using FEMA data and states a 100-year flood of 375,000 cfs.
6	ARCADIS uses an assumed roughness coefficient of 0.03 in their model, but without the regulatory model, it is once again impossible to determine if this value is the same as that used by FEMA in the regulatory model. If the regulatory model value is higher, then the ARCADIS model will predict lower water surface elevations. ARCADIS has also used an assumed geometry for the downstream railroad bridge. If this assumption results in a larger hydraulic cross-sectional area, then less backwater effect and lower upstream water surface elevations may be predicted. These model parameters must be the same as those in the FEMA regulatory model to make an accurate comparison between predicted water surface elevations and regulatory Base Flood Elevations (BFEs). If reasons exists for using different values than those presented in the regulatory model, then ARCADIS must present substantiated evidence to support changes to model input parameters that are used in the corrected effective model.	The roughness coefficient used within the HEC-RAS model presented in the PSE was determined based upon readily available literature sources and is expected to be similar in magnitude to that of the FEMA model. Although a greater roughness coefficient may lead to higher water surface elevations than those presented in the PSE, the difference between existing and proposed scenarios is expected to be the same regardless of magnitude of roughness coefficient. The difference in water levels is similarly not expected to be affected by a change in the geometry of the railroad bridge just downstream of the site.
7	ARCADIS makes the following assertion in Section 4.3: "*the* (modeling) *results demonstrate that in all tidal conditions analyzed, the impact of the conceptual CDF on water surface elevations would be negligible along the reach of river alongside the Site."* However, there is no evidence in the Draft PSE that supports this assertion as there is no comparison of proposed predicted water surface elevations to regulatory BFEs. Furthermore, an additional assertion is made in Section 4.3 which states: "*water surface elevations were observed to decrease in a number of sections, with an associated minimal rise in velocity (less than 0.2 foot per second in all cases)."* EPA presumes that ARCADIS is comparing current to proposed conditions, but how this was done is not linked clearly to the model output in Appendix B. Inspection of the cross sections and numeric output indicates that the upper portion of the cross-sections were not included in the model. If this is the case, the model does not represent actual conditions in either the regulatory, existing or developed scenarios.	Existing and proposed results were shown in the PSE; however, consistent with EPA's June 19, 2008 letter and LSS' July 25, 2008 response, they will be more clearly presented in subsequent submittals of the floodway analysis to explicitly call out the existing and proposed lines.
8	Finally, ARCADIS states in Section 4.3 that since there is no adverse impact on BFEs, no encroachment of the floodway will exist under proposed conditions. If the CDF is placed within the floodway boundaries as identified on the FIRM (Map Number 4101830080E), then a floodway encroachment will exist and the proposed action must meet the Federal no-rise criteria.	Consistent with EPA's June 19, 2008 letter and LSS' July 25, 2008 response, and as detailed above, the FEMA model will be obtained and the proposed CDF will be evaluated within this model.

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9	Due to the apparently inadequate analytical methodology and lack of appropriate data to support the assertions in Section 4.3 and without coordination with FEMA, EPA cannot unequivocally state that there is sufficient evidence to proceed with detailed analysis of the proposed CDF alternative. It is highly likely that any fill of this magnitude within the regulatory floodway or river channel, unless offset by a similar dredged amount at the same location, could adversely affect BFEs. A flood insurance/floodway development variance may be needed by the appropriate regulatory agencies. If ARCADIS believes that the parameters in the regulatory model are inaccurate and do not represent current conditions, then evidence must be presented to support such an assertion and, if appropriate, the changed condition(s) can be incorporated in the corrected effective model that reflects current conditions.	LSS is prepared to follow the new requirements outlined in the letter which are basically the same as those required for a CLOMR. The level-of-detail and presentation in the PSE is consistent with EPA's June 19, 2008 letter and LSS' July 25, 2008 response.
10	The contention in Section 5 and Appendix C that fill at the Site can be mitigated through cuts elsewhere along the river may not meet FEMA or Section 404 requirements, plus, unless Arkema can guarantee that such cuts will in fact be done, there is no basis at this time to rely on this premise. In general, balancing cut and fill is intended to preserve channel and floodway conveyance at the location of proposed modification. If fill is made at the Site but cuts are proposed upstream or downstream of the river reach that will experience the impacts, the fill will result in increased water surface elevations in the vicinity of the Site and the cut will result in lower water surface elevations in its vicinity. The decrease in water surface elevations from the proposed cut will not have the beneficial impact of offsetting the predicted increases at the Site.	Dependent on the results of the hydraulic modeling exercise, LSS will review available areas to balance cut and fill. The level-of-detail and presentation in the PSE is consistent with EPA's June 19, 2008 letter and LSS' July 25, 2008 response.
11	In summary, ARCADIS has not adequately addressed National Flood Insurance Program (NFIP) requirements and state channel and floodplain regulations with regards to the proposed location of the CDF. ARCADIS has not presented sufficient evidence that the proposed CDF placement will meet the no-rise criteria for fill placed in a regulatory floodway. The assertion by ARCADIS that BFE impacts from the proposed fill can be mitigated by cuts elsewhere on the river will not offset probable increases in BFEs at the site.	LSS is prepared to follow the general requirements outlined in the letter for the EE/CA which are basically the same as those required for a CLOMR. The level-of-detail and presentation in the PSE is consistent with EPA's June 19, 2008 letter and LSS' July 25, 2008 response. LSS will obtain the FEMA effective model, in preparation for floodway issues evaluated in the EE/CA, including an assessment of the CDF.
12	At a minimum, the next steps for further analysis on flood rise issues are: 1. Provide cut and/or decreased roughness in the immediate vicinity of the Site sufficient to offset the loss of conveyance resulting from the proposed CDF.	LSS will evaluate the need to revise the submittal based on the floodway analysis in the EE/CA. The level-of-detail and presentation in the PSE is consistent with EPA's June 19, 2008 letter and LSS' July 25, 2008 response.
13	2. Coordinate with FEMA on the entire analysis and obtain their approval of any conclusion that no rise will occur.	LSS will coordinate with FEMA during the EE/CA analysis, as appropriate and in accordance with EPA's June 19, 2008 letter and LSS' July 25, 2008 response.
14	3. Obtain a variance from state river channel and local floodplain regulations and federal NFIP requirements.	LSS will conduct the necessary tasks during the EE/CA, consistent with EPA's June 19, 2008 letter and LSS' July 25, 2008 response.
15	Step 1 addresses changes in channel roughness and/or geometry to offset losses in conveyance area from the proposed CDF fill. Proposing cuts in the vicinity of the proposed CDF is an appropriate approach; however, changes in roughness coefficients that result in increased velocities resulting in decreased	LSS is prepared to follow the general requirements outlined in the letter for the EE/CA. The level-of-detail and presentation in the PSE is consistent with EPA's June 19, 2008 letter and LSS' July 25, 2008 response.

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	predicted water surface elevations is more problematic as such changes can have adverse impacts on downstream property owners by accelerating flood waves. Such an impact to downstream properties needs to be analyzed should the proposed CDF proceed to a detailed evaluation. Steps 2 and 3 are necessary in order to assure that the remedial action will not cause the NFIP-participating community to be put on probation by FEMA in which case it loses flood insurance benefits as well as any other federal assistance for lands within regulatory flood hazard zones. Any proposal that includes fill in the floodway should be approved by all agencies with a regulatory interest in the Willamette River and its floodplain prior to the inception of any work. LSS is strongly urged to obtain the assistance of a professional engineer and certified floodplain manager to successfully coordinate these regulatory processes. EPA will need to be involved and participate in discussions with FEMA.	
SHORT-TERM CONTAMINANT TRANSPORT		
16	During construction and filling of the proposed CDF, particulate releases to the river system would be profoundly damaging. The Draft PSE concludes in Section 3.1.5.2 that short-term contaminant transport is not expected to impact the feasibility of the conceptual CDF. The conceptual layouts of the proposed CDF designs as presented in Figures 8 and 10 of the Draft PSE do not contain all of the presented Contaminated sediment volume assumed by the 5 milligram/kilogram (mg/kg) DDx contour line. Although the final footprint of the Removal Action Area (RAA) is yet to be determined, dredging of sediments outside of the area contained by the proposed CDF is presented within Figures 8 and 10 as part of the proposed Conceptual layouts. The Draft PSE cites silt curtains as a sediment resuspension control measure to address the short term contaminant transport issues presented during construction of the proposed CDF and dredging outside of the containment area. LSS claims in the Draft PSE (Section 3.3.2) that the installation of rigid resuspension controls is not feasible.	The EE/CA will evaluate any impacts to the river during filling of the conceptual CDF. The final footprint of the RAA, which has not yet been established, will be used in the EE/CA.
17	EPA does not agree that rigid resuspension controls are infeasible. For example, anchoring points for rigid resuspension controls may be drilled intermittently into the bedrock. EPA's position on rigid hydraulic controls was articulated in EPA's letter to LSS dated August 28, 2007. This letter states that mechanical dredging would be allowed for consideration, but only when combined with rigid hydraulic containment of the dredge area (EPA 2007a). The EPA letter to LSS dated February 21, 2009 includes the resolution of disputed issues pertaining to the use of silt curtains as a primary method for controlling resuspension residuals. According to the resolution, "*LSS agrees that it will not retain silt curtains as a primary method for controlling resuspension residuals in conjunction with mechanical dredging. LSS will only evaluate them, if at all, in conjunction with other control devices (e.g. sheet pile/coffer dam)*" (EPA 2009c). According to the terms of the dispute resolution, the Draft PSE does not present an acceptable solution to the issues related to the short-term containment of contaminated sediments outside of the proposed cofferdams.	As per previous agreement with EPA, LSS will evaluate rigid and non-rigid resuspension controls in the EE/CA. This commitment has not changed.

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HABITAT IMPACTS AND MITIGATION		
18	The Draft PSE does not address potential issues related to habitat mitigation or potential impacts to fisheries and wildlife. Mitigation for habitat loss and potential impacts to fish and wildlife, particularly to endangered fish species, has been raised as a significant issue in previous correspondence. EPA considers this issue to potentially represent a "fatal flaw" which could preclude selection a CDF for cleanup of Arkema's contaminated sediment. Although the construction of a CDF can be considered a beneficial reuse (i.e., creating new land for development), it also constitutes a complete loss of shoreline habitat along its length and a complete loss of shallow water habitat in its footprint. The proposed change in the nearshore environment may have such site-specific impacts to endangered fish species or other aquatic organisms that acceptable offsetting measures may not be feasible. Even if habitat mitigation is determined to be technically acceptable, comments expressed by U.S. Fish and Wildlife Service and the National Marine Fisheries Service have highlighted the concern that potential mitigation sites may simply not be available. Habitat mitigation and endangered species consultation are feasibility-related issues that have been repeatedly communicated to LSS as early as June 19, 2008 in a letter from the EPA (2008c). The Draft PSE does not address habitat mitigation. As highlighted by examples and in guidance, feasibility of habitat mitigation is an important screening criterion for project development.	The EE/CA will include an evaluation of habitat impacts and possible mitigation for the CDF as well as other alternatives. A formal Section 7 consultation cannot be initiated until the EE/CA, which includes the draft biological assessment, is prepared; however, informal consultations with the natural resource agencies, including NMFS, have been initiated in order to understand and incorporate their concerns into design considerations and a habitat mitigation plan. A 404b analysis will also be included as an attachment to the EE/CA that will evaluate how the preferred alternative will comply with the substantive requirements of the CWA. LSS will coordinate future consultations on this matter with EPA.
19	Section 3.1.2 of the Draft PSE cites examples of other EPA Region 10 supported CDF projects in the Pacific Northwest. Although these examples do not have similar site conditions as Arkema (as explained further within this letter), these examples clearly indicate that mitigation is a significant part of any CDF development and can increase costs of a project significantly. Habitat mitigation is not included as a component of the proposed Arkema CDF.	As mentioned in the previous response, habitat mitigation will be evaluated as part of the CDF and other alternatives in the EE/CA.
20	Section 8.2.2. and Appendix D of the Draft PSE both cite EPA's *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (EPA 2008e) as a set of criteria for evaluating the environmental effects of a remediation technology. The criteria include "*land and ecosystem impacts (e.g., impacts on flora and fauna habitat, change in impervious coverage affecting stormwater generation)*" as one of six criteria to be used during evaluation. The Draft PSE does not include this criterion in the CDF evaluation.	This is a new comment from EPA that was not previously requested for the PSE. These criteria will be included in the evaluation of the CDF and other alternatives in the EE/CA.
21	Compliance with EPA performance standards for CDFs within the Portland Harbor Superfund Site will require that proposed harborwide CDFs "*be managed in a manner that minimizes impacts to fisheries and wildlife. Potential and short-term exposures of fish and wildlife to contaminated sediments and/or water within a CDF shall be fully assessed and disclosed*" (EPA 2010). The Draft PSE does not address these issues.	These performance standards are new and were not part of the CDF screening level evaluation agreed to by LSS and EPA. LSS understands that they are in draft form. If performance standards for CDFs are finalized prior to completing the EE/CA, LSS will consider them during screening of the CDF alternative in the EE/CA. LSS notes that until that time, the standards that have been presented in letters from EPA on this matter will be considered in the CDF alternative development.
22	The Draft PSE acknowledges that compliance with the substantive requirements of Section 404 would be an ARAR for the proposed project. However, the report does not evaluate what would be involved in meeting the substantive requirements of Section 404 and whether it is feasible to do so. Compliance with the substantive requirements of Section 404 of the Clean Water Act will require	Section 404b analysis will be required for the selected EE/CA action regardless of the removal action elements (i.e., CDF, dredging, capping, etc.) A 404b analysis will also be included as an attachment to the EE/CA that will evaluate how the preferred alternative will comply with the substantive requirements of the CWA.

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	mitigation for both short-term water quality impacts and the potential impacts to habitats and fish and wildlife, including direct, indirect, temporal, and cumulative impacts.	
23	Compliance with the substantive requirements Section 404 also involves compliance with the Endangered Species Act which may require offsetting measures to compensate for potential impacts to fish and wildlife and their habitats.	As previously mentioned, formal consultation with the natural resource agencies will be conducted in compliance with the ESA requirements. This is a requirement for the EE/CA regardless of which removal action is selected for the site. A 404b analysis will also be included as an attachment to the EE/CA that will evaluate how the preferred alternative will comply with the substantive requirements of the CWA.
24	Arriving at appropriate mitigation that meets substantive requirements of potential ARARs and is acceptable to all the various agencies with authority can be complex and difficult. The proposed CDF project could have many different types of impacts that would need to be accounted for, including: • Direct and indirect impacts to in-water habitats and organisms from in-water construction activities such as pile driving, discharges to the water, turbidity, loss of habitat due to structures designed to isolate the work zone. • Permanent loss of shallow in-water and nearshore habitats. • Permanent loss of beach and riparian habitats. • Impacts to fish and wildlife from alteration of nearshore environment and bathymetry such as impacts to fish migration corridors or blockage of fish migration. • Proposed off-site cuts to balance the CDF fill could result in even greater impacts to nearshore habitats that would also require mitigation.	Conceptual mitigation requirements and costs will be evaluated for each alternative evaluated in the EE/CA including the CDF alternative.
25	On-site mitigation is often required at a minimum ratio of 2:1 (area:area) and could be higher given the cumulative impacts from the whole project, such as significant temporal effects. Offsite mitigation is usually required at even greater ratios, such as, ratios of 3:1 to 10:1 and mitigation that proposes habitat enhancement of existing habitats to mitigate for impacts may be required at ratios even higher. Given the total absence of even a conceptual mitigation evaluation and cost analysis, the PSE is significantly lacking in highly pertinent information to support that there are no fatal flaws in the feasibility of the CDF. During the August 8, 2008 site visit, representatives of the U.S. Fish and Wildlife Service and the National Marine Fisheries Service cautioned that potential mitigation sites in the lower Willamette system may be extremely limited in size and suitability for a project of this size. On-site mitigation may also not be feasible due to the size of the proposed impact. To date, there has been no indication that LSS has assessed the type and size of mitigation site that may be needed for the project or determined whether such mitigation would be feasible. The Draft PSE does not address this issue.	Conceptual mitigation requirements and costs will be evaluated for each alternative evaluated in the EE/CA including the CDF alternative.

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GEOTECHNICAL EVALUATION		
26	EPA's review of the geotechnical components of the proposed circular cell cofferdam has not found any "fatal flaws" that would prevent the CDF evaluation from proceeding in the EE/CA. The circular cell cofferdam would essentially be a large gravity structure resting on the bedrock. The assumptions and preliminary design parameters ARCADIS provided appear to be reasonable.	Agreed.
27	EPA has concerns about the lack of "keying" of the cofferdam into the bedrock. The driven sheet piles may not provide a good key into the bedrock, especially with information that indicates the basalt bedrock may be weathered and/or fractured. It should be noted that much of the basalt that has been found in the uplands, with fractures and other weathered features, would allow the water and contaminants to flow through the upper basalt formation. This same issue would occur along the upper basalt surface which is the proposed base for the CDF. Note that some of the wells into the basalt at other upland facilities in Portland Harbor have had many feet of weathered basalt where originally it was assumed the top of basalt was sound and competent. A similar problem is likely to be present at the Arkema site.	The PSE discusses the possibility of groundwater flow underneath the containment structure. Downward leakage is generally prevented under steady-state conditions. Gradient reversal during temporary, transient conditions may be possible. However, water quality issues due to downward and outward migration of DDx is not expected because of the limited solubility and limited mobility of DDx in this environment. The effects on groundwater flow and contaminant transport due to transient conditions would be analyzed during design of the CDF. As stated in the PSE, secondary containment may be an option to mitigate for gradient reversal scenarios. Long-term water quality impacts due to migration of DDx are not expected at this time.
28	The sediment inside the base of the circular cells of the cofferdam could be amended (as noted on page 3-9 of the Draft PSE) to make a more impermeable seal at the cell base rock interface. However, the Draft PSE does not currently indicate that this would be performed.	As stated on page 3-9 of the PSE, the existing sediment could be amended to improve the strength and or permeability of the sediment. The addition of this amendment will be considered in the evaluation of the CDF in the EE/CA.
29	EPA also has concerns about hydrostatic loads on the cofferdam from potential high river stages during construction. ARCADIS states on Page A-6 "*Hydrostatic loads on the wall depend on the water levels within the CDF and in the river. Water level differentials that act toward the CDF wall were not considered at this time, but may need to be considered during subsequent design stages to take into account high river stages during construction. Contingency measures, such as flooding of the enclosed area, may be used to counteract large hydrostatic loads pushing toward the CDF. For the conceptual-level design analysis, only relatively common water levels were considered*." ARCADIS also states on page A-7, "*For the conceptual-level design analysis, a low river stage elevation of +6 feet NAVD 88 was combined with a water level within the CDF of +8 feet NAVD 88*." This analysis was not conducted using "relatively common" water levels. The mean monthly stage in the river ranges from 8 to 13 ft according to ARCADIS in Table 1. The minimum monthly stage varies from 6.1 to 7.6 ft and the maximum monthly stage ranges from 11.1 to 32.2 ft.	The intent of the preliminary cofferdam stability analysis was to show that the cofferdam structure is generally feasible. For the actual design of the structure, it is expected that a range of loading cases would be established along with appropriate factors of safety that would depend on the severity of the loading. Based on these loading cases, an appropriate design would be selected, which may require a larger or smaller effective cofferdam width. However, adjustments to the size of the cofferdam are not expected to be substantial. The design would also cover certain construction scenarios where high river stages could result in relatively large hydrostatic loads on the cofferdam. This is expected to be addressed using the contingency measures outlined in the PSE (e.g., installation of a temporary weir that would allow controlled flooding of the CDF during extreme river stages). Additional preliminary analyses are not expected to change the outcome of the assessment that the cofferdam structure is feasible.
30	Furthermore, as described above, there is considerable uncertainty in the groundwater levels that will be attained within the CDF. Other areas of the document state that the predicted water level in the CDF is predicted to be 13 ft, not 8 ft. The document should describe how the conclusions of the hydrostatic load analysis would vary with varying water levels in the CDF and river stage elevations.	As stated above, the cofferdam design depends on the selection of an appropriate combination of loading cases and factors of safety. Using a water level in the CDF of +13 ft NAVD88 may increase the effective cofferdam width by 3 to 5 feet. However, appropriate combinations of loads and factors of safety have not been established and therefore the selection of exact cofferdam dimensions would be premature. While the cofferdam width may change slightly during design, this is not expected to affect the overall feasibility of the cellular cofferdam structure.

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HYDRAULIC CONTAINMENT EVALUATION		
31	Conclusions in the Draft PSE regarding the general contaminant transport/hydraulic containment of DDx do not necessarily apply to other contaminants present at the Arkema site. For example the Draft PSE states within the Executive Summary, "*the primary contaminant (DDx, the sum of the DDE, DDD, and DDT isomers) has limited solubility and limited mobility in most soil environments and is expected to have minimal leachability from sediment within and outside a CDF at the Site. As such, vertical migration of DDx from the sediment into groundwater and through the bedrock during a temporary gradient reversal would be negligible*." This conclusion regarding the short-term contaminant transport/hydraulic containment of DDx does not address the migration of other contaminants from the sediment into groundwater and through the bedrock during temporary gradient reversals. In addition, the presence of chlorobenzene (also known as monochlorobenze [MCB]), as detected in groundwater samples (Integral 2003), may influence the solubility of contaminants (including DDx) in the sediment. MCB is a volatile organic compound used as one of the raw materials in the manufacture of DDT. As noted within the Integral report, "*There is a close correlation between MCB and DDT concentrations in groundwater both in the upland areas and in sediments (Figures 11 and 14). In selected samples, DDT concentrations in sediment groundwater are up to two orders-of-magnitude more than the aqueous solubility of DDT. Note, however, that because the groundwater samples were collected using the Geoprobe® temporary well screen that the introduction of fine suspended particulate matter could add a high-bias to the measured groundwater DDT concentrations. In general, the areas with exceedances of the aqueous solubility of DDT are collocated with areas of higher MCB concentrations, indicating a likely cosolvent relationship between DDT and MCB. The highest DDT concentration in sediment groundwater (1,900 /ug/L) was measured at WB-10 at -18.0 to -22.0 ft CPD*" (Integral 2003).	The EE/CA will include an evaluation of whether the CDF would influence transport of other upland chemicals. Also, as EPA points out in their comment, the purported DDx cosolvency issue is more a function of the limits of the sampling technique used in 2003 and not cosolvency. In addition, MCB, due to its solubility and mobility is not of particular concern for recontamination of sediments. See Section 6.4 of the EPA Draft EE/CA Work Plan dated May 2007.
32	The Draft PSE further notes that contaminated sediment historically placed in CDFs remains in a saturated state, but that the proposed Arkema CDF would place some sediment above the steady state water elevation that at times would remain unsaturated. The Draft PSE however, does not address how this affects contaminant migration, particularly for contaminants that react with oxygen (e.g., metals).	The evaluation of the CDF in the EE/CA will consider this condition further. Metals are not a high priority COC at the site (see Sections 6.2 and 6.4 of the Draft EPA EE/CA Work Plan dated May 2007). Any metals that could potentially mobilize in the unsaturated portion of the CDF, in order to exit the CDF would have to pass though saturated sediments, thereby being re-sequestered in the saturated sediments, Further, these sequestered metals would also have to somehow mobilize in the saturated zone and pass into and through the bedrock beneath the CDF. In addition, the driving conditions for movement are the hydraulic gradients discussed in the PSE. Gradients under ambient conditions have been predicted to be inward, outward gradients have been predicted to only occur in a transient (i.e., very short term) gradient reversal conditions.
33	Variation in gradients and flow between the CDF and the river could also result in transport of contaminants from the CDF via the basalt bedrock. The Draft PSE acknowledges this by stating, "*Vertical hydraulic containment would rely in part on prevention of infiltration by a low permeability surface cap and depend largely on the hydraulic properties of the underlying basalt bedrock. Transient conditions could cause temporary gradient reversals and potentially allow temporary outward migration of groundwater from the CDF. It may be feasible to control transient flow reversals by implementing secondary containment measures, such as groundwater extraction from within the CDF*." As previously noted in this letter, there is a potential for the upper basalt surface that forms the foundation of the CDF to be weathered and/or fractured which could increase the significance of this concern.	The evaluation of the CDF in the EE/CA will consider this condition further.

Master Comment Number	Comment	Response
34	An understanding of the relationship between groundwater levels in the CDF and the Willamette River Stage is essential to evaluating the potential for migration of contaminants from sediment in the CDF. Because lateral flow will be eliminated by the up gradient extraction system and cofferdam, and areal recharge will be minimized by the cap, water levels in the CDF will depend on the water levels in the basalt layer. The Draft PSE states that "*Water levels inside the CDF would be controlled by the potentiometric head within underlying basalt bedrock.*" Additionally the Draft PSE states that "*The water level within the CDF is estimated to be approximately +13 feet NAVD 88 based on water levels from five Basalt Zone monitoring wells measured in April 2007*." However, estimated groundwater levels within the CDF are considerably more uncertain than indicated.	Agreed. However, as stated in the PSE, these will be looked at in the EE/CA, and hydraulic control measures can be effectively evaluated and added as necessary.
35	Limited groundwater monitoring data were used to obtain the estimated CDF water level. The Draft PSE does not indicate which five wells were used to obtain the average basalt groundwater elevation of 13 ft. Without this information, EPA cannot determine whether the average groundwater level is representative of water levels in the basalt near the CDF. At a minimum, ARCADIS should discuss the water level variability observed in the basalt monitoring wells near the river, rather than assuming the water level in the CDF will be a constant 13 ft.	LSS agrees that the water level in the CDF will not be a constant 13 ft. The conceptual site model indicates that the Basalt Zone is hydraulically connected to the river and that river stage fluctuations affect Basalt Zone heads. The presence of fine grained sediments overlying the Basalt Zone within the CDF will reduce the hydraulic connection between the Basalt Zone and hydraulic conditions inside the CDF; however, insufficient data exist to evaluate the transient effects of fluctuating surface water elevations and fluctuating Basalt Zone heads on water levels within the CDF. This will be considered further in the EE/CA, and as previously mentioned, the use of amendments could be considered to further reduce the hydraulic conductivity of sediments overlying the basalt. The following text will be added to the report to clarify how the value of 13 feet was selected: "ARCADIS used data collected in April 2007 to estimate groundwater heads within the hydrostratigraphic zones at the site. Monitoring wells RP-10-130, RP-08-107, RP-09-64, RP-02-66, W-19D, and MWA-21b are screened within the Basalt Zone. MWA-21b, with a measured potentiometric head in April 2007 of 13.66 ft NAVD88, was taken to be the most representative of Basalt Zone hydraulic conditions adjacent to the conceptual CDF. As indicated above, this single measurement is not believed to represent a constant head present in the Basalt Zone, but instead was used in developing the conceptual site model for hydraulic containment of the CDF which indicates that transient effects of fluctuating river stage will affect head within the CDF."
36	The Draft PSE does not provide hydraulic properties of the basalt or the "*fine-grained sediment at the basalt surface*" which are needed to support conclusions about the extent to which this layer might reduce the interaction between water in the CDF and water in the basalt. Again, the potential for the upper basalt surface to be weathered and/or fractured is of significance.	The evaluation of the CDF in the EE/CA will consider this condition further, and as previously mentioned, the use of amendments could be considered to further reduce the hydraulic conductivity of sediments overlying the basalt.

Master Comment Number	Comment	Response
37	The extent to which the groundwater extraction system will capture basalt bedrock groundwater flow is also uncertain. Although the Draft PSE states that "*some groundwater in the Basalt Zone may also be captured by the groundwater extraction system*," the document does not state how much water might be captured by the groundwater system, and how this might influence gradients and water levels in the basalt and thus in the CDF.	The evaluation of the CDF in the EE/CA will consider this condition further. An analysis of hydraulic capture cannot be completed until after the final RAA boundary is determined and the footprint of a CDF is determined.
38	The Draft PSE also does not address the long-term effectiveness of the CDF regarding contaminant migration and transport. Specifically, the Draft PSE does not state how these issues would be addressed after the 100-year life of the proposed CDF, or the degree of contaminant transport possible should the upland barrier wall fail.	The evaluation of the CDF in the EE/CA will consider this condition further.
39	A complete analysis of the potential for contaminant transport of all contaminants found in the sediments under conservative hydraulic conditions should be conducted for any evaluation of removal actions that leave sediments in contact with groundwater.	The evaluation of the CDF in the EE/CA will consider this condition further.
COMPLIANCE WITH HARBORWIDE CDF PERFORMANCE STANDARDS		
40	EPA presented harborwide CDF performance standards for the Portland Harbor Superfund Site Feasibility Study in a February 18, 2010 letter to the Lower Willamette Group (EPA 2010). LSS should evaluate and comply with these harborwide CDF performance standards. Two examples of non-compliance include the lack of an evaluation of impacts to fisheries and wildlife and also an evaluation of impacts associated with utilities, storm drain lines, and/or other conduits located near the proposed CDF.	These performance standards are new and were not part of the CDF screening level evaluation agreed to by LSS and EPA. Since the referenced letter from EPA to the LWG regarding performance standards for CDFs within the Portland Harbor Superfund site was dated one day prior to the submittal of the PSE, it would have been impossible to include an evaluation of these standards in the PSE. LSS understands that they are in draft form. If performance standards for CDFs are finalized prior to completing the EE/CA, LSS will consider them during screening of the CDF alternative in the EE/CA. LSS notes that until that time, the standards that have been presented in letters from EPA on this matter will be considered in the CDF alternative development.
41	The performance standards indicate that during construction and filling, the evaluation of the CDF should fully assess and disclose impacts to fisheries and wildlife habitat (EPA 2010). As previously explained, the Draft PSE does not address impacts to fisheries and wildlife or feasibility of habitat mitigation. LSS should clearly present an identification of issues and possible mitigation as part of any further evaluation of the proposed CDF.	These performance standards are new and were not part of the CDF screening level evaluation agreed to by LSS and EPA. Since the referenced letter from EPA to the LWG regarding performance standards for CDFs within the Portland Harbor Superfund site was dated one day prior to the submittal of the PSE, it would have been impossible to include an evaluation of these standards in the PSE. LSS understands that they are in draft form. If performance standards for CDFs are finalized prior to completing the EE/CA, LSS will consider them during screening of the CDF alternative in the EE/CA. LSS notes that until that time, the standards that have been presented in letters from EPA on this matter will be considered in the CDF alternative development.
42	The harborwide standards also indicate the CDF shall be designed to "*Minimize water flow into and out of the CDF, including preventing or restricting preferential flow paths of clean or contaminated groundwater into or out of the CDF. The evaluation should include identifying, removing or modifying utilities trenches, storm drain lines, wells, and other conduits within 500 feet of the CDF (or other distance as determined to be appropriate). Utilities, storm drain lines and other conduits are not allowed under or within the contaminated sediment fill prism*." ARCADIS indicated in Section 2.2 that a discharge pipe is present from the groundwater remediation	These performance standards are new and were not part of the CDF screening level evaluation agreed to by LSS and EPA. Since the referenced letter from EPA to the LWG regarding performance standards for CDFs within the Portland Harbor Superfund site was dated one day prior to the submittal of the PSE, it would have been impossible to include an evaluation of these standards in the PSE. LSS understands that they are in draft form. If performance standards for CDFs are finalized prior to completing the EE/CA, LSS will consider them during screening of the CDF alternative in the EE/CA. LSS notes that until that time, the standards that have been presented in letters from EPA on this matter will be considered in the CDF alternative development.

Master Comment Number	Comment	Response
	system located on the former Rhône Poulenc site. As part of any further evaluation of the proposed CDF, LSS should present an evaluation of the impacts to the designed CDF associated with the identified conduits.	
43	As presented, the Draft PSE partially addresses the performance standards. However, if the proposed CDF is retained for further evaluation in the EE/CA or FS, LSS must evaluate and demonstrate compliance with all harborwide CDF performance standards.	These performance standards are new and were not part of the CDF screening level evaluation agreed to by LSS and EPA. Since the referenced letter from EPA to the LWG regarding performance standards for CDFs within the Portland Harbor Superfund site was dated one day prior to the submittal of the PSE, it would have been impossible to include an evaluation of these standards in the PSE. LSS understands that they are in draft form. If performance standards for CDFs are finalized prior to completing the EE/CA, LSS will consider them during screening of the CDF alternative in the EE/CA. LSS notes that until that time, the standards that have been presented in letters from EPA on this matter will be considered in the CDF alternative development.
EXAMPLES OF EPA REGION 10 SUPPORTED CDF PROJECTS		
44	The draft PSE cites nearshore CDF projects in the Pacific Northwest which EPA Region 10 has supported under CERCLA guidance. The Commencement Bay Nearshore/Tideflats Superfund site examples presented include the Milwaukee Waterway Nearshore CDF and the Blair Waterway Slip 1 Nearshore CDF. The two examples are located in marine environments of the Puget Sound. The proposed Arkema CDF would be located in the Willamette River, which is considered a freshwater environment. The proposed CDF would also constitute an extension of the riverbank into the river. The principal threat material within the sediments on the Arkema site is primarily, but not limited to DDx. The sediment from the Sitcum Waterway used to fill the Milwaukee Waterway Nearshore CDF were contaminated primarily by metals. The sediments disposed of in the Blair Waterway Slip 1 Nearshore CDF (from the Hylebos Waterway and Middle Waterway) were contaminated with PAHs, SVOCs, VOCs, PCBs and metals. The effectiveness of the Commencement Bay Nearshore/Tideflats CDF examples cited should not be used as a basis for the Arkema design. As stated in the EPA letter on April 16, 2008, there are no entirely comparable CDFs that have been constructed with principal threat material such as DDx, on a river, implemented using a removal action process in this country to date (EPA 2008f).	The EE/CA will not consider the effectiveness of other CDFs in evaluating site-specific issues for a potential CDF at the Arkema site. However, the cursory comparison to the other CDFs is relevant and appropriate, to show that CDFs have been successfully constructed in Region 10. Principal threat material has no application to this NTCRA per previous discussions between EPA and LSS…"EPA and Arkema agree that the term "Principal Threat Material" or "PTM" should be removed from the May 2007 Work Plan as unnecessary for articulating the basis for taking a removal action at the Arkema site. EPA and Arkema were not able to come to agreement as to what concentrations and chemicals at the site constitute Principal Threat Material, but EPA and Arkema have agreed on the RAA boundary in which the EE/CA analysis will be conducted, and agree that a non-time critical removal action in that RAA boundary will address a significant amount of high concentration sediment and will significantly reduce risk to human health and the environment. Principal Threat Material and/or PTM is no longer deemed relevant to the discussion of the screening level values in chapters 6 and 7 of the May 2007 Work Plan. EPA and Arkema agree to remove the term "Principal Threat Material" in relation to the screening level values (e.g., 1 x PEC and 1,000 x bioaccumulation SLV). The screening level values will remain in the Work Plan, including both the 1 x PEC and 1000 x bioaccumulation SLV, for purposes of evaluating dredging and judging the effectiveness of the removal action in the EE/CA."
TREATMENT TECHNOLOGY EVALUATION		
45	**Constituents of Interest** It should be noted that ARCADIS uses the term "constituent of interest" in the Draft PSE whereas the Arkema Work Plan uses "chemical of interest" for the acronym COI (EPA 2007b).	Noted. The term "chemical of interest" will be used for the acronym COI in the EE/CA.

Master Comment Number	Comment	Response
46	The Draft PSE presents several statements in Section 8 and Appendix D pertaining to the COIs that are incomplete or conflicting. For example, within the Draft PSE table summarizing the COIs and potential treatment technology applicability (Table D-1), it is misleading to suggest that the only COIs associated with Arkema are DDx compounds. Some of the contaminants in this list, while they may also be found throughout the harbor, are found on the Arkema site. The header "*Other Harborwide COIs*" should be changed to "*Other COIs*." The effectiveness and implementability of treatment technologies for sediments should be evaluated based on parameters for all contaminants at that site, not just those parameters for DDx.	The EE/CA will evaluate the effectiveness of all alternatives for addressing DDx and other Harborwide COIs.
47	The Draft PSE also presents several statements regarding the solubility and mobility of DDx which appear to conflict. For example, when describing DDx solubility and mobility, the Draft PSE claims, "*Routes of loss and degradation include Runoff/erosion, volatilization, photolysis, and biodegradation (both anaerobic and aerobic).*" However, within Section 8.1.1, the Draft PSE states that DDx compounds are not volatile. Also, the documented historical persistence of DDx compounds does not lend to a presumption that biodegradation of DDx is occurring at any appreciable rate. Volatilization and biodegradation should not be included in the list of routes of loss and degradation. Issues relating to biodegredation as it pertains to the bioremediation treatment evaluation is presented in the section below titled Bioremediation.	LSS has edited the edited the document so the two discussions/citations are consistent in the May 11, 2010 version.
48	Solubility parameters for DDx compounds are presented in the table within Section 8.1.2; however, the published reference for these parameters is not stated. This unreferenced table should include ranges of related values from more than one published reference source, for any parameters that will be used in the document. Also, the solubility parameters for all contaminants found in the sediments at that site should be presented and referenced. It is not acceptable to simply provide unreferenced values or even a single value for parameters which could be critical to any calculation.	The May 11, 2010 version of the PSE includes this information.
49	**Sustainability Considerations** The EE/CA process (EPA 1993) requires an evaluation of each removal action alternative with respect to short- and long-term aspects of three broad criteria which are effectiveness, implementability, and cost. A screening evaluation of treatment technologies is presented in the Draft PSE using the criteria of effectiveness and implementability. However, LSS also uses sustainability as a separate broad criterion for screening out treatment technologies. EPA supports the consideration of sustainability and green remediation issues for all removal action alternatives. However, sustainability of a treatment technology is not a factor which EPA guidance supports in making screening decisions. The EPA Region 10 Clean and Green Policy, which applies to the Arkema site, states "*this clean and green policy does not fundamentally change how and why cleanup decisions are made, but calls for more sustainable methods of implementing those cleanups*" (EPA 2009b). Using the sustainability of a treatment technology as a deciding criterion is contrary to the EPA Region 10 Clean and Green Policy and can unfairly bias the technology screening evaluation.	The EE/CA will not consider the sustainability of potential alternatives as a primary criteria for screening their effectiveness, implementability, and cost.

Master Comment Number	Comment	Response
50	Using sustainability issues in both the evaluation of effectiveness or implementability unfairly biases technology screening. For example, the Draft PSE presents references to overall health and safety risks associated with air emissions (i.e. LTTD, general in-situ applications, and chemical oxidation) in the evaluation of the sustainability for treatment options. According to the CERCLA guidance, the evaluation of the protection of public health and the community, protection of workers during implementation, and protection of the environment are presented under the broad criteria of effectiveness (EPA 1993). Addressing air emissions, as it affects overall health and safety, within implementability appears to incorrectly address the same issue twice. Independent of the alternative chosen, methods to reduce air-emissions should be considered in the design process when carrying out greener cleanup environmental footprint assessments and evaluating best practices that may be useful during the cleanup process.	The EE/CA will not consider the sustainability of potential alternatives as a primary criteria for screening their effectiveness, implementability, and cost.
51	As presented, there has been no indication that LSS has fully assessed the energy requirements (total energy use and renewable energy use) of possible treatment technologies. It is not expected that total energy evaluations be conducted at this stage of evaluation; however, presenting sustainable energy requirement claims for screening a technology is unacceptable. For example, the Draft PSE makes claims regarding "*fewer*" or "*significantly greater*" energy requirements of treatment technologies. The Draft PSE states that in-situ applications would likely have fewer energy requirements than ex-situ applications, and thermal techniques have significantly greater energy requirements. The Draft PSE presents these claims as a major reason for the decision to exclude these technologies from further evaluation. As discussed further in the following section (Ex-situ versus In-situ Treatment Technologies), LSS has not substantiated conclusions that energy conservation for in-situ treatment technologies is greater than ex-situ treatment technologies. However, mitigation of impacts, such as reductions in energy requirements and air pollution control devices can be achievable with any technology and should be considered as part of the design process once an alternative is selected.	The EE/CA will not consider the sustainability of potential alternatives as a primary criteria for screening their effectiveness, implementability, and cost.
52	According to the EPA document "Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites", the use of green principles is desirable "*to maximize the net environmental benefit of cleanup actions*" (EPA 2008e), and the comparison of practices as they affect the environmental footprint or the sustainability of the cleanup actions is a beneficial decision making strategy. As discussed further in the following sections (Ex-situ versus In-situ Treatment Technologies and Thermal Desorption), claims of low sustainability were used to eliminate ex-situ solidification/stabilization and thermal desorption for further evaluation. However, the sustainability of a treatment technology is not a factor which EPA supports in making screening decisions because the decision for screening the most qualified treatment options should be focused on maximizing the CDFs ability to satisfy threshold requirements for protectiveness and meet other site specific cleanup objectives. Also, according to the EPA Principles for Greener Cleanups memorandum, "*The Principles are not intended to trade cleanup program objectives for other environmental objectives*" (EPA 2009a).	The EE/CA will not consider the sustainability of potential alternatives as a primary criteria for screening their effectiveness, implementability, and cost.

Master Comment Number	Comment	Response
53	**Ex-situ versus In-situ Treatment Technologies** EPA's directed comment regarding ex-situ treatment provided in the December 23, 2008 letter to LSS was that ex-situ treatment will be evaluated in the EE/CA in conjunction with onsite upland and in water disposal, to ensure protectiveness (EPA 2008a). The presented Draft PSE only cites in-situ solidification/stabilization as viable for further evaluation in the EE/CA. EPA agrees that solidification/stabilization should be carried through for further evaluation in the EE/CA. However, EPA's consistent position throughout discussions with LSS has been that ex-situ treatment technologies should be considered during the EE/CA evaluation. LSS has failed to comply with the directed comment regarding this issue.	The EE/CA will include the evaluation of ex-situ soil mixing treatment technologies as part of the CDF alternative.
54	The conclusion of screening out of ex-situ solidification/stabilization in favor of in-situ solidification/stabilization is not consistent with the following claims regarding ex-situ versus in-situ soil mixing technologies summarized in the effectiveness and implementability evaluation of treatment technologies (Section 8.2.1): • *"ex-situ treatment would be more effective because it allows for better mixing/contact and engineering"* and • *"any technology that relies on contact to achieve treatment or stabilization would be easier to implement and engineer in an ex-situ application."* Also as noted in Section 4.1 of Appendix D, ex-situ mixing could meet treatment objectives within a shorter timeframe as compared to in-situ mixing.	The EE/CA will include the evaluation of ex-situ soil mixing treatment technologies as part of the CDF alternative.
55	It appears that the Draft PSE eliminates ex-situ solidification/stabilization from further consideration primarily due to sustainability considerations. However, in-situ mixing will not necessarily be more efficient and energy conservative because it will take longer to homogenize the materials and will likely need extensive use of diesel-powered crane- or track-mounted, large diameter augers for mixing and may not be totally effective at homogenization, potentially requiring several attempts.	The EE/CA will include the evaluation of ex-situ soil mixing treatment technologies as part of the CDF alternative.
56	While there are drawbacks to ex-situ technologies such as additional management of contaminated sediments and potentially preconditioning of sediments, those drawbacks can be managed and are not insurmountable (EPA 2008a, EPA 2008b, and EPA 2008c). It may be appropriate to evaluate the use of both in-situ and ex-situ soil mixing as a hybrid approach at the site. For example, in-situ mixing may be effective for submerged sediments within the existing boundary of the cofferdam that will not be dredged, and ex-situ mixing may be more effective and easier to implement for sediments dredged and placed within the cofferdam.	LSS agrees. The EE/CA will include the evaluation of ex-situ soil mixing treatment technologies as part of the CDF alternative.

Master Comment Number	Comment	Response
57	The conclusion to exclude ex-situ treatment from the short list of technologies or hybrid technologies does not adequately reflect the effectiveness and implementability evaluations presented in Appendix D of the Draft PSE and is contrary to EPA's previous directed comment to LSS. For further consideration in the EE/CA, the short list of technologies or hybrid approaches shall include ex-situ treatment technologies and accurately reflect an unbiased analysis for enhancement of the performance of the CDF. **This is a reiteration of a previously directed comment to LSS.**	LSS agrees. The EE/CA will include the evaluation of ex-situ soil mixing treatment technologies as part of the CDF alternative.
58	**Thermal Desorption** LSS screens out thermal desorption as a possible qualified treatment option for further evaluation in the EE/CA using following reasoning: "*low temperature thermal desorption* (*LTTD) process is not considered a feasible technology at this site.*" The Draft PSE claims that the presence of harborwide COIs such as dioxin and PCBs, would render thermal desorption (LTTD) infeasible because these harborwide COIs would go untreated. The Draft PSE claims that the temperatures necessary for volatilization of harborwide COIs such as dioxin and PCBs are well above the limits for LTTD. EPA has previously indicated that LTTD should not be the sole thermal technology considered for site application. High Temperature Thermal Desorption (HTTD) as a possible qualified treatment option was indicated as early as June 19, 2008 in a letter from the EPA (2008b). LSS does not consider use of HTTD as a possible treatment technology within Appendix D of the treatment technology. The Draft PSE claims that thermal desorption is infeasible because the process would create additional dioxins from high temperature and extended residence time in the treatment unit. Thermal desorption is a physical separation process designed to volatilize water and organic contaminants not destroy organics by oxidation. Thermal desorption technologies consist of two 15 basic steps: heating the contaminated material to volatilize contaminants and treating the exhaust gas stream to prevent emissions of the volatilized contaminants to the atmosphere. The contaminant information LSS provides illustrates the need to carefully select the type of thermal desorption unit for evaluation and the need for additional off-gas treatment, for example only, the use of afterburners or catalytic oxidizers.	The presence of these COIs does not preclude the use of HTTD/incineration, but it definitely increases the cost/complexity of treatment. As LSS demonstrated in previous correspondence, there are no HTTD units currently operating in the US (none for quite some time and the only unit and company potentially experienced with a similar chemical and physical matrix, no longer exists). However, HTTD/incineration will be evaluated in the EE/CA as part of the CDF alternatives. In addition, based upon initial discussions with local regulators, permitting an HTTD/incinerator at the site is not realistic given the public concerns over this type of treatment.
59	While limited examples of thermal desorption used at sediment sites exist, ex-situ thermal desorption is a proven technology that has been used for over two decades on hundreds of sites for a wide variety of persistent, bioaccumulative, and toxic contaminants in soil, including but not limited to DDx, PCBs, and dioxins/furans. Therefore, the presence of PCBs and dioxins/furans does not preclude the use of thermal desorption for the treatment of Arkema contaminated sediments.	As discussed above, HTTD/incineration will be evaluated in the EE/CA as part of the CDF alternative.
60	The Draft PSE also presents in the evaluation of the sustainability of thermal desorption, that LTTD is not considered a sustainable and green alternative. However, as stated in the above section titled Sustainability Considerations, the sustainability of a treatment technology is not an evaluation criterion that should be used to make determinate screening decisions. Also, the reductions in energy requirements and greenhouse gas emissions can be achieved with any technology (including thermal desorption) and should be considered as part of the design process once an alternative is selected.	The EE/CA will not consider sustainability as a primary criteria of potential alternatives for screening their effectiveness, implementability, and cost.

Master Comment Number	Comment	Response
61	The presentation of these issues by LSS as reason for not evaluating thermal desorption further in the EE/CA is incomplete and does not support an unbiased evaluation of thermal desorption as a treatment alternative. For further consideration in the EE/CA, the short list of technologies or hybrid technologies should include ex-situ HTTD treatment technologies and accurately reflect an unbiased analysis for enhancement of the performance of the CDF.	The EE/CA will evaluate ex-situ HTTD/incineration treatment technologies as part of the CDF alternative.
62	**Bioremediation** The Draft PSE presents the proprietary technology DARAMEND® for sequenced anaerobic-aerobic bioremediation of organochlorine pesticides. The Draft PSE concludes that sequenced anaerobic-aerobic bioremediation technologies including ZVI DARAMEND® are "*moderately effective toward organic targets*" have "*medium/moderate implementability*." EPA maintains the position, that the use of DARAMEND® technology or in-situ bioremediation is not applicable to the Arkema site as described within the letter to LSS dated October 3, 2008 (EPA 2008b). Some of the limitations listed for DARAMEND® include: • Tillage equipment depth limitation of 2 feet; • Presence of other toxic compounds (heavy metals) may be detrimental to soil microbes; • Soils with high humic content may slow down cleanup; • Soil moisture must be controlled during treatment (i.e. the target moisture content at the beginning of each cycle for the THAN site was 33% [dry weight basis] or 90% of the soil's water holding capacity). • This technology cannot be applied to sites that are prone to seasonal flooding or have a water table that fluctuates to within 3 feet of the site surface	As stated in the PSE and previous correspondence, the limitations cited by EPA in their comment do not directly apply to the Arkema Portland Site, The EPA cited limitation (actually design operating requirements) were project specific design operating requirements that applied to the THAN Superfund Site in Montgomery, Alabama. Therefore, the EE/CA will include bioremediation as a potential in-situ and ex-situ treatment technologies as part of the CDF alternative.

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Preliminary CDF Screening Evaluation

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Preliminary CDF Screening Evaluation

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Acronyms and Abbreviations

AOC	Administrative Order on Consent
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
^{o}C	degrees Celsius
CAD	confined aquatic disposal
CAIT	Center for Advanced Infrastructure & Transportation
CDF	confined disposal facility
CDF screening evaluation	Preliminary CDF Screening Evaluation
CDSM	cement deep soil mixing
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CLE	contingency-level event
cm/sec	centimeters per second
CO_2	carbon dioxide
COI	constituent of interest
CSM	conceptual site model

CWA	Clean Water Act
cy	cubic yard
DBP	4,4-dichlorobenzophenone
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DDx	the sum of DDT, DDD, and DDE isomers
DEQ	Department of Environmental Quality
DO	dissolved oxygen
DSL	Department of State Lands
DWT	deadweight tonnage
EE/CA	engineering evaluation/cost analysis
ERD	enhanced reductive dechlorination
ERH	electrical resistive heating
ERM	ERM-West, Inc.
EVS	Environmental Visualization System
^{o}F	degrees Fahrenheit
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study

F_{oc}	fraction of organic carbon
FRTR	Federal Remediation Technologies Roundtable
ft/ft	foot per foot
gpm	gallons per minute
GWRTAC	Groundwater Remediation Technologies Analysis Center
HEC-RAS	Hydraulic Engineering Center River Analysis System
IRM	interim remedial measure
IRZ	in-situ reactive zone
ISCO	in-situ chemical oxidation
ISTD	in-situ thermal desorption
ITRC	Interstate Technology and Regulatory Council
LSS	Legacy Site Services LLC
LTTD	low-temperature thermal desorption
Metro	Metro Regional Government
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
NAVD 88	North American Vertical Datum of 1988
NAVFAC	Naval Facilities Engineering Command

NGVD 29	National Geodetic Vertical Datum of 1929
OAR	Oregon Administrative Rule
OHW	ordinary high water
Oregon DEQ	Oregon Department of Environmental Quality
Oregon DSL	Oregon Department of State Lands
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	perchloroethylene
PCP	pentachlorophenol
PGA	peak ground acceleration
PRB	permeable reactive barrier
psf	pounds per square foot
RCl	reduction of chlorinated organics
redox	reduction-oxidation
SCM	source control measure
SMC	Stauffer Management Company
S/S	solidification/stabilization
SVOC	semivolatile organic compound
TIN	Triangulated Irregular Network
USACE	U.S. Army Corps of Engineers

USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound
ZVI	zero-valent iron

Executive Summary

This Preliminary CDF Screening Evaluation (CDF screening evaluation) has been prepared on behalf of Legacy Site Services LLC (LSS), which is Arkema Inc.'s agent for remediation activities at the Arkema Portland Site (the Site). A non-time-critical removal action is being conducted at the Site under a 2005 Administrative Order on Consent (AOC) that was entered into between the U.S. Environmental Protection Agency (USEPA) and Arkema Inc.

The AOC defines the Site as "that portion of the former chemical manufacturing facility, located at 6400 NW Front Avenue, Portland, Multnomah County, Oregon, and areas adjacent to it where hazardous substances or pollutants or contaminants from the facility have been released, disposed of, and/or otherwise come to be located." The Site is adjacent to the Willamette River and portions of the Site are partly within the Portland Harbor Superfund Site Study Area.

In accordance with the AOC, an engineering evaluation/cost analysis (EE/CA) will be prepared to present feasible disposal options for contaminated sediment within the removal action area. The purpose of this CDF screening evaluation is to respond to the USEPA's request for further analysis, in advance of the EE/CA, regarding the feasibility of a confined disposal facility (CDF) to contain contaminated sediments adjacent to the Site. Specifically, the USEPA defined its request to include general design parameters, short- and long-term performance standards, construction impacts on Willamette River flood storage, balanced cut and fill requirements, and permitting and other potentially applicable or relevant and appropriate requirements (ARARs), as well as whether a treatment component could enhance the effectiveness of the conceptual CDF. Our analysis of CDF feasibility therefore centered on the following questions:

1. Is it possible to design an enclosure of sufficient volume at the Site given navigational needs, the shallow depth to bedrock, and Site geometry?

2. Can effective water quality controls be implemented to reduce the potential for short-term water quality impacts during construction?

3. Can long-term contaminant transport mechanisms be evaluated for the Site and, if necessary, effectively controlled? Is hydraulic containment achievable under the Site conditions?

4. Would construction or filling of the CDF increase the base flood elevation of the Willamette River?

5. Can fill deposited at or below the base flood elevation be balanced with at least an equal amount of soil removal or excavation to preserve the area's capacity for water flow and flood storage?

6. Will the Oregon Department of State Lands (Oregon DSL) approve this CDF on state-owned submerged land? Do other ARARs apply to this project?

Although not directly relevant to the *feasibility* of CDF construction at the Site, USEPA suggested that treatment options also be included in the evaluation to determine their effectiveness at enhancing CDF performance.

Following a description of the Site's physical setting and history and an overview of CDF construction in general, each of these issues was evaluated on a preliminary screening basis. The principal purpose of the evaluation was to identify whether the conceptual CDF was sufficiently likely to be feasible as to warrant carrying it forward for consideration in the upcoming EE/CA. The results of our evaluation are summarized below.

Geotechnical Issues and Facility Sizing

At the Site, several constraints imposed by the physical setting or the need to achieve specific objectives would influence technical aspects of the CDF design. These constraints include:

- The basalt bedrock that underlies the Site at relatively shallow depths
- The geometry of the area available for CDF construction
- The requirement to avoid CDF encroachment on the navigation channel
- The need to provide for vessel berthing (i.e., maintain river-dependent uses) at the CDF
- The volume of sediment to be contained within the limits of construction and disposed of in the CDF, which affects both the CDF's footprint and its volumetric capacity

Our analysis examined several types of containment structures, including earthen berms and a single-wall sheet pile structure. The earthen berm option was eliminated because its footprint would exceed the available space. The single-wall sheet pile

option was eliminated for this assessment because large lateral loads on the wall would have to be counterbalanced by relatively deep embedment of the sheet piles in strong sediment or soils; however, the Site is underlain by relatively shallow bedrock.

ARCADIS concluded that a circular cell cofferdam is the most feasible containment structure for the Site. Although other configurations or variations for confined disposal are potentially feasible, the circular cell cofferdam was selected for the feasibility analysis because of the shallow depth to bedrock, the volume of contaminated sediment, proximity to the Willamette River navigation channel, and navigational needs such as ship berthing. A circular cell cofferdam could be designed to accommodate all of these conditions.

Because the extent of the removal action is not yet known (it will be determined in the EE/CA), ARCADIS developed volume estimates and conceptual footprints for two options, referred to as the one-berth CDF and the two-berth CDF. The one-berth and two-berth conceptual CDF footprints necessary to contain 110,000 cubic yards (cy) to 260,000 cy of both in-situ and dredged material are 4 and 8 acres, respectively. A CDF of either size is feasible at the Site.

Short- and Long-Term Contaminant Transport/Hydraulic Containment

Means such as turbidity controls and water quality monitoring are readily available for controlling short-term contaminant transport during construction and filling. Short-term contaminant transport is therefore not expected to impact the feasibility of the conceptual CDF.

With regard to long-term contaminant transport, hydraulic containment is achievable for the conceptual CDF, and long-term contaminant transport is therefore not expected to impact its feasibility. Hydraulic containment would be achieved through the combination of an upland barrier wall (already planned as part of the upland source control measures), design of the circular cell cofferdam, and application of a low-permeability surface cap. The first two would provide lateral hydraulic containment, while the cap would provide vertical hydraulic containment by preventing infiltration. Short-term, transient conditions such as changes in upgradient groundwater extraction rates, tidal and seasonal fluctuations in river stage, and extreme flood events could cause temporary gradient reversals and potentially allow outward migration of groundwater from the CDF to the bedrock. However, the primary contaminant (DDx, the sum of the DDE, DDD, and DDT isomers) has limited solubility and limited mobility in most soil environments and is expected to have minimal leachability from sediment within and outside a CDF at the Site. As such, vertical migration of DDx from the

sediment into groundwater and through the bedrock during a temporary gradient reversal would be negligible. If necessary, the effects of transient potentiometric surface reversals can be addressed by implementing secondary containment measures, such as groundwater extraction from within the CDF. The potential for vertical migration of contaminants to groundwater can be addressed in the EE/CA. It is not expected to impact CDF feasibility.

Floodway Analysis

The Federal Emergency Management Agency defines a floodway as “the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height.” For the Willamette River, no new construction or filling is currently permitted in the floodway unless it can be demonstrated through hydraulic and hydrologic analysis that the construction or filling will not increase the river’s base flood elevation. Floodway modeling was therefore conducted to determine whether the conceptual CDF would result in an increase in the base flood elevation.

Eight simulations were run to determine the impact of the CDF on the 100-year flood flow of 375,000 cubic feet per second (cfs) for varied downstream water surface elevations. The results demonstrate that in all tidal conditions analyzed, the impact of the conceptual CDF on water surface elevations would be negligible along the reach of river alongside the Site. Water surface elevations were observed to decrease in a number of sections, with an associated minimal rise in velocity. An assessment was also performed for a lower flow situation of 75,000 cfs, which would be contained within the banks of the river. This case also resulted in negligible change in water surface elevation. The floodway analysis therefore determined that construction and filling of the conceptual CDF would have no impact on base flood elevation in the Willamette River and so would not encroach on the floodway.

Balanced Cut and Fill Analysis

Oregon law states that all fill (such as dredged material) placed at or below the base flood elevation in flood management areas must be balanced with at least an equal amount of soil material removal, or excavation, to preserve the area’s capacity for water flow and flood storage. Variances can be requested based on a variety of factors, including the importance of the services provided by the CDF to the community, the necessity of the waterfront location to the CDF, the availability of alternative locations, and the compatibility of the proposed use with existing and anticipated development.

For the purpose of this analysis, the total fill (including the cap) was estimated to range between 120,900 cy and 240,700 cy. Based on the definition of “cut” in the regulation, dredging does not count as a cut to mitigate fill within the same Flood Hazard Area. Therefore, it would be necessary to mitigate the fill with a cut or cuts of equivalent size. This might be accomplished by coordinating removals along other parts of the river with the City of Portland, state agencies, or other landholders.

DSL Authorization and Other State Requirements

The State of Oregon, through the DSL, owns and manages the beds and banks of the Willamette River. DSL issues several types of authorizations for the use of state-owned submerged and submersible land. Examples that might be applicable to a CDF adjacent to the Site include a lease, an easement, or a sale. Preliminary discussion with DSL indicates that while the final decision is made by the State Land Board, which would consider both how the conceptual CDF would enhance cleanup work at the Site and how it might affect adjacent landowners, it is likely that land for the CDF could be leased from the State of Oregon under existing regulation. Therefore, DSL authorization is not expected to affect CDF feasibility.

A full ARARs analysis was not conducted for the screening evaluation, but will be completed as part of the EE/CA. A preliminary review of potential ARARs indicates that Section 401 and Section 404 (b)(1) of the Clean Water Act will be applicable to a CDF at the Site. Neither of these potential ARARs is expected to affect CDF feasibility.

Treatment Evaluation

In a June 2008 letter to LSS, USEPA requested analysis of several issues to ensure that a feasible CDF option is presented in the EE/CA; evaluating whether a treatment component could enhance the effectiveness of the conceptual CDF was among those requests. The Oregon Department of Environmental Quality, in a letter dated November 20, 2008, indicated that sediment placed into the CDF will not require treatment. However, LSS agreed to continue evaluating potential treatment options that might provide some additional enhancement or benefit to the CDF option.

Several treatment options—for instance, variations of thermal desorption, chemical oxidation, soil mixing, bioremediation, and chemical reduction—were evaluated for their effectiveness at treating the Site’s organic contaminants (mainly, DDx), as well as their implementability and sustainability. The objective of this analysis was to move toward a short list of technologies or hybrid technologies that can be further evaluated in the EE/CA.

For several of the treatment technologies—in particular, ex-situ applications—increased effectiveness resulted in decreased implementability and sustainability. In other cases, treatments that involve high temperatures could damage the CDF or impact the river.

A form of soil mixing called solidification/stabilization appears to be the best overall option, offering high effectiveness and medium implementability at a medium cost. In-situ solidification/stabilization is also one of the three most sustainable treatment options under the Site-specific conditions. Although not a treatment for contaminant reduction, solidification/stabilization is likely the most effective means of fixing material in place within the CDF to improve hydraulic containment, as well as improve the geotechnical properties for subsequent redevelopment opportunities. We therefore concluded that solidification/stabilization should be further evaluated in the EE/CA. In addition, per a directed change from USEPA, LSS will further evaluate ex-situ soil mixing treatment technologies in the EE/CA.

Conclusion

Although some technical considerations will require further analysis in the EE/CA or during the design phase, no “fatal flaws” were identified through this screening, and the conceptual CDF is considered feasible.

1. Introduction

This Preliminary CDF Screening Evaluation (CDF screening evaluation) has been prepared on behalf of Legacy Site Services LLC (LSS), which is Arkema Inc.'s agent for remediation activities at the Arkema Portland Site (the Site). A non-time-critical removal action is being conducted at the Site under a 2005 Administrative Order on Consent (AOC) that was entered into between the U.S. Environmental Protection Agency (USEPA) and Arkema Inc. (USEPA 2005a).

The AOC defines the Site as "that portion of the former chemical manufacturing facility, located at 6400 NW Front Avenue, Portland, Multnomah County, Oregon, and areas adjacent to it where hazardous substances or pollutants or contaminants from the facility have been released, disposed of, and/or otherwise come to be located" (USEPA 2005a). The Site is adjacent to the Willamette River and portions of the Site are partly within the Portland Harbor Superfund Site Study Area.

In accordance with the AOC, an engineering evaluation/cost analysis (EE/CA) will be prepared to present feasible disposal options for contaminated sediment within the removal action area. The purpose of this CDF screening evaluation is to respond to the USEPA's request (USEPA 2008d) for further analysis, in advance of the EE/CA, regarding the feasibility of a confined disposal facility (CDF) to contain contaminated sediments adjacent to the Site. The CDF screening evaluation is intended to be thorough enough to determine whether the CDF is feasible under the EE/CA process, as well as under the harborwide remedial investigation/feasibility study process. This screening evaluation does not replace the need for a full and/or final evaluation of the CDF option in the EE/CA.

1.1 Project Background

The AOC calls for the cleanup of contaminated riverbank and sediment in the Willamette River adjacent to the Site and authorizes this cleanup as a non-time-critical removal action to reduce risks to human health and the environment before cleanup of the Portland Harbor Superfund Site is complete (USEPA 2005c).

In accordance with the AOC, an EE/CA will be prepared to present feasible removal action alternatives and technologies, including both on-Site and off-Site disposal options, for contaminated sediment within the removal action area. A draft EE/CA work plan was submitted to USEPA in 2005 (Integral Consulting 2005). Following several rounds of comments on the draft by USEPA and LSS, USEPA had its contractor prepare a revised draft EE/CA work plan in 2007 (Parametrix 2007). After several more

rounds of comments, USEPA directed that specific changes be made to the draft EE/CA work plan. LSS disputed some of these changes, one of which was USEPA's desire to delete the evaluation of a CDF as a potential disposal option.

In a May 2008 memorandum, USEPA documented its final decision on the disputed changes, stating that "It is appropriate to allow LSS the opportunity to include a CDF evaluation in the EE/CA" (USEPA 2008c). In a June 2008 letter, USEPA clarified its view regarding the CDF option and requested analysis of several issues to ensure that a feasible CDF option is presented in the EE/CA (USEPA 2008d). Correspondence between USEPA and LSS (USEPA 2008d, 2008e, 2008f, 2008g, 2009a; LSS 2008a, 2008b, 2008c, 2008d, 2009) defined these issues to include general design parameters, short- and long-term performance standards, construction impacts on Willamette River flood storage, balanced cut and fill requirements, and permitting and other potentially applicable or relevant and appropriate requirements (ARARs), as well as a general request as to whether a treatment component could enhance the effectiveness of the conceptual CDF.

1.2 Feasibility Considerations

The feasibility of constructing a nearshore CDF at the Site will be evaluated based on the findings with regard to the following questions:

1. Is it possible to design an enclosure of sufficient volume at the Site given navigational needs, the shallow depth to bedrock, and Site geometry? (Addresses USEPA's request to evaluate certain general design parameters; refer to Section 3.)

2. Can effective water quality controls be implemented to reduce the potential for short-term water quality impacts during construction? (Addresses performance standards for short-term contaminant transport and water quality controls during construction and filling; refer to Section 3.)

3. Can long-term contaminant transport mechanisms be evaluated for the Site and, if necessary, effectively controlled? (Addresses long-term performance standards and hydraulic containment; refer to Sections 3 and 7.)

4. Would construction or filling of the CDF increase the base flood elevation of the Willamette River? (Addresses whether the CDF will encroach on the floodway; refer to Section 4.)

5. Can fill deposited at or below the base flood elevation be balanced with at least an equal amount of soil removal or excavation to preserve the area's capacity for water flow and flood storage? (Addresses whether the CDF will meet balanced cut and fill requirements; refer to Section 5.)

6. Will the Oregon Department of State Lands (Oregon DSL; DSL) approve this CDF on state-owned submerged land? Do other ARARs apply to this project? (Addresses permitting and other state requirements; refer to Section 6.)

Although not directly relevant to the *feasibility* of CDF construction at the Site, USEPA has suggested that additional evaluation of treatment options (discussed in numerous written communications between USEPA and LSS) also be included in the CDF screening evaluation to determine their effectiveness at enhancing CDF performance. This issue is addressed in Section 8.

Section 2 describes the Site's history and its physical setting. Following the detailed evaluation presented in Sections 3 through 8, overall findings are summarized in Section 9.

2. Site Description

The Site is located in a heavily industrialized part of northwest Portland, Oregon, and portions of the Site are partly within the Portland Harbor Superfund Site Study Area. The Site is bounded by Front Avenue on the north and west and the Willamette River on the east. It is located on the southwest bank of the lower Willamette River, approximately between river miles 6.9 and 7.6 and just upstream of the Burlington Northern Santa Fe Railroad bridge. Figure 1 provides a site vicinity map; Figures 2 and 3 show a site map and site plan, respectively.

2.1 Site History

The Site was operated as a sodium chlorate facility between 1941 and 2001 (ERM-West, Inc. [ERM] 2008a). In addition, the facility manufactured chlorine, sodium hydroxide, hydrogen, and hydrochloric acid. Other products and processes were added and discontinued over time, including dichlorodiphenyltrichloroethane (DDT), ammonia, and ammonium perchlorate. The plant was decommissioned and subsequently demolished in 2004, with the exception of the main office building on the Site.

The facility was initially constructed and operated by Pennsylvania Salt Manufacturing, which later became known as Pennwalt Corporation (Integral Consulting 2006). Purchased by Societe Nationale Elf Aquitaine in 1989, Pennwalt Corporation was combined with two other companies in 1990 to form Elf Atochem North America, Inc. In 2000, Societe Nationale Elf Aquitaine merged with TOTALFINA to form TOTALFINA ELF, and Elf Atochem became ATOFINA Chemicals, Inc. In 2004, ATOFINA Chemicals changed its name to Arkema. In April 2006, LSS, the agent for Arkema, began handling remediation activities at the Site.

In 1998, Elf Atochem North America, Inc. entered into a Voluntary Agreement with the Oregon Department of Environmental Quality (Oregon DEQ; DEQ) under the Oregon Voluntary Cleanup Program to address impacts to environmental media associated with the manufacture of DDT in the Acid Plant Area and with pesticide-contaminated sediment in the Willamette River. In 2005, the USEPA and Arkema entered into an AOC that calls for the remediation of contaminated riverbank and sediment in the Willamette River adjacent to the Site. In 2008, the Oregon DEQ and Arkema entered into an Order on Consent, which effectively replaced the earlier Voluntary Agreement from an administrative standpoint. The Site is restricted to industrial use and is currently undergoing upland remedial activities under the Order on Consent.

2.2 Physical Setting

The Site consists of approximately 54 acres of land divided into four lots and one tract along the Willamette River (Integral Consulting 2005). Lots 1 and 2 are in the northern portion of the Site. They are undeveloped and covered by a mixture of grasses, bare soil, and disturbed, invasive scrub/shrub vegetation. Lots 3 and 4 are in the southern portion of the Site. These developed lots are where the majority of chemical manufacturing and processing occurred. The riverbank is steeply sloping above approximately elevation +20 feet North American Vertical Datum of 1988 (NAVD 88) and in some areas is covered with rubble used for bank stabilization.

The Site is located in the Guild's Lake Industrial Sanctuary (formerly the Northwest Portland Industrial Sanctuary). Zoning for this area is heavy industrial (IH), which means there are strict restrictions associated with non-industrial uses (Portland Development Commission 2004). The industrial sanctuary is bounded by U.S. Route 30 and the Portland Hills west of the Site and on the east by the Willamette River, which has historically been a commercial, industrial, and recreational waterway.

The in-water portion of the Site is defined as the land below mean high water (approximately 12 feet NAVD 88). In-water access to the Arkema facility was historically provided from three docks referred to as (from upstream to downstream) the Salt Dock, Dock 1, and Dock 2. The Site is bounded to the south (upstream) by the CertainTeed roofing products facility and the Willbridge petroleum storage terminal (consisting of Kinder Morgan, Chevron, and ConocoPhillips). To the north (downstream), the Site is bounded by a City of Portland sewer right-of-way, which includes a discharge pipe from the groundwater remediation system located on the former Rhône Poulenc site (Integral Consulting 2005), as well as formerly active Rhône Poulenc outfalls.

2.2.1 Geologic Setting

The Site is within the Portland Basin, a northwest-southeast structural basin filled with a thick sequence of alluvial deposits. The Portland Basin stratigraphy consists of (from youngest to oldest):

- Quaternary alluvial deposits (fill, floodplain, and channel deposits from the Willamette and Columbia rivers, Lake Missoula Flood deposits)
- Miocene/Pliocene alluvial deposits, including the Troutdale regional gravel aquifer and Sandy River Mudstone

- Miocene/Pliocene Columbia River Basalt Group lava flows

Regionally, the basalt bedrock varies from highly fractured to massive and from highly weathered to fresh. The fractured and weathered bedrock forms a semiconfined regional aquifer that includes highly conductive zones of breccia and gravel localized in paleotopographic features of the bedrock surface.

Unconsolidated sedimentary deposits in the area are bounded to the west by the Tualatin Mountains, where bedrock forms the local topographic high known as Portland's West Hills.

2.2.2 Local Hydrogeologic Conditions

Hydrogeology at the Site is characterized by the Site's location on the west bank of the Willamette River, which is the regional groundwater discharge zone. Four water-bearing zones are present within the alluvial overburden at the Site:

- Shallow Zone – fill and alluvial sand
- Shallow-Intermediate Zone – semiconfining silt
- Intermediate Zone – sand
- Deep Zone – sandy silt and silty sand

These unconsolidated sedimentary water-bearing zones overlie the Basalt Zone, which includes fractured to massive basalt and sometimes includes colluvial gravel lenses and/or angular basalt gravels.

Shallow groundwater occurs at the Site in the Shallow Zone above the semiconfining Shallow-Intermediate Zone. Deeper groundwater occurs below the semiconfining Shallow-Intermediate Zone, in the Intermediate Zone and Deep Zone silts and sands, Basalt Zone gravel (where present), and weathered and fractured bedrock.

2.2.3 Generalized Subsurface Conditions

The Site topography and bathymetry are provided on Figure 3 and subsequent plan view figures. The river sediment along the Site consists mainly of sandy silt and silty sand underlain by relatively shallow basalt bedrock. The thickness of the sediment layer varies between approximately 20 and 30 feet near the shore, with the sediment

thickness decreasing significantly near the navigation channel to about 4 to 8 feet. The sediment/soil thickness is shown in plan view on Figure 4 and on the cross sections presented on Figure 5.

2.2.4 Water Levels

Willamette River stage data were collected at Portland as minimum, mean, and maximum monthly stages for the period of record water years 1973 through 2003 (U.S. Army Corps of Engineers [USACE] 2004). Maximum monthly stages in the Willamette River at Portland usually occur during the winter (December through February) and the spring (March through June). Notable maximum monthly stages of 32.2 feet in February and 27.7 feet in January indicate the effects that large runoff years have on Willamette River stage at Portland. Minimum monthly stages usually occur between July and October, with the lowest water level most likely to occur in September. This is also the time of year (summer and fall) when tidal fluctuations have the most influence on river stage in Portland Harbor. River stage data for water years 1973 through 2003 are summarized in Table 1.

3. CDF Design and Construction

3.1 General Discussion of CDFs

3.1.1 Overview

The purpose of a confined disposal facility is to isolate dredged material from people and the environment. CDFs are designed to use engineered dikes, berms, sheet piles, or gravity retaining structures[1] (or combinations and variations of these) to contain the dredged material and prevent it from contacting the surrounding water body.

CDFs are typically constructed before dredging takes place. The CDF is then filled with dredged material until the design fill elevation is reached. Once full, the CDF is typically capped to contain the sediments and prevent their exposure to the surrounding environment. The completed cap also provides a useable surface or structure.

3.1.2 History

Approximately 300 million cubic yards (cy) of sediment are dredged annually in the United States to maintain navigation channels (USACE and USEPA 2003), not primarily because of contamination in the dredged material. About 30 percent of this dredged material is disposed of in CDFs. Over the last 20 years, however, CDFs have come to also be used as a management tool for the disposal of contaminated sediment.

The containment of dredged material in a CDF can be considered a beneficial reuse, because constructing and capping a CDF can create new land for development. As stated in the USEPA's Contaminated Sediment Remediation Guidance (USEPA 2005f), "….a CDF can be integrated with site reuse plans to both reduce environmental risk and simultaneously foster redevelopment in urban areas and brownfield sites."

The USACE has constructed and/or operated 45 CDFs to manage over 90 million cy of moderately highly to highly contaminated sediments dredged from Great Lakes harbors and channels. Approximately 2 million cy of sediments dredged annually from

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[1] Gravity retaining structures are retaining structures that develop their resistance to soil pressure and miscellaneous loads primarily from their own weight. (From: *Handbook of Port and Harbor Engineering* by Gregory Tsinker.)

federal navigation projects in the Great Lakes are placed into existing CDFs. In addition, 36 out of 40 sediment remedial actions conducted in the Great Lakes have used confined disposal for the management of dredged materials instead of commercial landfills or on-site facilities (USACE and USEPA 2003).

In Europe, CDFs are increasingly used to manage contaminated sediment. In The Netherlands, the Ijsseloog CDF was constructed to contain 23 million cubic meters (30 million cy) of contaminated sediment from Lake Ketel and other contaminated sites. The Slufter CDF, approximately 640 acres in size with a capacity of 100 million cubic meters (130 million cy), was constructed to contain contaminated sediment and dredged material from Rotterdam Harbor. In Sicily, Italy, a CDF has been proposed to contain contaminated sediments from Rada di Augusta, a large bay on the east side of the island. Large-scale CDFs have also been constructed in Germany and Belgium to contain both contaminated sediment and navigational dredged material (Permanent International Association of Navigation Congresses 2002; USACE 2000, 2003).

In the Pacific Northwest, USEPA Region 10 has supported the use of nearshore CDFs in several applications, including the following two examples:

- Milwaukee Waterway Nearshore CDF, Tacoma, Washington

  In one of the first cleanup actions at the Commencement Bay Nearshore/Tideflats Superfund Site, contaminated sediment was dredged from the Sitcum Waterway and disposed of in a CDF constructed in the nearby Milwaukee Waterway. Long-term water quality monitoring focuses on metals, and the results indicate that metals are not leaching from the sediment or being transported outside of the CDF in groundwater. These findings confirm the efficacy of the CDF remedy. Two habitat mitigation sites are also undergoing long-term monitoring of their physical, chemical, and habitat features. After 10 years of monitoring, both mitigation sites are considered successful (Verduin et al. 1996; USEPA 2004, 2005b). Since construction was completed in 1995, the Port of Tacoma has used the surface of the Milwaukee Waterway CDF for container storage associated with a marine terminal.

- Blair Waterway Slip 1 Nearshore CDF, Tacoma, Washington

  A more recent cleanup action in the Commencement Bay Nearshore/Tideflats Superfund Site involved the dredging of contaminated sediment from the Hylebos Waterway and its disposal in the Blair Waterway Slip 1 nearshore CDF. The Blair Waterway Slip 1 CDF is a 16-acre facility that contains approximately 630,000 cy

of contaminated subtidal sediment transported to the CDF via barge. To compensate for the filling of Slip 1, habitat mitigation areas were constructed at multiple shoreline locations along Commencement Bay and adjoining waterways (USEPA 2004, 2005b). A long-term groundwater monitoring program is being conducted to verify that hazardous constituents do not migrate from the CDF into Commencement Bay. A long-term monitoring program is also being conducted to verify the success of the habitat mitigation (USEPA 2005b). The Port of Tacoma uses the CDF surface for container storage associated with a marine terminal.

As this brief review of CDF history demonstrates, CDF technology is widely accepted around the world and in the Pacific Northwest as a means of effectively isolating contaminated dredged material from contact with humans and the environment.

3.1.3 Types and Functions

In general, four types of CDFs can be constructed to contain contaminated sediment:

- **Upland CDFs** are typically constructed on land above the water table and are not connected to a water body. Sediment placed in an upland CDF dries over time, resulting in characteristics similar to upland soils. Depending on the characteristics and mobility of the contaminants, upland CDFs can be constructed with a liner and/or low-permeability cap to prevent the migration of contaminants.

- **Nearshore CDFs** use the existing shoreline as part of the containment structure, with the remainder of the containment provided by berms, dikes, sheet pile walls, or gravity retaining structures. Many nearshore CDFs have been constructed in the Pacific Northwest, including the Milwaukee Waterway, St. Paul Waterway, and Blair Waterway Slip 1 CDFs in Tacoma, Washington, and the Terminal 3 CDF in Seattle, Washington. If constructed, the CDF for the Site would be of the nearshore type.

- **Island CDFs** are enclosed solely by engineered berms, dikes, or sheet pile walls and are connected to the upland by a causeway or similar structure. An island CDF is being constructed in Hamilton, Ontario, to manage contaminated sediments within Hamilton Harbour. New port facilities will be constructed on top of the CDF and rail and truck traffic will access the facilities via a causeway.

- **Subaqueous CDFs**, referred to as confined aquatic disposal (CAD) facilities, contain dredged material within a natural or excavated depression in the bottom of a water body. The dredged material is capped with clean sand to reduce its

erosion. CAD facilities are more commonly used for the disposal of navigational dredged material and have not been widely used to contain dredged material from environmental projects (USEPA 2005b).

CDFs have a variety of possible end uses, and the end use selected typically depends on the nature and quality of the dredged material, as well as the type and setting of the CDF. Feasible end uses for CDFs include airport expansions, port terminals, wildlife habitat, recreational areas and facilities, aggregate storage, and temporary storage of dredged material prior to processing.

The USACE has researched the use of CDFs for the management of contaminated dredged material through a variety of research and technical support programs. The results of this research have been used to develop USACE engineering manuals and technical guidance that should be referenced for design standards when designing and siting a CDF.

3.1.4 Construction and Maintenance

A CDF is usually constructed in three principal stages:

1. Installation of the containment structure
2. Filling of the CDF with dredged sediment
3. Capping of the CDF

In most cases, the containment structure involves an earthen berm, a sheet pile wall, a gravity retaining structure, or a combination of the three.

During filling, the dredged sediment is placed in the CDF and inert fill, such as uncontaminated navigational dredged material, is then placed over the contaminated sediment. If the contaminated sediment is being mechanically dredged, filling can be accomplished from barges floated into the CDF. With hydraulic dredging, dredged material is transported via a closed pipeline that deposits the sediment directly behind the CDF containment structure. The filling sequence is usually designed to allow the sediment to gradually settle, which helps to control water quality impacts from the discharge of excess water and suspended sediment.

Capping usually involves placing an inert layer over the dredged sediment. Often, a relatively thick layer is placed to provide additional surcharge to accelerate consolidation of the sediment. Controlling the long-term settlement rate is important for

final development and use of the CDF surface, which is normally covered with a low-permeability pavement to prevent the infiltration of precipitation into the fill. After capping is completed, facilities can be developed on the capped surface of the CDF.

CDF maintenance typically includes long-term groundwater monitoring and surface water quality monitoring around the perimeter of the CDF. Monitoring of settlement and consolidation of the dredged material within the CDF, as well as the underlying materials on which the CDF was constructed, is also typically part of the long-term maintenance.

3.1.5 Technical/Design Considerations

The following technical/design considerations are critical to the success of a CDF.

3.1.5.1 Geotechnical Issues and Facility Sizing

Geotechnical considerations include consolidation of the dredged material and underlying sediments, the stability of the containment structure, and the loads that will be applied in the facility's end use. These issues are relevant for filling of the CDF and for its long-term operation and maintenance. A seismic evaluation can also be completed to design for factors of safety that are acceptable to withstand seismic events.

Proper sizing of a CDF is an iterative process that depends on site constraints and objectives and on water quality considerations. Design considerations that pertain to facility sizing include required settling/retention time, dredge volumes, dredging method, dredged material properties, geotechnical engineering issues, and future site uses. A preliminary design of the CDF is required to assess water quality impacts.

3.1.5.2 Short-Term Contaminant Transport

Short-term contaminant transport can include volatilization of the contaminants during filling of the CDF, water discharged from the CDF, transport losses that occur during filling, and seepage of contaminants or sediment through the CDF containment structure during filling. Air emissions modeling can assist in predicting contaminant volatilization, and mitigation measures can be taken to reduce volatilization. Air monitoring during construction can confirm that mitigation measures are adequately protecting human health and the environment. Proper design and sizing of the CDF reduces contaminant losses from water discharge and from seepage of contaminants from the containment structure.

3.1.5.3 Long-Term Contaminant Transport

Potential long-term transport mechanisms include leaching of contaminants to the groundwater, seepage of contaminants or sediment through the CDF containment structure, and stormwater runoff from the CDF cap. To properly address these mechanisms, the solubility and mobility of the contaminants are evaluated along with the groundwater and tidal regime at the site to determine the potential for vertical and lateral migration of contaminants, as well as the ability of the containment structure to reduce the lateral movement of contaminants. The CDF cap can be designed to provide an adequate barrier against the infiltration of precipitation into the contaminated sediment, if necessary, to prevent the uptake of contaminants by plants or animals and to isolate the contaminants from humans.

3.1.6 Summary

In summary, CDF technologies of various types and sizes have been proven over an extended time and a variety of applications. Nonetheless, CDF designs are usually complex. CDFs are powerful tools for the containment of contaminated sediment when the following conditions are present:

- Hydrogeology surrounding the CDF site is favorable.
- There is a need to increase waterfront land area.
- Upland disposal is too costly or not practical.
- A large quantity of sediment needs to be removed.
- The owner is prepared to undertake long-term monitoring.

3.2 Site-Specific Technical/Design Considerations

At the Site, constraints imposed by the physical setting or by the need to achieve specific objectives would influence technical aspects of the CDF design. As discussed in the following subsections, these constraints include:

- The basalt bedrock that underlies the Site at relatively shallow depths
- The geometry of the area available for CDF construction

- The requirement to avoid CDF encroachment on the navigation channel
- The need to provide for vessel berthing (i.e., maintain river-dependent uses) at the CDF
- The volume of sediment to be contained within the limits of construction and disposed of in the CDF, which affects both the CDF's footprint and its volumetric capacity

3.2.1 Geotechnical Issues and Facility Sizing

This section presents the containment structure type selected for consideration in this screening evaluation and how that choice was made; a preliminary evaluation of CDF footprint and capacity based on the constraints outlined above; and a conceptual-level design analysis of the circular cell cofferdam structure selected here and carried forward for consideration. It should be noted that the circular cell cofferdam is a robust structure with a relatively large footprint; other configurations with a smaller footprint may also be feasible but are not considered here.

3.2.1.1 Type of Containment Structure

CDF containment structures typically incorporate earthen berms, dikes, sheet pile walls, gravity retaining structures, or a combination of these. Several containment structure options have been initially considered and eliminated for the Site in this assessment, including earthen berms and a traditional single-wall sheet pile structure.

Because earthen berms typically have side slopes of 2 horizontal to 1 vertical (or less steep), they often require a large footprint to meet stability requirements. Given the side slope requirements and the anticipated dredge volume, an earthen berm at the Site would have a footprint in excess of 200 feet in width, which is not practical because of the limited space between the riverbank and the harbor line, vessel berthing requirements, and the large amount of sediment that would have to be dredged from the berm footprint prior to construction.

A single-wall sheet pile structure, which offers the capacity to contain a high volume of dredged material, is not feasible at this Site because of the exposed height of the wall and the presence of relatively shallow bedrock, particularly moving away from the riverbank toward the navigation channel. The large exposed height of the wall would result in large lateral loads on the wall, which would have to be counterbalanced by relatively deep embedment of the sheet piles in sufficiently strong sediment or soils.

The wall would also need additional lateral support above the mudline, which typically is provided by anchors. The placement of anchors is not feasible within the CDF footprint, because the anchors would have to be in place before the CDF was filled.[2]

Given these constraints and based on our analysis, a circular cell cofferdam is a robust and feasible containment structure that can be designed for the specific conditions at the Site, i.e., the shallow depth to bedrock, the volume of contaminated sediment, proximity to the Willamette River navigation channel, and navigational needs such as ship berthing. Circular cell cofferdams are suitable for use in difficult in-water environments, are capable of resisting relatively large lateral loads, and are capable of retaining soil and sediment.

A circular cell cofferdam is essentially a hybrid between a sheet pile structure and a gravity retaining structure. Flat steel sheet piles are used to construct circular cells (i.e., cylinders). These cylinders are then backfilled with granular soil to provide sufficient weight to the structure such that the cofferdam essentially serves as a gravity structure. The circular cells are constructed at predetermined intervals, leaving a gap between each circular cell. The gaps between the cells are then closed by installing sheet piles in the shape of an arc. This creates smaller cells between the circular cells, which are then also filled or topped off with granular soil. Large circular templates are used to install the flat steel sheet piles. This allows the contractor to remove sediment from inside the cofferdam, as necessary, before backfilling with clean, granular fill.[3]

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[2] Anchors typically consist of an anchor wall (e.g., sheet piling) or anchor blocks (reinforced concrete "deadman" anchors) placed a predetermined distance behind the main wall, on the upland side of the main wall. Tie rods (i.e., steel bars) connect the main wall with the anchor wall. The anchors would need to be installed prior to backfilling of the CDF so that the lateral earth pressure from the dredged fill could be counterbalanced and excessive deflection of the main wall prevented. At the Site, however, the main wall would generally be quite far from the shore and between 60 and more than 300 feet from the top of the riverbank. The required tie rod lengths would be impractical and sagging of the rods as well as settlement of the dredged fill would cause significant problems and stresses in the tie rods. Development of sufficient soil resistance (i.e., passive earth pressure) during construction (before the CDF is backfilled) would be extremely difficult to achieve considering the large height of the main wall and associated large loads.

[3] It is possible that under some conditions, the cells could remain filled with sediment made more rigid with the addition of amendments to strengthen it. This possibility may be evaluated in the EE/CA or during the design phase.

3.2.1.2 CDF Footprint and Capacity

The conceptual CDF would be constructed along the riverbank in the Willamette River. Because the CDF cannot encroach on the navigation channel, the entire CDF footprint would have to be on the upland side of the harbor line. This means that the CDF would have to be designed to accommodate the berthing of vessels for loading and unloading. Vessels frequenting the Willamette River vary in size from recreational boats to ocean-going Panamax ships (the largest vessels capable of transiting the Panama Canal). Based on typical vessel sizes[4] within the Port of Portland and the Willamette River, a 100-foot offset from the navigation channel boundary has been selected for the conceptual alignment of the exterior CDF wall to accommodate a variety of bulk carriers and fenders for berthing these vessels. This offset would allow for the berthing of large barges and a variety of Handysize bulk carriers whose beam width is up to about 95 feet. Dredging of the berth could be required following CDF construction to provide sufficient water depth for some of the larger Handysize vessels.

The sediment volumes to be contained within the limits of construction and to be dredged and filled into the CDF both affect the size of the CDF. A preliminary sediment containment volume of 110,000 cy (LSS 2008a) was previously estimated based on existing sediment quality data using the Environmental Visualization System (EVS) (USEPA 2009b). In plan view, the removal area is bounded by the 5 milligrams per kilogram (mg/kg) DDx[5] contour line, which is shown on Figure 6.

The dredge depth associated with this area and volume is approximately 15 feet (although the removal depth delineated from the EVS model has been used to calculate volumes for the sizing of the conceptual CDF). The removal depths are noted on the cross sections shown on Figure 5.

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[4] Handysize, Handymax, and Panamax are subcategories of bulk carriers (vessels designed to carry bulk solids or liquids). (Other subcategories exist as well.) Definitions of the subcategories by deadweight vary from source to source. Handysize carriers range from about 10,000 to 30,000 deadweight tonnage (DWT). Handymax carriers range from about 30,000 to 50,000 DWT. Panamax vessels are generally ocean-going cargo vessels of the maximum size possible to pass through the locks of the Panama Canal. The deadweight of these vessels typically ranges from 50,000 to 80,000 DWT. (Source: http://www.worldtraderef.com/WTR_site/vessel_classification.asp.)

[5] DDx is the sum of DDT, dichlorodiphenyldichloroethane (DDD), and dichlorodiphenyldichloroethylene (DDE) isomers.

The final removal volume will not be defined until the EE/CA is completed, and additional sediment quality data are still being collected to refine the horizontal and vertical extent of the removal action. Therefore, we have developed two options for sizing of the CDF in which the facility is scaled not only to contain the estimated sediment volume, but also to support river-dependent uses by allowing berthing for either one vessel or two. Scaling the CDF based on its berthing capacity makes it a more cost-effective and practical investment even as it addresses the containment needs.

One-Berth Option: The 5 mg/kg DDx contour line and associated volume were used to size the one-berth CDF. The associated CDF footprint, an area of approximately 4 acres, was placed within the 5 mg/kg DDx contour line to maximize the volume of contaminated sediment confined by the CDF containment structure. The layout of the one-berth CDF is depicted on Figure 7. Figure 8 presents the volume capacity and dredge volumes associated with the one-berth CDF.

Two-Berth Option: The limits of the two-berth CDF removal area are shown on Figure 6. Although somewhat arbitrary, these limits should be sufficient to determine whether the volume of the removal action area influences CDF feasibility. The 5 mg/kg DDx area derived from the earlier EVS modeling was increased, and the associated removal volume was estimated using the approximate dredge depth of 15 feet, resulting in a volume of approximately 260,000 cy. The associated CDF footprint is an area of approximately 8 acres. The layout of the two-berth CDF is shown on Figure 9. Figure 10 presents the volume capacity and dredge volumes associated with the two-berth CDF.

Another consideration in determining the one-berth and two-berth conceptual CDF footprints is to reduce impacts of dredging to the riverbank. Dredging near the riverbank to relatively large depths below the mudline has potential to destabilize the riverbank and could require cutting of the entire riverbank to avoid slope stability issues. The plan views presented in the figures show how the containment structures that connect the CDF wall into the riverbank would be strategically placed to avoid dredging at the toe of the riverbank.

Historically, contaminated sediment has been placed in CDFs so as to remain in a saturated state (i.e., below the groundwater or surface water elevation). Based on our preliminary assessment of the hydrogeologic conditions at the Site, the estimated steady-state groundwater surface elevation within the CDF would be approximately +13 feet (NAVD 88). This means that some of the dredged sediment confined within the CDF would be in an unsaturated state.

3.2.1.3 CDF Wall Analysis

This section provides a brief overview of the conceptual-level analyses that were performed to estimate the size of the cofferdam. A detailed discussion of these analyses is provided in Appendix A. The cofferdam structure is depicted in plan view on Figures 7 and 9, as well as in the cross sections on Figure 11.

For this conceptual-level design analysis, two conditions that would affect sizing of the cofferdam structure were assessed: sliding and overturning for static and seismic conditions. Additional analyses would be required during subsequent design stages.

In addition, the basis of the conceptual design consists of preliminary assumptions and design criteria necessary only for this feasibility analysis. Therefore, only basic loading cases were considered for the conceptual-level design. Additional loading cases may need to be considered during subsequent design stages.

3.2.1.3.1 Design Loads

The following design loads were used to size the circular cell cofferdam:

Lateral Earth Pressures: Lateral earth pressures were calculated using Rankine earth pressure theory. Soil parameters were selected using professional engineering judgment.

Hydrostatic Load: A low-river stage at elevation +6 feet (NAVD 88) was selected in combination with a water level within the CDF at elevation +8 feet (NAVD 88).

Surcharge Load: A uniform surcharge load of 1,000 pounds per square foot was selected to represent an average load for container facilities.

Dynamic Thrust (Seismic Stability): Dynamic pressures would act upon the wall during strong seismic shaking. A pseudostatic dynamic force was calculated for the design seismic event, discussed below.

3.2.1.3.2 Design Seismic Event

The Site is located in a seismically active region of the Pacific Northwest. It is assumed that a CDF constructed adjacent to the Site would be designed to meet the same seismic design criteria as the CDF planned for the Port of Portland's Terminal 4, which is approximately 2.5 miles from the Site (Anchor 2006). The conceptual-level analysis was performed for the contingency-level event, which corresponds to an earthquake

with a 10 percent probability of exceedance in 50 years (i.e., a 475-year return period). A peak ground acceleration for rock outcrop of 0.2g (g = acceleration of gravity) was used for the analysis of the conceptual CDF cofferdam based on U.S. Geological Survey seismic hazard maps for the 475-year event. This acceleration was further modified to account for amplification using an amplification factor. The peak ground acceleration at the top of the CDF was estimated to be 0.24g.

3.2.1.3.3 Analysis Results

Based on the conceptual design analyses described above, an effective cofferdam width of 54 feet is required to meet the minimum factors of safety for sliding and overturning. A circular cell cofferdam structure can be sized to meet the demands of the Site and is generally considered a feasible containment structure option. Additional details regarding the analysis results are provided in Appendix A.

3.2.2 Short-Term Contaminant Transport

Short-term contaminant transport is another technical issue that must be considered in the CDF design. Short-term contaminant transport can include volatilization of the contaminants during filling of the CDF, water discharged from the CDF, transport losses that occur during filling, and seepage of contaminants or sediment through the CDF containment structure during filling. All of these transport mechanisms can be addressed during design by specifying the use of silt curtains, turbidity controls, air emissions modeling and mitigation measures, and proper design and sizing of the CDF to reduce water discharge and seepage from the containment structure. Means for controlling short-term contaminant transport and performance standards to measure the success of those controls are readily available. Short-term contaminant transport is therefore not expected to impact the feasibility of the conceptual CDF.

3.2.3 Long-Term Contaminant Transport

Potential long-term contaminant transport mechanisms include the leaching of contaminants to the groundwater, seepage of contaminated groundwater or sediment through the CDF containment structure, and stormwater runoff from the CDF cap.

Proper design and sizing of the CDF, including the cap, can reduce discharge and seepage from the containment structure and the impact of stormwater runoff. Discharge, seepage, and runoff can be effectively controlled and are not expected to impact the feasibility of the conceptual CDF. Performance standards for long-term monitoring would be developed.

To address the potential for contaminants to leach from the CDF to the surface water, a hydraulic containment evaluation of the potential for vertical and lateral migration (i.e., fate and transport model) of the contaminants may be required. The results of a preliminary hydraulic containment evaluation completed for the conceptual CDF are presented in Section 7. As discussed there in detail, hydraulic containment is achievable for the conceptual CDF, and long-term contaminant transport under steady-state conditions is not expected to impact its feasibility.

3.3 Conceptual CDF Construction Sequence

3.3.1 Containment Structure

The construction sequence for the one-berth and two-berth CDFs would be essentially the same. If necessary, a dewatering pad would be constructed as part of the Site preparation. After mobilization, sheet piles for the cofferdam structure would be installed. One or two circular cells would be constructed at a time. After each circular cell was completed, the contaminated sediment inside of the cell would be hydraulically dredged and pumped to the shore, where the sediment would be pumped into geotubes or a settling pond for dewatering and temporary storage. The water from the dewatering process would be stored temporarily and tested. Water that met surface water quality standards would be discharged to the river. Water that did not meet standards would be treated at the existing on-Site water treatment facility before being discharged to the river. Following installation of each circular cell, the excess voids of the cofferdam cells would then be backfilled with either dredged sediment from outside the wall or clean, granular material, depending on the final design mix needed to achieve the desired weight. A concrete cap beam would then be installed along the face of the bulkhead, along with proper fendering, bollards, and electrical facilities for vessel berthing.

On the upland side of the CDF, a groundwater cutoff (barrier) wall is currently being planned as part of the upland remedial activities (Figure 7); it is assumed that the barrier wall will be in place before the cofferdam would be installed. This barrier wall will be aligned parallel to the riverbank and will extend to the top of the basalt bedrock. Both ends of the cofferdam would be connected into the shore, and the containment structure would be connected to the upland barrier wall to provide hydraulic containment along all sides of the CDF. Regular Z-shaped sheet piles would be used to connect the barrier wall and the circular cell cofferdam. For the two-berth CDF, the length of the barrier wall would have to be increased over what is currently planned, either before or during cofferdam installation. Once the containment structures were in place, dredging outside of the cofferdam footprint would begin.

3.3.2 Dredging

Prior to dredging, turbidity controls, such as silt curtains, would be installed around the construction area as a sediment resuspension control measure. Given the local subsurface conditions, which include bedrock at shallow depths below the mudline, installing rigid resuspension controls (e.g., sheet piles) would take considerable effort, may not be feasible, and likely would not be cost-effective.

Dredging outside of the cofferdam footprint could be conducted either mechanically or hydraulically; the current assumption is that mechanical dredging (a cable-operated clamshell dredge) would be employed. The dredged sediment would first be placed in a barge and then rehandled by another clamshell excavator located on the CDF cofferdam structure for placement into the CDF. Alternatively, the sediment could be transported to the CDF using a high-solids pump and pipelines.

3.3.3 Capping

The dredged material placed in the CDF would be covered with a geomembrane liner to encapsulate the material and then capped with clean fill material. Groundwater monitoring wells would then be installed along the cofferdam alignment for long-term groundwater monitoring. In addition, extraction wells installed within the CDF footprint are under consideration as a contingency measure that would allow modification of the hydraulic gradients, if found to be necessary based on the results of the fate and transport/hydraulic modeling. Settlement plates would be installed to monitor settlement of the dredged material. Following the installation of these monitoring controls, the final cap layer, which is currently envisioned as asphalt pavement, would be placed.

3.4 Constructability of Conceptual Wall Design

Several marine contractors capable of installing circular cell cofferdams were contacted regarding the constructability of the structure envisioned in this screening evaluation. These discussions are summarized in the following three subsections.

3.4.1 Cofferdam Construction Sequence

The cofferdams would be constructed using prefabricated, circular templates that typically are secured at each cell location using four vertical pipe piles. At least two template levels would be installed for each circular cell. The pipe piles would be pushed or driven into the sediment; therefore, some sediment thickness is necessary

above the bedrock to install the template. After installation of a cofferdam cell, the sediment within the cell would be dredged before the cofferdam structure was completed. Since it would not be possible to place the dredged material in the CDF at that point, the material would need to be dredged to an upland dewatering pad.

3.4.2 Shallow Bedrock

The thickness of sediment above bedrock generally decreases from the riverbank toward the navigation channel, with the minimum available thickness being approximately 10 to 15 feet along the CDF alignment. The available sediment thickness in most areas is on the order of 15 to 20 feet or more. Based on discussion with local contractors, it is anticipated that a sediment thickness of 10 to 15 feet would be sufficient for the installation of the circular cell cofferdam, including installation of the templates.

3.4.3 Dredging within Cofferdam Cells

To provide proper containment of the contaminated sediment, sediment would be dredged not only from areas outside of the CDF footprint, but also from the footprint of the circular cell cofferdam. Dredging within the cofferdam cells would be performed after sheet pile installation and before backfilling of the cells.[6] Because of the cells' circular shape and because the templates would still be in place during dredging, mechanical dredging within the cells is not practical. Discussions with local contractors indicated that the sediment could be dredged hydraulically and pumped to the upland dewatering pad.

3.5 Cofferdam Design Life

The design life of the cofferdam is primarily a function of the durability of the steel sheet piles, and the main factor that affects durability is corrosion. Corrosion influences the steel sheet piles by decreasing the thickness of the steel, thereby weakening the sheet pile sections. The following design measures can be implemented to increase the durability and the design life of the cofferdam (ArcelorMittal 2008a; ThyssenKrupp 2007):

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[6] It is possible that under some conditions, the cells could remain filled with sediment made more rigid with the addition of amendments to strengthen it. This possibility may be evaluated in the EE/CA or during the design phase.

- Select sheet pile sections that are initially heavier than needed to compensate for a future loss in steel thickness.
- Select a higher grade of steel to increase the initial factor of safety against failure of the steel.
- Apply a protective surface (e.g., epoxy) coating.
- Perform hot-dip galvanization (i.e., coat the steel with a thin layer of molten zinc).
- Install cathodic protection.
- Install a concrete cap.
- Incorporate a combination of the above measures.

A design life of greater than 100 years is expected to be feasible for the cofferdam structure if appropriate measures are taken to protect the steel sheet piles. The design life of the cofferdam structure would be addressed in more detail in the EE/CA. Durability calculations can be performed to determine the protection requirements based on the conditions at the Site.

3.6 Screening Outcome: CDF Design and Construction

Our analysis concludes that a circular cell cofferdam is a feasible containment structure for the Site given the shallow depth to bedrock, the volume of contaminated sediment, proximity to the Willamette River navigation channel, and navigational needs such as ship berthing. A circular cell cofferdam could be designed to accommodate all of these conditions.

ARCADIS developed volume estimates and footprints for both a one-berth and a two-berth CDF, because the extent of the removal action is not yet known. Volume estimates for the one-berth CDF were based on the 5 mg/kg DDx contour line, which was extended to estimate a potential removal area for the two-berth CDF. In light of that analysis, the one-berth and two-berth conceptual CDF footprints necessary to contain the estimated sediment volumes are 4 and 8 acres, respectively. A CDF of either size is feasible at the Site.

The potential for both short- and long-term contaminant transport was evaluated. Means for controlling short-term contaminant transport are readily available. Short-term

contaminant transport is therefore not expected to impact the feasibility of the conceptual CDF. With regard to long-term contaminant transport, hydraulic containment is achievable for the conceptual CDF, and long-term contaminant transport is therefore not expected to impact its feasibility. Means for controlling vertical migration of contaminants to groundwater, if necessary, would be addressed in the design phase, as discussed in Section 7.

4. Floodway Analysis

Currently, no new construction or filling is permitted in the floodway[7] unless it can be demonstrated through hydraulic and hydrologic analysis that the construction or filling will not increase the base flood elevation of the Willamette River. To address USEPA's concerns regarding floodway encroachment (USEPA 2009a), floodway modeling was conducted to determine whether the conceptual CDF would result in an increase in the base flood elevation. The results of the floodway modeling are presented below and the modeling output is provided in Appendix B.

4.1 Hydrologic Information

The Willamette River is a tributary of the Columbia River and flows from the mountains south and southeast of Eugene at the southern end of the Willamette Valley. The site of the conceptual CDF falls within the lower reach of the Willamette River, directly downstream of the City of Portland and approximately 7 miles upstream of the confluence with the Columbia River.

A Flood Insurance Study (FIS) of the area was prepared by the Federal Emergency Management Agency (FEMA). This study analyzed flooding associated with the Columbia and Willamette rivers, Johnson Creek, and Columbia Slough, all of which are located within the corporate limits of Portland. This FIS, which assessed the 100-year flood water levels in the reach of the Willamette River that is alongside the Site, was used to provide background information for the floodway modeling analysis. In addition, a large (greater than 100-year) flood had occurred in early February 1996. The flood flow from that event was tested during the modeling to determine the accuracy of the floodway model.

Two gauging stations in the vicinity of the Site provide flow and stage data for the area. One gauge is located approximately 5 miles upstream of the Site on the upstream end of Morrison Bridge in Portland. This gauge provides flow and water elevation data from 1972 to the present. The other gauge is located 7 miles downstream from the Site at

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[7] A "Regulatory Floodway" means the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. Communities must regulate development in these floodways to ensure that there are no increases in upstream flood elevations. (Federal Emergency Management Agency definition taken from http://www.fema.gov/plan/prevent/floodplain/nfipkeywords/floodway.shtm.)

the confluence of the Willamette and Columbia rivers. This gauge provides flow data dating back to 1988 and water elevation data from late 1996 to the present. (A maximum water elevation from the February 1996 flood is also in the summary data for this gauge.) Data from the upstream gauge in early February 1996 indicate a maximum flood flow of 420,000 cubic feet per second (cfs), with a corresponding water elevation of 27.74 feet above the National Geodetic Vertical Datum of 1929 (NGVD 29). Stage data from the tidal gauge at the confluence of the Columbia and Willamette rivers indicate a maximum tidal level at that time of 27.2 feet NGVD 29. The minimum recorded stage for the gauge is 1.24 feet NGVD 29.

A 100-year flood flow of 375,000 cfs for the Willamette River was described in a March 2005 technical memorandum from Parsons Brinckerhoff ("Floodway and Flood Storage Technical Explanation and Analysis") as presented in the Terminal 4 Early Action EE/CA (Blasland, Bouck, and Lee 2005). Although the document indicates that the flow of 375,000 cfs was found in the FIS for the area, this flow was not reported in the FIS. It is assumed to have been taken from the FEMA model used to produce the results that appeared in the FIS. The FIS was revised in 2004 to include the large storm of February 1996, so the 100-year flood flow calculation described in 2005 is assumed to have taken data from that large flow into account.

4.2 Modeling Input Parameters

The hydraulic model selected for use in this analysis was the USACE Hydraulic Engineering Center River Analysis System (HEC-RAS), version 4.0. The HEC-RAS software allows the user to perform one-dimensional steady and unsteady flow river hydraulics calculations. In this application, we selected the steady-flow analysis, which calculates water surface profiles for steady, gradually varied flow and is based on the solution of the one-dimensional energy equation.

Bathymetric data covering the river in the vicinity of the Site were obtained from earlier surveys of the river (refer to notes on Figure 3 for survey details). The elevations were reported in feet and referenced to the NGVD 29. These data were imported into Trimble's Terramodel application, which was used to generate a Triangulated Irregular Network (TIN) of the bathymetry. Elevation grids measuring 20 square feet were created from the TIN and a HEC-RAS geometry file was then exported from Terramodel. The geometry file contained 70 sections at approximately 100-foot centers. Approximate locations of the cross sections are provided on Figure 12.

A roughness factor of 0.03 was assumed for each cross section within the river reach, which describes a clean, straight, full channel with no rifts or deep pools (Chow 1959).

One bridge exists within the extent of the model, Burlington Northern Santa Fe Railroad Bridge 5.1. Very little data were available for the geometry of this bridge and how the bridge might influence water passage. Given the lack of data, a number of assumptions were made on the geometry of the bridge. Available data indicate that the bridge consists of five sections, with the central section having the longest span of 516 feet. Other plan-view geometry data were obtained using the measuring function in Google Earth. A bridge deck elevation of 8 feet NGVD 29 was assumed.

The February 1996 flood flow was tested to determine the accuracy of the floodway model. A flow of 420,000 cfs was entered at the upstream extent of the model. As described above, gauged data of 27.2 feet NGVD 29 and 27.74 feet NGVD 29 were found for the gauges approximately 7 miles downstream and 5 miles upstream, respectively. These values were interpolated to the area in question to give water surface elevations for the upstream and downstream boundaries of 27.5 feet NGVD 29 and 27.4 feet NGVD 29, respectively. The downstream value was input as the downstream boundary to the model. The model was then run to determine how the upstream interpolated gauged measurements corresponded to the model output.

The resulting water surface elevation at the upstream end of the model was found to be 28.2 feet NGVD 29. The difference in elevation from the interpolated gauged data is attributed to the fact that the floodplain does not extend as far as the measured extent of flooding from the February 1996 event, so HEC-RAS overestimated the water surface elevation along the reach by a small amount. This is not expected to make a difference to the elevation variations between existing and proposed modeled conditions.

The model was also compared to the FIS prepared by FEMA. The HEC-RAS model indicated a 0.56-foot rise along the extent of the modeled area at a downstream water elevation of 30 feet, which correlates well with the approximately 0.5-foot rise along the same reach from the FIS for the 100-year flood (which also includes a downstream boundary of approximately 30 feet NGVD 29).

Following setup of the existing conditions model, a second proposed model was saved; this model included the extent of encroachment of the larger, two-berth conceptual CDF footprint into the river. The encroachment of the two-berth CDF footprint results in a maximum decrease in cross-sectional flow area of less than 1 percent for low tide options and less than 5 percent for high tide options. To model this situation, ineffective flow areas were added to all cross sections affected by the CDF. It was assumed that the two-berth CDF footprint would provide a worst-case impact, if any, on flood elevations.

Eight simulations were run to determine the impact of the CDF on the 100-year flood for different downstream water surface elevations. To assess this impact on water surface elevation for a range of downstream elevations, the upstream flow boundary was set at the 100-year flood flow of 375,000 cfs, and the downstream boundary was changed to range between a low tide of 0 and high tide of 30 feet NGVD 29, which correspond to just above and below the maximum and minimum gauge height readings, respectively, at the confluence of the Columbia and Willamette rivers. Table 2 summarizes the eight simulations that were run.

4.3 Screening Outcome: Floodway Analysis

All tabulated and graphical results from HEC-RAS modeling of the existing and proposed conditions are included in Appendix B. Table 3 summarizes the results for water surface elevation. The results demonstrate that in all tidal conditions analyzed, the impact of the conceptual CDF on water surface elevation would be negligible along the reach of river alongside the Site. Water surface elevations were observed to decrease in a number of sections, with an associated minimal rise in velocity (less than 0.2 foot per second in all cases). An assessment was also performed for a lower flow situation of 75,000 cfs, which would be contained within the banks of the river. This case also resulted in negligible change in water surface elevation. The floodway analysis therefore determined that construction and filling of the conceptual CDF would have no impact on base flood elevation in the Willamette River and so would not encroach on the floodway.

5. Balanced Cut and Fill Analysis

The base flood elevation at the Site is +31 feet NAVD 88, according to the current FEMA Flood Insurance Rate Map (FIRM) for Portland, Oregon (revised October 19, 2004), which is provided in Appendix C. The Site is within Flood Hazard Area Willamette River FIRM Flood Zone AE.

5.1 Substantive Requirements

The Metro Regional Government (Metro) Urban Growth Management Functional Plan (Title 3: Water Quality and Flood Management) regulates development within Water Quality and Flood Management Areas (Metro Code §§3.07.310 – 3.07.370). Chapter 24.50 (Flood Hazard Areas of the Portland City Code) implements the Title 3 regulations to protect the public health, safety, and welfare by restricting uses that are dangerous in times of flood or that cause increased flood heights.

Title 3 and Chapter 24.50 both state that all fill placed at or below the base flood elevation in flood management areas will be balanced with at least an equal amount of soil material removal, or excavation, to preserve the area's capacity for water flow and flood storage (§3.07.340; Chapter 24.50.060 F8). In addition, excavation will not be counted as compensation for fill if the excavated areas are filled with water in non-storm winter conditions. Chapter 24.50 further clarifies that all soil material removal will be within the same Flood Hazard Area where the fill is placed.

Variances from these requirements can be requested based on a variety of factors, including the importance of the services provided by the CDF to the community, the necessity of the waterfront location to the CDF, the availability of alternative locations, and the compatibility of the proposed use with existing and anticipated development. Requests are evaluated in light of specific conditions under which variances in general are granted.

5.2 Impact of Requirements on CDF Option

To complete the balanced cut and fill evaluation, the Title 3 Land delineation was obtained from Metro. The Title 3 Land delineation is shown on Figures 13 and 14 for the one-berth and two-berth conceptual CDFs, respectively, and is described in greater detail in Appendix C. This delineation, in conjunction with the base flood elevation of +31 feet NAVD 88, was used to calculate the cut and fill volumes. Both the one-berth and two-berth CDF layouts fall entirely within the Title 3 Land delineation, up to the

base flood elevation of +31 feet NAVD 88. The proposed finished grade of both CDF layouts would extend up to +35 feet NAVD 88.

For the purposes of the balanced cut and fill evaluation, dredging volumes were calculated outside the footprint of the CDF to determine the dredged material component of the fill to be placed within the CDF. In addition, fill would be placed within the cofferdam walls and as cap material over the top of the dredged material within the CDF, to an elevation of +35 feet NAVD 88. Volumes for each of these elements, for both the one-berth and two-berth conceptual CDF footprints, were calculated to determine total fill below the base flood elevation of +31 feet NAVD 88. These quantities are summarized in Table 4. Note that based on the definition of “cut” in the Title 3 regulation, dredging does not count as a cut to mitigate fill within the same Flood Hazard Area.

5.3 Screening Outcome: Balanced Cut and Fill

The total fill quantities must be balanced with an equal amount of cut within the same Flood Hazard Area Flood Zone AE and within the Title 3 Land delineation above elevations that are inundated during non-storm winter conditions. This can be accomplished by either cutting material from the shoreline along the Site property or mitigating the fill volume in other areas of the river having the Flood Zone AE designation. There is potential for coordinating removal along other parts of the river to mitigate the fill placed during construction of the CDF. These opportunities could be identified through discussions with the City of Portland, state agencies, or other landholders along the river.

6. Limited Evaluation of DSL and Other Requirements

This section considers whether the Oregon Department of State Lands would approve construction of the conceptual CDF on state-owned submerged land and provides limited analysis of other ARARs. A complete ARARs analysis will be included in the EE/CA.

The State of Oregon, through the DSL, owns and manages the beds and banks of the Willamette River. State ownership of submerged and submersible land is typically to the line of ordinary high water (OHW), which is generally defined as the upward limit to which a river will normally rise each year. For the Lower Willamette River, the USACE has defined OHW as 16.6 feet NGVD 29 (USACE 2004).

DSL issues several types of authorizations for the use of state-owned submerged and submersible land. Examples that might be applicable to a CDF adjacent to the Site include a lease, a sale, an easement, or a registration, in which pertinent information is recorded with the state without a fee. Oregon Administrative Rules (OARs), Section 141-067-0140, establish procedures for the sale, exchange, and purchase of land by DSL and allow for the sale of land to “facilitate the legal disposal of hazardous materials as part of a plan approved by the appropriate state and/or federal environmental agencies.”

DSL has developed the Lower Willamette River Management Plan to manage use of the lower 17.5 miles of the Willamette River (Oregon DSL 1992). The plan describes allowable activities and conditions for waterway management areas based on state public trust values (fisheries, recreation, and navigation). This plan was adopted by the state as an administrative rule in 1992 and provides policy direction for DSL’s interests in the river. DSL has designated the area adjacent to the Site as a Development Area, which in this segment of the river allows for filling to create upland for river-related or river-dependent uses on a provisional basis. Because the CDF as envisioned would have a river-related or river-dependent use, it appears to be consistent with the waterway management area as outlined in the plan and should be consistent with the public trust values.

Because a CDF constructed adjacent to the Site would be located primarily on state lands, authorization or sale from DSL would be required. The area that would require authorization from DSL would depend on the size of the CDF. Based on the analysis presented in Section 3, the lease area would range from approximately 4 to 8 acres.

In addition, most removal and fill activities below OHW typically are subject to the permitting requirements of the Oregon Removal Fill Law (OAR 141-085, et seq.). However, in our discussions with DSL, it was indicated that removal actions directed under a USEPA order are exempt for purposes of the state's Removal Fill Law, which requires people who will remove or fill 50 cy or more of material in waters of the state to obtain a permit from DSL.

6.1 Discussions with DSL

The following DSL representatives provided information about how the agency would assess the CDF.

- Steve Purchase, Assistant Director for the Land and Water Management Division
- Mike McCabe, Senior Resource Coordinator for the Wetland & Waterways Conservation Division

Steve Purchase (pers. comm. 2009) indicated that DSL has a number of options for authorizing access to the footprint required for a CDF adjacent to the Site, including sale, lease, and easements. A final decision would be authorized by the State Land Board, which would consider how the action would enhance the cleanup work at the Site. The Land Board would also consider potential sale or lease of the necessary land from the perspective of a concerned adjacent landowner and would evaluate the potential for future impacts from the CDF. For the Port of Portland CDF at Terminal 4, the state sold land associated with the CDF footprint at that facility (Oregon DSL 2005).

Mike McCabe (pers. comm. 2009) indicated that the conceptual CDF would be exempt from the state's removal fill rules because this removal action is directed under an AOC entered into with the USEPA.

6.2 Other State Requirements

The Oregon DEQ has stated that dredged sediments are excluded from the definition of hazardous waste under certain circumstances, including if the dredged material is subject to a permit that has been issued under the Clean Water Act (CWA) Section 404 (Oregon DEQ 2008).

6.3 Other Considerations

A full ARARs analysis was not conducted for the purposes of this screening evaluation, but will be completed as part of the EE/CA. A preliminary review of potential ARARs

indicates that Section 401 and Section 404 (b)(1) of the CWA will be applicable to a CDF at the Site. Neither of these two potential ARARs is expected to affect CDF feasibility.

6.4 Screening Outcome: DSL Authorization/Other Requirements

Based on our discussions with DSL, it is likely that land for the CDF could be leased from the State of Oregon under existing regulation. Therefore, DSL authorization is not expected to affect CDF feasibility.

The Oregon DEQ and USEPA agree that dredged material would not be classified as a hazardous waste so long as the CDF is subject to a CWA Section 404 permit, which USEPA has stated it would require (USEPA 2008g). Regardless of whether treatment is performed, treatment would not affect CDF feasibility.

Any other potential ARARs will be determined during the EE/CA but are not expected to affect CDF feasibility.

7. Hydraulic Containment Evaluation

Hydraulic containment was evaluated to address USEPA concerns about the potential for contaminant transport out of the CDF via the groundwater pathway, although the limited solubility and limited mobility of DDx (refer to Section 8.1.2) suggest this pathway is likely to be of minimal consequence for DDx. Nonetheless, as an initial conservative estimate to address the long-term transport mechanisms of contaminant leaching to groundwater and seepage of contaminated groundwater or sediment through the CDF, a hydraulic containment evaluation of the potential for vertical or lateral contaminant migration was performed. Modeling of contaminant solubility, leachability, and fate and transport was not performed for this initial conservative evaluation.

The potential for hydraulic containment by the conceptual CDF was evaluated by developing a conceptual site model (CSM), which compiles regional and Site-specific geologic and hydrogeologic data to conceptualize the groundwater flow patterns and groundwater-surface water interactions that would develop within the CDF. In addition to hydraulic parameters for the hydrostratigraphic units, manufacturer specifications/estimates for hydraulic properties of constructed CDF components were used to estimate the potential groundwater flux that will occur into and out of the CDF.

The CSM and results of the hydraulic containment evaluation are summarized in the following sections. Our conclusion is that long-term water quality is very manageable.

7.1 Planned Upland Source Control Activities

Hydraulic characteristics and assumptions presented in a numerical groundwater flow model previously developed for the upland portion of the Site (ERM 2008a) to support design of the groundwater source control measures (SCMs) largely informed the CDF CSM presented here. The groundwater CSM consists of the following primary components:

1. A groundwater cutoff (barrier) wall to physically separate the affected upland portions and in-water portions of the Site

2. Hydraulic control (“groundwater extraction and treatment”) to prevent groundwater containing unacceptable contaminant concentrations from moving around, over, or under the containment barrier wall

3. Management of treated groundwater from the ex-situ treatment system

The planned groundwater cutoff wall will be constructed along the top of the riverbank with necessary setback using conventional barrier wall technology to the top of the basalt (approximately 50 to 85 feet below ground surface) (ERM 2009). Hydraulic control of the upland groundwater plumes will be established through groundwater extraction upgradient of the barrier wall. Although screening-level estimates for groundwater extraction rates have been developed (ERM 2008a), additional characterization of hydrogeologic conditions and subsequent groundwater modeling will be conducted to verify the required groundwater pumping rate, recovery well layout, and recovery well design. Extracted groundwater will be treated and discharged to the Willamette River (ERM 2009).

7.2 Conceptual Site Model and Predicted Hydrogeologic Conditions

The CSM is intended to enable conceptualization of the factors that would control hydraulic conditions related to CDF construction at the Site. The major components of the CSM consist of the Site history, Site-specific geology, hydrogeology, existing water budget, estimates and assumptions for hydraulic parameters associated with CDF construction, and semiquantitative/conceptual groundwater flux into and out of the conceptual CDF. The CSM is illustrated on Figure 15 and summarized below.

Groundwater present within alluvial overburden upland of the Site (upgradient of the mean river stage) currently discharges at the Willamette River and would be captured by the groundwater extraction system that is planned as part of the upland SCMs (ERM 2009). Some groundwater present in the Basalt Zone may also be captured in the groundwater extraction system.

Water levels inside the CDF would be controlled by the potentiometric head within underlying basalt bedrock. The CDF would be bounded by very low permeability structures, including an upland barrier wall and an in-water circular cell cofferdam installed to the top of the basalt. Under existing conditions, the hydraulic connection between sediment and the Basalt Zone is limited by the presence of fine-grained sediment at the basalt surface, which acts to reduce permeability and thus groundwater flux from the underlying basalt to the sediment.

With active upgradient groundwater extraction, the potential for underflow beneath the barrier wall and into the CDF would be reduced due to the reduced gradients that would develop across the barrier wall, and leakage through the upgradient barrier wall would be on the order of 9×10^{-3} gallons per minute (gpm).

The gradient across the cofferdam is estimated to be approximately 0.1. The very low permeability of the sealed sheet pile cofferdam structure would effectively prevent lateral leakage through the cofferdam, with an estimated flux of only $2x10^{-3}$ gpm from the CDF to the river through the sealed joints between sheet piles of the cofferdam. Recharge through the low-permeability surface cap into the CDF is estimated to be on the order of $2x10^{-6}$ gpm.

Gradients would be generally upward from the Basalt Zone to the CDF; however, short-term, transient gradient reversals may occur related to major changes in river stage or changes in upgradient conditions. Although effects observed within the CDF may be inconsequential, development of a calibrated numerical flow model may be required during the design phase to provide Site-specific data for evaluating flow at this boundary.

7.3 Conceptual Hydraulic Containment Design

Hydraulic containment of contaminated sediment within the CDF would be achieved by the following containment elements:

- Upland barrier wall
- Circular cell cofferdam
- Low-permeability surface cap

Lateral hydraulic containment could be achieved through implementation of the upland groundwater remedy (cutoff wall and groundwater extraction) and proper construction of the cofferdam enclosure. Recharge could be prevented by construction of a low-permeability surface cap. If necessary, additional evaluation of vertical hydraulic containment related to transmissivity of the underlying Basalt Zone would be performed during the design phase.

Secondary containment could include a groundwater extraction system from within the CDF that would operate on an as-needed basis related to the short-term, transient events that could affect hydraulic conditions within the CDF.

If necessary, the effectiveness of hydraulic containment could be confirmed by monitoring the potentiometric surface differential along the perimeter of the CDF within the cofferdam backfill.

7.4 Effectiveness of Hydraulic Containment

Hydraulic containment of the conceptual CDF would depend not only on well-designed and well-constructed containment structures, but also on the hydrogeologic setting in which the CDF would be constructed. Under steady-state conditions, there is the potential for extremely small leakage rates into the CDF from upgradient and through the cap and out of the CDF through the cofferdam. Downward leakage from the CDF through the Basalt Zone would be prevented under steady-state conditions by the upward gradient from the Basalt Zone to the CDF. The water level within the CDF is estimated to be approximately +13 feet NAVD 88 based on water levels from five Basalt Zone monitoring wells measured in April 2007.

ARCADIS used data collected in April 2007 to estimate groundwater heads within the hydrostratigraphic zones at the Site. Monitoring wells RP-10-130, RP-08-107, RP-09-64, RP-02-66, W-19D, and MWA-21b are screened within the Basalt Zone. MWA-21b, with a measured potentiometric head in April 2007 of 13.66 feet NAVD 88, was taken to be the most representative of Basalt Zone hydraulic conditions adjacent to the conceptual CDF. This single measurement is not believed to represent a constant head present in the Basalt Zone, but instead was used in developing the CSM for hydraulic containment of the CDF, which indicates that transient effects of fluctuating river stage will affect head within the CDF.

Transient conditions such as changes in upgradient groundwater extraction rates, tidal and seasonal river stage fluctuations, and extreme flooding events could cause small, short-term gradient reversals and potentially allow temporary outward migration of groundwater from the CDF to the bedrock. However, DDx, the primary contaminant, has limited solubility and limited mobility in most soil environments and is expected to have minimal leachability from sediment within and outside of a CDF at the Site (refer to Section 8.1.2). As such, vertical migration of DDx, if any, from the sediment into groundwater and through the underlying sediments to bedrock during a temporary gradient reversal would be negligible. If necessary, the potential for vertical migration of contaminants to groundwater can be addressed in the design phase.

The feasibility of controlling the effects of transient conditions on the hydraulic containment by implementing secondary containment measures, such as groundwater extraction from within the CDF, can be addressed in the design phase if necessary.

7.5 Screening Outcome: Hydraulic Containment

Hydraulic containment is feasible for the conceptual CDF, and long-term water quality is very manageable. Lateral hydraulic containment would be provided by the upland barrier wall and in-water circular cell cofferdam. Vertical hydraulic containment would rely in part on prevention of infiltration by a low-permeability surface cap and depend largely on the hydraulic properties of the underlying basalt bedrock. Transient conditions could cause temporary gradient reversals and potentially allow temporary outward migration of groundwater from the CDF. It may be feasible to control transient flow reversals by implementing secondary containment measures, such as groundwater extraction from within the CDF. Groundwater control during transient conditions would be evaluated further during the design phase.

8. Treatment Evaluation

In a memo dated November 20, 2008 (Oregon DEQ 2008), the Oregon DEQ indicated that sediment placed into the CDF conceived for the Site will not require treatment. However, in a June 2008 letter to LSS, USEPA requested analysis of several issues to ensure that a feasible CDF option is presented in the EE/CA (USEPA 2008d); evaluating whether a treatment component could enhance the effectiveness of the conceptual CDF was among those requests. Accordingly, LSS agreed to continue evaluating potential treatment options that might provide some additional enhancement or benefit to the CDF option. The following treatment technologies have been evaluated:

- Low-temperature thermal desorption (LTTD)
- Chemical oxidation (persulfate, ozone, permanganate, and hydrogen peroxide)
- Soil mixing (solidification/stabilization and zero-valent iron [ZVI] clay)
- Bioremediation (in-situ and ex-situ anaerobic and aerobic)
- Chemical reduction (dithionate, polysulfide, and ZVI)

The objective of this analysis is to move toward a short list of technologies or hybrid technologies that can be further evaluated in the EE/CA. The results of the analysis are summarized below and presented in detail in Appendix D.

8.1 Constituents of Interest

Varied constituents of interest (COIs) are present within the sediment of the Willamette River adjacent to the Site. However, while specific COIs are associated with Site activities, many of the COIs originate from upstream and other sources in this highly industrial area.

8.1.1 DDx

To focus the screening of potential treatment options for use in conjunction with the conceptual CDF, emphasis was placed primarily on DDx (the sum of the pesticides DDT, DDE, and DDD isomers). DDx consists of high-molecular-weight, low-solubility compounds with elevated partitioning coefficients. Given these characteristics, the compounds will tend to partition to organic materials and fine grains within the silty

sand sediment matrix and have very limited mobility[8]. These compounds are also characterized by low vapor pressure, low Henry's law coefficients, and high boiling points. As such, they are not volatile or strippable and would require high temperatures to be desorbed and mobilized from the soil, particularly as vapor. In addition, DDx is somewhat resistant to biodegradation, but capable of dechlorination in anaerobic conditions, particularly for the more chlorinated parent compounds (as compared to intermediates and daughter products of dechlorination). Aerobic biodegradation may be slightly more appropriate for the intermediate products.

8.1.2 DDx Solubility and Mobility

While DDT is persistent in the environment, it has limited solubility and mobility in most soil environments. Routes of loss and degradation include runoff/erosion, photolysis, and biodegradation (both anaerobic and aerobic). In general, naturally-occurring anaerobic biodegradation of the parent DDT compound in a saturated soil environment will proceed at relatively better rates than the naturally-occurring aerobic biodegradation pathways. However, all of these loss and degradation processes will generally occur very slowly at normal site conditions and temperatures, which is why a typical half-life for DDx in the environment is on the order of 2 to 15 years.

The solubility, octanol-water partition coefficients (log K_{ow}), and soil sorption coefficients (log K_{oc}) for DDT, DDD, and DDE are summarized below. As the compound dechlorinates, the less chlorinated DDx isomers do show a slight increase in solubility and a lower partitioning coefficient. Again, these variations are all relative, in that leaching of DDx from soils is expected to be minimal.

Compound	Molecular Formula	Molecular Weight	Solubility (at 25°C)	Log K_{ow}	Log K_{oc}
(p, p' and o, p') DDT	$C_{14}H_9C_{l5}$	354.49[a]	0.025 mg/L[a]	6.91[a]	5.18[b]
(p, p' and o, p') DDD	$C_{14}H_8C_{l4}$	318.03[a]	0.12 mg/L[a]	6.51[a]	4.70[c]
(p, p' and o, p') DDE	$C_{14}H_{10}C_{l4}$	320.05[a]	0.09 mg/L[a]	6.02[a]	5.18[d]

mg/L = milligrams per liter

[a]Howard and Meylan 1997
[b]Swann, et al. 1981
[c]Sabljic 1984
[d]Meylan, et al. 1992 (values estimated from a fragment constant method)

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[8] The fraction of organic carbon (F_{oc}) of the sediments is needed to further quantify adsorption-desorption kinetics of these compounds.

In addition to the characteristics of the DDx isomers themselves, other factors can affect the leachability of DDx from soil. The most important is the amount of organic carbon present in the soils. DDx consists of hydrophobic compounds that will strongly partition to organic carbon, and the octanol-water partitioning coefficients are correspondingly high.

In summary, the leachability of DDx from sediments both within and outside a CDF at the Site is expected to be minimal. If necessary, Site-specific data could be collected during the EE/CA regarding the leachability of the DDx isomers from sediments placed within the conceptual CDF.

All of the biological and chemical destruction treatment technologies evaluated for this assessment rely on the desorption and availability of DDx for treatment. Therefore, it is likely that such technologies would remediate only a portion of the DDx mass, i.e., the fraction that is dissolved. Given the limited solubility and mobility of DDx, however, the question of whether any treatment is necessary could be further evaluated during the design phase. If needed, a more cost-effective strategy could be solidification/stabilization (S/S) of sediments within the CDF. An S/S technique would also provide additional geotechnical stability to the CDF and minimize the requirement for long-term hydraulic controls within the CDF itself.

8.2 Evaluation of Treatment Options

The screening criteria discussed in this section are briefly described below.

For use in combination with the conceptual CDF, some technologies could require bench or field testing for proof of process or to gather necessary data that can be used to design and scale up a larger application. Some technologies, such as chemical oxidation, might not be suitable in combination with the CDF (e.g., materials, layout, size, and volume) as currently conceived.

8.2.1 Effectiveness and Implementability

Available literature and academic research were used to evaluate which technologies have been proven at the bench or field scale and especially which technologies have been applied at USEPA-regulated CERCLA sediment sites with pesticides/DDx. Often, only a few of these criteria are met in the literature review. Table 5 summarizes the screened technologies and the principal conclusions.

Based on this review and the properties of the COIs, the effectiveness of the evaluated technologies toward the suite of organic compounds is summarized below, from most to least effective:

- Effective toward organic targets: ex-situ LTTD. However, the presence of harborwide COIs such as dioxin and polychlorinated biphenyls (PCBs) render the LTTD approach infeasible.
- Moderately effective toward organic targets: soil mixing with chemical oxidants; soil mixing with ZVI (and clays, i.e., chemical reduction); bioremediation with sequenced anaerobic-aerobic technology. These technologies can be applied ex-situ or in-situ (within the CDF). Generally, ex-situ treatment will be more effective because it allows for better mixing/contact and engineering.
- Low or partial effectiveness toward organics: stand-alone aerobic or anaerobic bioremediation (ex-situ or in-situ).

Solidification/stabilization could be effective at reducing the mobility and leachability of the target organics, but would not provide contaminant reduction unless other reagents are added to the S/S mixture.

Some of the technologies evaluated would not provide effective treatment of metals. LTTD typically destroys the organic carbon content of the soil, thereby limiting the metal sorption capacity of the treated soil or otherwise creating a metals precipitation problem where none previously existed. Some forms of anaerobic bioremediation could precipitate some of the heavy metals as sulfide or iron sulfide complexes, but these minerals can also be solubilized, pending the local geochemical environment. And in some biological treatments that use iron, metals can be removed from the dissolved phase.

While several technologies do appear to have potential to be technically effective toward DDx, they may not be implementable given the Site conditions; the anticipated materials, size, layout, or volume of the conceptual CDF construction; or other logistical factors. Implementability of the technologies is summarized below:

- Medium/moderate implementability:
  - In-situ soil mixing and in-situ sequenced anaerobic-aerobic bioremediation – Both techniques would require mobilizing large equipment to achieve sufficient soil mixing within the CDF to ensure homogenization and contact with reagents.

  - Ex-situ soil mixing technology – Any technology that relies on contact to achieve treatment or stabilization would be easier to implement and engineer in an ex-situ application.
  - Ex-situ sequenced anaerobic-aerobic bioremediation and ex-situ aerobic bioremediation – Both techniques would require multiple acres at the Site to landfarm soils and provide aeration, but are feasible. They could also require dust suppression.
- Low/no implementability:
  - LTTD – While the factors of cost and sustainability and the potential to create more toxic compounds (dioxins and furans) could ultimately screen this technique from consideration, it is implementable given the availability of space on Site, appropriate power, and the ability to obtain multiple permits.
  - Chemical oxidation (persulfates/ozone) – Persulfate in-situ chemical oxidation (ISCO) shows the most promise toward treating the organic compounds. However, persulfate chemical oxidation has the potential to corrode and degrade metal sheeting used in construction of the CDF wall. Fenton's reagent and ozone technology also show promise, but are too short-lived to achieve contact.

8.2.2 Sustainability

Green remediation is the practice of considering all environmental effects of remedy implementation and incorporating options to maximize the net environmental benefit of cleanup actions. USEPA's technology primer, Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites (USEPA 2008b), outlines the principles of green remediation and best management practices for reducing the footprint of environmental cleanups throughout a project's lifetime. USEPA addresses green remediation by focusing on the following six core elements:

- Energy requirements (e.g., mobile and stationary forms)
- Air emissions (e.g., from mobile and stationary sources of energy, off-gassing from the remedial technology)
- Water requirements and impacts on water resources (e.g., potable water use, water reuse, water generated on site from treatment, discharge of process water to surface waters, stormwater management, groundwater supply and quality)
- Land and ecosystem impacts (e.g., impacts on flora and fauna habitat, change in impervious coverage affecting stormwater generation)
- Material consumption and waste generation (all material throughput of the system during every stage of the project, including temporary and permanent materials and how they are handled)

- Long-term stewardship actions (a broad topic that includes aspects indirectly affected by the remedial system, such as community vitality, health and safety concerns, contribution to climate change)

In evaluating a remedial system on the basis of these six core elements, activities performed during investigation, pilot study, installation/construction, and operation and maintenance are all considered.

A qualitative review of the sediment treatment alternatives in light of the six core elements of green remediation provides a valuable perspective from which to evaluate the treatment technologies. The in-situ applications would likely have fewer energy requirements and associated air emissions than would ex-situ applications that involve double handling of the sediment with trucks and heavy equipment. However, all thermal techniques (i.e., LTTD) have significantly greater energy requirements and air emissions than do the other techniques. Thermal treatments also pose greater health and safety risks because of the unsupervised heating periods (i.e., overnight and weekends).

Dewatering operations for all technologies (excepting in-situ aerobic and anaerobic bioremediation, ISCO, and in-situ chemical reduction) would produce another treatment need to manage the water, which would require additional energy use and create a potential surface water discharge.

The treatment alternatives have varying degrees of material consumption, which would require more detailed evaluation to reach a definitive conclusion. The chemical oxidation treatment technologies that require ozone generation on the Site would increase risks to health and safety. Any treatment requiring multiple injection or mixing events could consume more energy and materials than comparable technologies that do not require multiple events.

Based on this cursory evaluation, the three most sustainable treatment technologies are in-situ anaerobic bioremediation, in-situ soil mixing (S/S), and in-situ aerobic bioremediation. The least sustainable treatment technology is ex-situ LTTD.

8.3 Screening Outcome: Treatment

As Table 5 illustrates, treatment is feasible, although some of the treatment technologies with the greatest effectiveness for DDx also have low implementability, high cost, and low sustainability. For that reason, in-situ solidification/stabilization appears to be the best overall option if treatment is needed, offering high effectiveness

and medium implementability at a medium cost. In-situ S/S is also one of the three most sustainable treatment options under the Site-specific conditions.

Given the limited solubility and mobility of DDx, however, the question of whether any treatment is necessary should be further evaluated during the design phase. Although not a treatment for the purpose of contaminant reduction, solidification/stabilization is likely the most effective means of fixing the material in place within the CDF to further reduce the potential leaching and migration of contaminants, if necessary.

Therefore, we conclude that treatment is feasible. Although the preliminary analysis suggests that solidification/stabilization would be effective, determining the best Site-specific approach to treatment will require further analysis. Ex-situ soil mixing treatment technologies will be specifically evaluated in the EE/CA per a directed change from the USEPA (USEPA 2010). In addition, it is also possible that selected treatment technologies could be combined to increase effectiveness; this possibility would also be evaluated during the EE/CA.

9. Overall Evaluation of CDF Option

This CDF screening evaluation focused on the most critical feasibility issues (i.e., potential “fatal flaws”). To address the key feasibility issues, we performed the following evaluations and analyses:

- Assessment of general design considerations, including geotechnical issues and conceptual CDF footprint and capacity
- Floodway analysis
- Balanced cut and fill assessment
- Assessment of DSL concurrence and other state requirements
- Hydraulic containment assessment

In addition, at USEPA’s request, LSS agreed to continue evaluating potential treatment options that might provide some additional enhancement or benefit to the CDF option.

The results of each of these evaluations are summarized below.

9.1 General Design Considerations

The evaluation of design considerations focused on the stability and durability of the structure. Other performance standards not related to potential fatal flaws would be addressed in the EE/CA, i.e., best management practices and appropriate construction materials that could be used to meet miscellaneous construction-related performance standards.

A circular cell cofferdam constructed using steel sheet piles has been identified as a generally feasible CDF containment structure able to meet the performance standards used for the Port of Portland’s nearby Terminal 4 CDF with respect to stability and resistance to erosive forces. Evaluation of the cofferdam took into account static and seismic loading, constructability, and corrosion of the steel sheet piles. Numerous circular cell cofferdams have been constructed in similar environments and have performed properly. The effect of corrosion on the service life of the structure would need to be addressed during design, but could be managed using a variety of technical solutions to increase the durability of the steel sheet piles.

Because the dredge area and dredging depth are not yet delineated, the conceptual CDF footprint was evaluated on the basis of dredge volumes for a one-berth CDF and a two-berth CDF to meet the requirement that the CDF provide berthing for cargo vessels. The conceptual CDF footprints evaluated for this feasibility screening were selected such that dredging of the sediments near the riverbank could be avoided, assuming the impacted material within the CDF footprint would not need to be dredged—thus eliminating the potential exposure inherent in dredging contaminated material that is not currently posing a threat or risk. This is important because cutting into the toe of the riverbank could destabilize the riverbank and would pose significant technical challenges.

A portion of the dredged sediment would need to be placed above the water table because of constraints that include the geometry and size of the Site, the width of the cofferdam, the requirement to accommodate water-dependent uses, and the expected water level within the CDF.

9.2 Floodway Analysis

HEC-RAS modeling was performed for the 100-year flood associated with flows of 375,000 cfs and 75,000 cfs. Changes in water level during these events were found to be negligible for the one-berth and two-berth CDF footprints. Therefore, construction of the conceptual CDF is not expected to alter flooding scenarios within the Willamette River.

9.3 Balanced Cut and Fill

The balanced cut and fill evaluation showed that significant portions of the total CDF volume would count toward fill, while none of the dredged volume would count toward cut. Therefore, it would be necessary to implement mitigation measures, which could include:

- Cutting material from the shoreline along the Site
- Mitigating the fill volume in other areas of the river within the same flood hazard zone

It could be possible to coordinate removal along other parts of the river within the same flood hazard zone to mitigate the fill placed during CDF construction. These opportunities would need to be evaluated in the EE/CA through discussions with the City of Portland, state agencies, or other landholders along the river.

9.4 Limited Evaluation of DSL and Other State Requirements

The State of Oregon owns and manages the beds and banks of the Willamette River, which includes the majority of the one-berth and two-berth conceptual CDF footprints. During discussions with DSL, DSL expressed that options exist for authorizing access to the footprint required for the CDF, including sale, lease, and easements. As part of negotiations with the state during preparation of the EE/CA, it will be necessary to demonstrate that the removal action would enhance cleanup work and that potential impacts from the CDF are either nonexistent or acceptable.

Handling of the dredged material was also addressed as part of the feasibility screening with regard to state rules about the handling of waste that contains pesticide residuals. The Oregon DEQ and the USEPA concur that these rules are not applicable to dredged sediments under a CWA Section 404 permit.

9.5 Hydraulic Containment Assessment

For the preliminary screening evaluation, hydraulic containment was assessed mainly for steady-state conditions using semiquantitative calculations that were based on the Site-specific hydrogeologic conditions.

Transient conditions such as changes in upgradient groundwater extraction rates, tidal and seasonal river stage fluctuations, and extreme flooding events could cause temporary gradient reversals and potentially allow groundwater migration from the CDF to the bedrock.

If necessary, the effects of transient potentiometric surface reversals can be addressed by implementing secondary containment measures, such as groundwater extraction from within the CDF. Transient conditions would need to be evaluated further as part of the EE/CA.

9.6 Treatment Evaluation

Effectiveness, implementability, and sustainability were considered in the treatment evaluation. For several of the treatment technologies—in particular, ex-situ applications—increased effectiveness resulted in decreased implementability and sustainability. However, ex-situ soil mixing treatment technologies will be specifically evaluated in the EE/CA per a directed change from the USEPA (USEPA 2010).

Some of the treatment technologies with the greatest effectiveness for DDx also have low implementability, high cost, and low sustainability. Ex-situ LTTD effectively targeted organic contaminants. However, LTTD has the potential to create more toxic byproducts (i.e., dioxins and furans), scored lower on sustainability, and would be costly.

Sequenced anaerobic-aerobic bioremediation is an in-situ option that effectively targets Site contaminants.

Soil mixing with chemical oxidants, ZVI, or clay targets the Site contaminants as effectively as some other technologies, but the ability to conduct the mixing within the CDF makes soil mixing a more implementable and sustainable option. In-situ solidification/stabilization appears to be the best overall option, offering high effectiveness and medium implementability at a medium cost. In-situ S/S is also one of the three most sustainable treatment options under the Site-specific conditions. Although not strictly a contaminant reduction treatment, solidification/stabilization is likely the most effective means of fixing the unsaturated material in place within the CDF to limit the already low potential for leaching and migration of contaminants. In addition, selected treatment technologies may be effectively combined to further reduce post-treatment mobility and leachability, thereby increasing the effectiveness of S/S.

9.7 Conclusions

No fatal flaws were identified during the preliminary CDF screening evaluation. However, several technical considerations might require further evaluation during the EE/CA or the design phase, as summarized below:

- **Stability of Containment Structure:** It is expected that a circular cell cofferdam constructed of steel sheet pile can be designed to meet the requirements for stability and durability. Proper sizing of the cofferdam and protection of the steel sheet piles would be refined during the EE/CA.

- **Floodway Analysis:** Based on the floodway analysis, the CDF would not increase the risk of flooding. A supporting analysis would need to be performed during the EE/CA using the conceptual CDF footprint.

- **Balanced Cut and Fill:** It will be necessary to negotiate mitigation measures within the same flood zone.

- **DSL Concurrence:** Negotiations with the state would be required during the EE/CA, but initial communications with DSL indicate that DSL concurrence is likely.

- **Other ARARs:** The EE/CA will include a full ARARs analysis.

- **Hydraulic Containment:** Hydraulic containment at the Site is achievable through implementation of the upland groundwater remedy and proper construction of the cofferdam enclosure. Recharge could be prevented by construction of a low-permeability surface cap. If necessary, further assessment of hydraulic containment could include groundwater flow computer modeling for fate and transport analysis as well as analysis of transient conditions and the necessity of using secondary containment. Secondary containment may involve groundwater extraction to counteract gradient reversals during extreme events.

- **Sediment Treatment:** Sediment treatment could present technical challenges, depending on the option, and cost implications. If necessary, treatability options may be further refined.

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Tables

Table 1

Willamette River Stage Data at Portland, Oregon (Water Years 1973–2003)

Preliminary CDF Screening Evaluation

Arkema Early Action

Portland, OR

Month	Minimum Monthly Stage (feet)	Mean Monthly Stage (feet)	Maximum Monthly Stage (feet)
October	6.4	8.0	12.2
November	6.6	9.8	22.5
December	7.2	11.8	21.6
January	7.6	12.2	27.7
February	7.5	12.2	32.2
March	7.6	12.0	19.3
April	7.0	11.7	22.4
May	6.1	12.9	22.4
June	7.0	13.0	23.5
July	6.1	9.8	14.6
August	6.2	8.6	11.6
September	6.1	8.2	11.1

Source: USACE 2004

Table 2

Simulations Run to Determine Impact

of the Conceptual CDF on a 100-year Flood Event

Preliminary CDF Screening Evaluation

Arkema Early Action

Portland, OR

Simulation	Plan Name	Description	Flow (cfs)
1	Arkema_existing_ND	Existing Conditions Model with normal depth downstream WSE (0.0021)	375,000
2	Arkema_upper_bound_ND	Proposed Conditions Model with normal depth downstream WSE (0.0021)	375,000
3	Arkema_existing_0	Existing Conditions Model with 0 feet NGVD 29 downstream WSE	375,000
4	Arkema_upper_bound_0	Proposed Conditions Model with 0 feet NGVD 29 downstream WSE	375,000
5	Arkema_existing_15	Existing Conditions Model with 15 feet NGVD 29 downstream WSE	375,000
6	Arkema_upper_bound_15	Proposed Conditions Model with 15 feet NGVD 29 downstream WSE	375,000
7	Arkema_existing_30	Existing Conditions Model with 30 feet NGVD 29 downstream WSE	375,000
8	Arkema_upper_bound_30	Proposed Conditions Model with 30 feet NGVD 29 downstream WSE	375,000

Notes:
NGVD 29 = National Geodetic Vertical Datum of 1929
WSE = water surface elevation
cfs = cubic feet per second

Table 3

Summary of Existing and Proposed Water Surface Elevations

Under a 100-year Flood Event and Various Downstream Boundary Conditions

Preliminary CDF Screening Evaluation

Arkema Early Action

Portland, OR

River Station[1]	Downstream Boundary Condition					
	Normal Depth			0 feet NGVD 29		
	Existing WSE	Proposed WSE	Difference in WSE	Existing WSE	Proposed WSE	Difference in WSE
1.170	-7.03	-7.04	-0.01	2.56	2.56	0.00
1.133	-7.10	-7.11	-0.01	2.53	2.52	-0.01
1.095	-7.18	-7.18	0.00	2.47	2.46	-0.01
1.057	-7.23	-7.23	0.00	2.43	2.42	-0.01
1.019	-7.30	-7.30	0.00	2.40	2.38	-0.02
0.981	-7.39	-7.39	0.00	2.35	2.34	-0.01
0.943	-7.66	-7.66	0.00	2.24	2.22	-0.02
0.905	-7.75	-7.75	0.00	2.20	2.18	-0.02
0.867	-7.88	-7.88	0.00	2.15	2.12	-0.03
0.830	-8.22	-8.22	0.00	2.00	2.00	0.00

Notes:
1. Representative sections presented through area of proposed CDF construction

NGVD 29 = National Geodetic Vertical Datum of 1929
WSE = water surface elevation

Table 3 (continued)

Summary of Existing and Proposed Water Surface Elevations

Under a 100-year Flood Event and Various Downstream Boundary Conditions

Preliminary CDF Screening Evaluation

Arkema Early Action

Portland, OR

River Station[1]	Downstream Boundary Condition					
	15 feet NGVD 29			30 feet NGVD 29		
	Existing WSE	Proposed WSE	Difference in WSE	Existing WSE	Proposed WSE	Difference in WSE
1.170	16.09	16.09	0.00	30.55	30.55	0.00
1.133	16.08	16.08	0.00	30.54	30.54	0.00
1.095	16.05	16.05	0.00	30.53	30.52	-0.01
1.057	16.01	16.00	-0.01	30.50	30.49	-0.01
1.019	15.99	15.98	-0.01	30.49	30.47	-0.02
0.981	15.98	15.96	-0.02	30.48	30.46	-0.02
0.943	15.93	15.91	-0.02	30.45	30.44	-0.01
0.905	15.92	15.89	-0.03	30.45	30.42	-0.03
0.867	15.90	15.87	-0.03	30.44	30.41	-0.03
0.830	15.83	15.83	0.00	30.40	30.40	0.00

Notes:
1. Representative sections presented through area of proposed CDF construction

NGVD 29 = National Geodetic Vertical Datum of 1929
WSE = water surface elevation

Table 4

Balanced Cut and Fill Analysis for

Two CDF Footprints

Preliminary CDF Screening Evaluation

Arkema Early Action

Portland, OR

Fill Element	Fill Quantity (cy)	
	One-Berth CDF Layout	Two Berth CDF Layout
Dredged Material	25,700	73,800
Cofferdam Cells	79,300	126,600
CDF Cap Material	15,900	40,300
Total Fill Quantity	120,900	240,700
Cut Element	**Cut Quantity (cy)**	
N/A	N/A	

Table 5

Summary of Treatment Technologies

Preliminary CDF Screening Evaluation

Arkema Early Action

Portland, OR

Treatment Technology	Treatment Location		Effectiveness on DDx	Effectiveness on Harborwide COIs	Implementability (Under Site Conditions)	Relative Cost	Sustainability of Technology
	Ex-Situ	In-Situ (in the CDF)					
Low-Temperature Thermal Desorption (LTTD)	X		High	Potentially Extremely Adverse	Low	High to Extreme	Low
Chemical Oxidation	X	X	Medium	Medium	Low to Medium	Medium to High	Low to Medium
Soil Mixing—Zero-Valent Iron and Clays	X	X	Medium	Medium to High	Medium	Medium to High	Medium
Soil Mixing—Solidification/Stabilization	X	X	High	Medium to High	Medium	Medium	Medium to High
Anaerobic Bioremediation	X	X	Low to Medium	Medium	Medium	Medium to High	Medium to High
Aerobic Bioremediation	X	X	Low	Low	Low	Medium to High	Medium to High
Sequenced Anaerobic-Aerobic Bioremediation	X	X	High	Medium to High	Medium	Medium to High	Low to Medium
Chemical Reduction		X	Medium	Low to Medium	Medium	Medium to High	Medium

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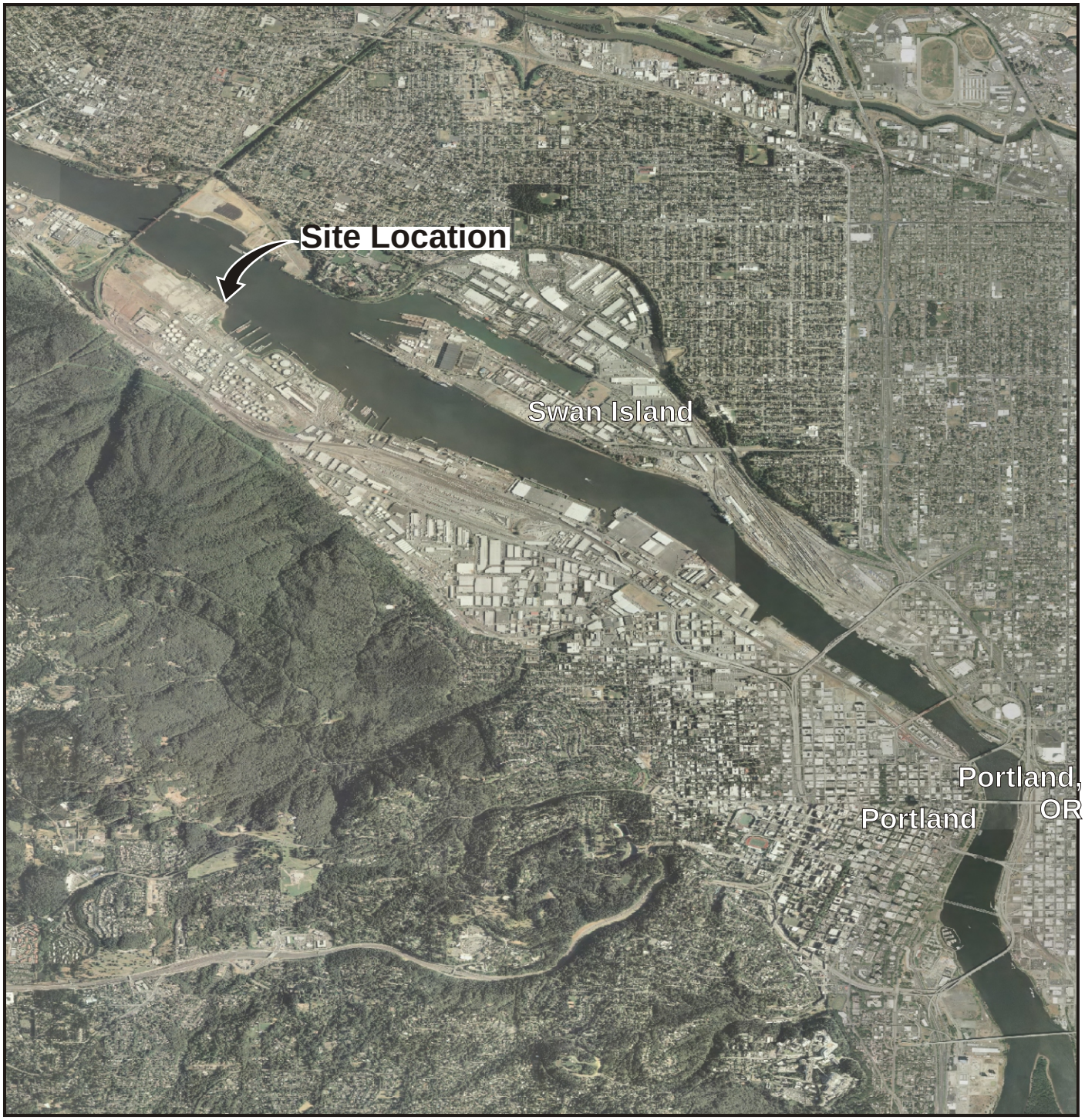
Figures



REFERENCE: HALF-METER 2005 IMAGERY DOWNLOADED FROM HTTP://WWW.OREGONEXPLORER.INFO/IMAGERY/.

Area Location

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

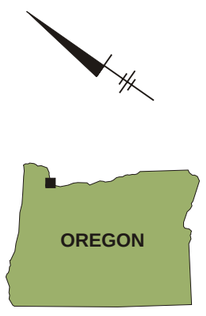
SITE VICINITY MAP

ARCADIS

FIGURE
1

09/08/09 SYRACUSE, NY-ENV/CAD-DJHOWES
MN000609/0001/00005/CDR/00609N03.CDR

REFERENCE: METRO REGIONAL GOVERNMENT. 2007. AERIAL PHOTOGRAPH OBTAINED FROM METRO REGIONAL GOVERNMENT, PORTLAND, OREGON



Area Location

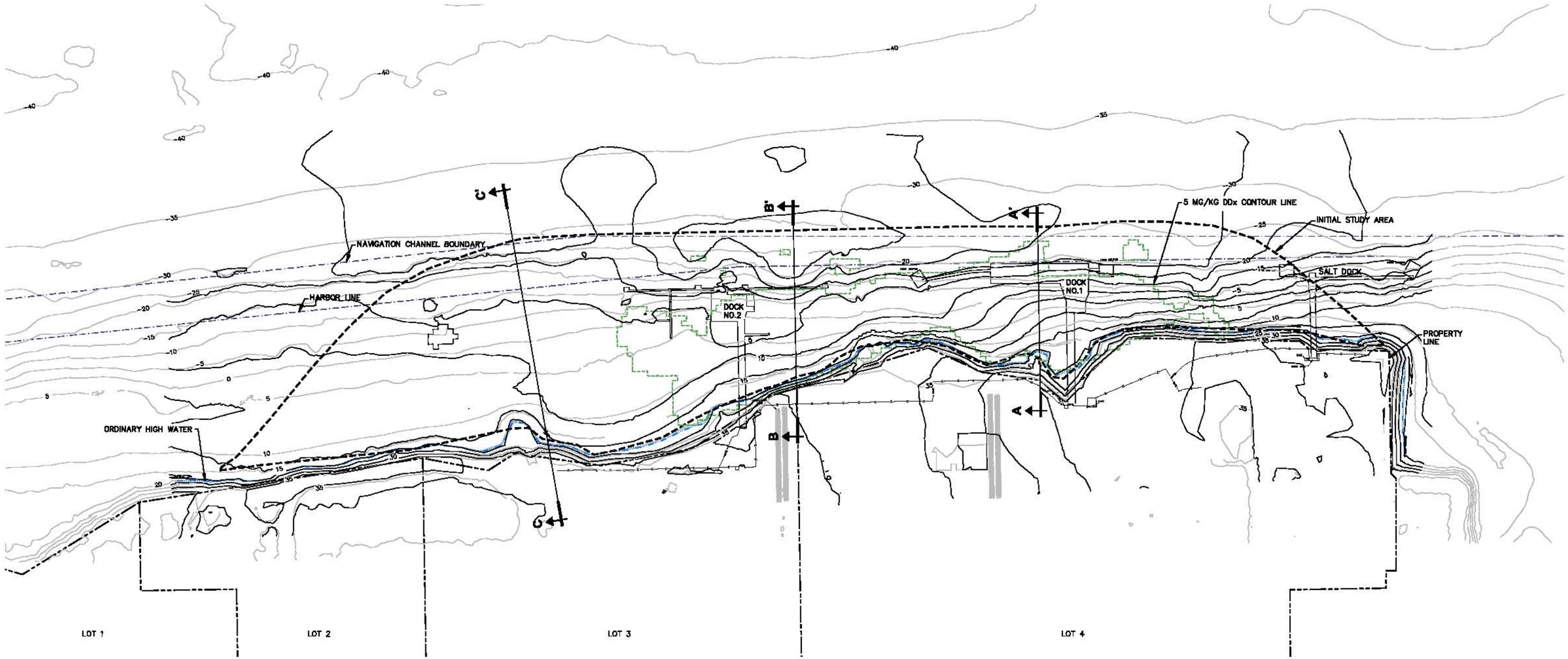
LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

SITE MAP

ARCADIS

FIGURE
2

09/17/09 SYRACUSE, NY-ENV/CAD-DJHOWES
MN000609/0001/00005/CDR/00609N04.CDR



NOTES:

1. THE 5 MG/KG DDx CONTOUR LINE AND BOTTOM OF THE ASSOCIATED PRELIMINARY REMOVAL VOLUME ARE BASED ON INFORMATION THAT WAS PROVIDED TO USEPA IN A LETTER FROM LEGACY SITE SERVICES LLC DATED JULY 25, 2008 (LSS RESPONSE TO JUNE 19, 2008 LETTER RE: ARKEMA CDF EVALUATION).
2. BATHYMETRIC AND TOPOGRAPHIC DATA WERE COLLECTED BY DAVID EVANS AND ASSOCIATES, INC. IN FEBRUARY 2004 AND MAY 2007, RESPECTIVELY. OLDER LIDAR DATA WERE USED TO FILL IN DATA GAPS BETWEEN THE BATHYMETRY AND THE TOPOGRAPHY DATA FOR VOLUME CALCULATIONS. THE LIDAR DATA WERE COLLECTED BY SPENCER B. GROSS, INC. IN DECEMBER 2001.
3. THE HORIZONTAL DATUM IS THE NORTH AMERICAN DATUM OF 1983 (NAD83), OREGON NORTH ZONE.
4. THE VERTICAL DATUM IS THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).

0 100' 200'
GRAPHIC SCALE

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

SITE PLAN

ARCADIS

FIGURE
3

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL K. SINSABAUGH LD: G. STEINBERGER PIC: (Opt) PM:(Req) TM: C. BECKER LYR: ON=*;OFF=*REF*
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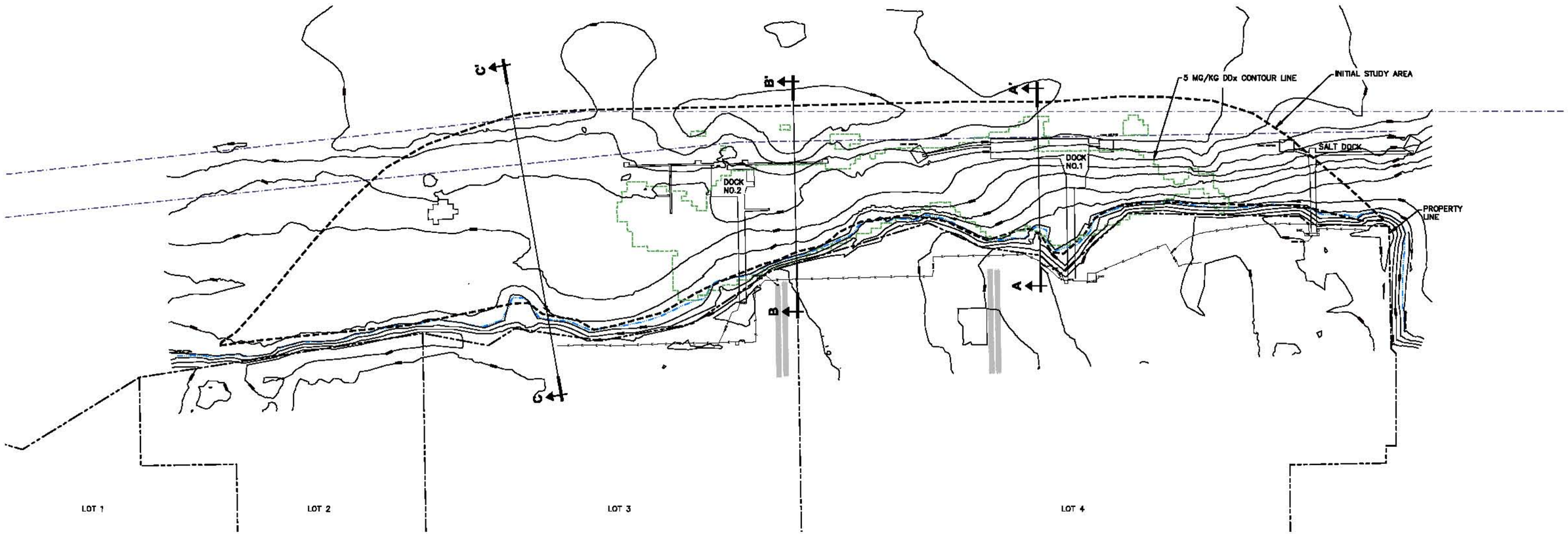

NOTES:

1. THE ISOPACH LINES SHOWN ON THIS FIGURE REPRESENT THE APPROXIMATE SEDIMENT/SOIL THICKNESS ABOVE BEDROCK IN FEET.
2. BEDROCK ELEVATIONS WERE PROVIDED BY INTEGRAL CONSULTING, INC. THE BEDROCK ELEVATIONS ARE APPROXIMATE AND WERE INFERRED FROM EXISTING BORINGS PERFORMED AT THE SITE.
3. BATHYMETRIC AND TOPOGRAPHIC DATA WERE COLLECTED BY DAVID EVANS AND ASSOCIATES, INC. IN FEBRUARY 2004 AND MAY 2007, RESPECTIVELY. OLDER LIDAR DATA WERE USED TO FILL IN DATA GAPS BETWEEN THE BATHYMETRY AND THE TOPOGRAPHY DATA FOR VOLUME CALCULATIONS. THE LIDAR DATA WERE COLLECTED BY SPENCER B. GROSS, INC. IN DECEMBER 2001.
4. THE 5 MG/KG DDx CONTOUR LINE AND BOTTOM OF THE ASSOCIATED PRELIMINARY REMOVAL VOLUME ARE BASED ON INFORMATION THAT WAS PROVIDED TO USEPA IN A LETTER FROM LEGACY SITE SERVICES LLC DATED JULY 25, 2008 (LSS RESPONSE TO JUNE 19, 2008 LETTER RE: ARKEMA CDF EVALUATION).

0 100' 200'
GRAPHIC SCALE

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

SEDIMENT/SOIL THICKNESS

ARCADIS

FIGURE
4

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL K. SINSABAUGH LD: G. STEINBERGER PIC: (Opt) PM:(Reqd) TM: C. BECKER LYR: ON=*;OFF=*REF
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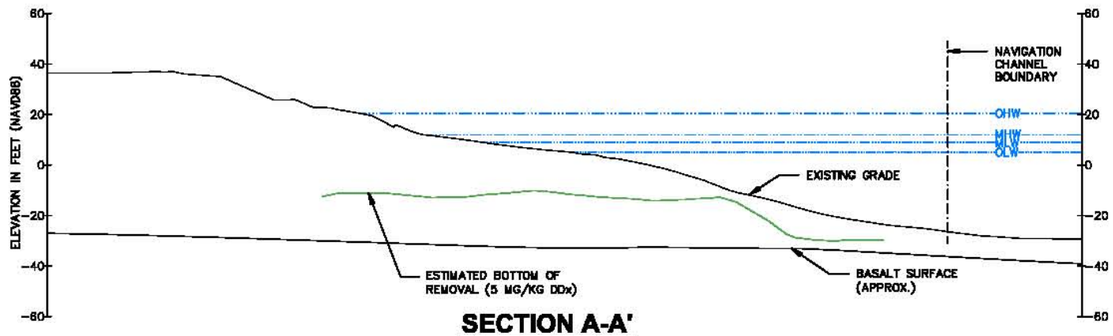
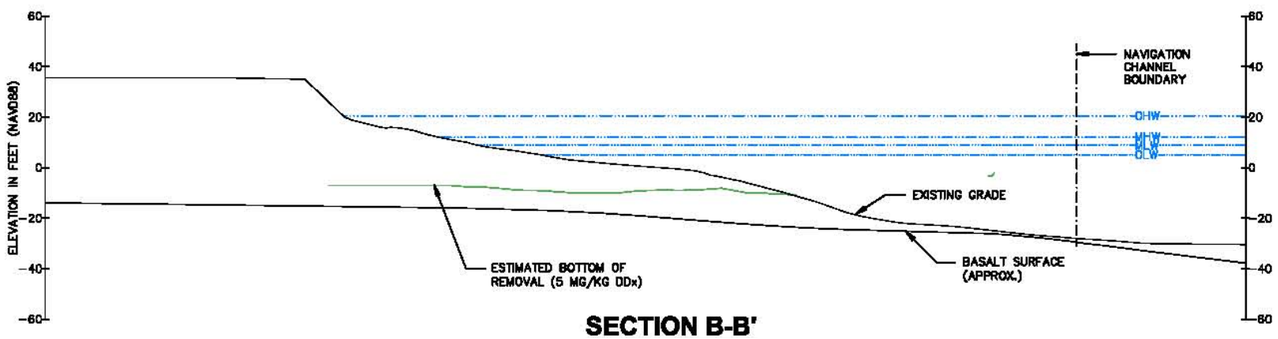
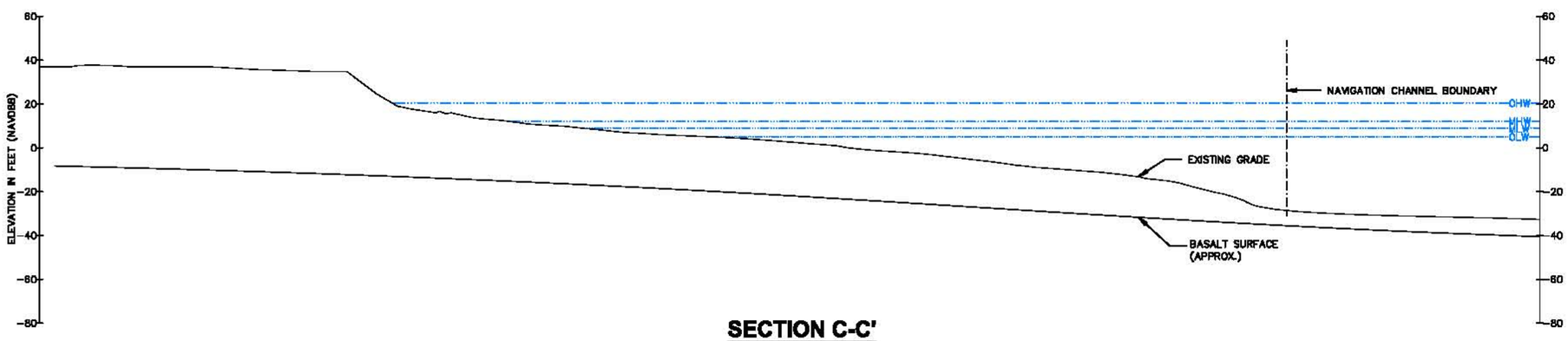


SECTION A-A'



SECTION B-B'



SECTION C-C'

NOTES:

1. WATER LEVELS IN NAVD88:
   OHW = 20.5 FEET
   MHW = 12.0 FEET
   MLW = 9.0 FEET
   OLW = 5.1 FEET
2. MEAN HIGH WATER (MHW) AND MEAN LOW WATER (MLW) WERE OBTAINED FROM THE 2007 EE/CA WORK PLAN. THE REFERENCE PROVIDED IN THE WORK PLAN IS: HTTP://WWW.NWD-WC.USACE.ARMY.MIL. MHW AND MLW ARE AVERAGES OF DAILY WATER LEVELS FROM JANUARY 1972 THROUGH DECEMBER 2005.
3. ORDINARY HIGH WATER (OHW) WAS OBTAINED FROM THE 2007 EE/CA WORK PLAN. BASED ON THE WORK PLAN, THE OHW WAS DELINEATED BY DAVID EVANS AND ASSOCIATES (DEA) IN APRIL 2006.
4. ORDINARY LOW WATER (OLW) WAS OBTAINED FROM THE WILLAMETTE RIVERBANK DESIGN NOTEBOOK: PORTLAND, OREGON, PUBLISHED BY CITY OF PORTLAND, OREGON, BUREAU OF ENVIRONMENTAL SERVICES, PORTLAND DEVELOPMENT COMMISSION (MAY 2001).

0 30' 60'
GRAPHIC SCALE

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

CROSS SECTIONS A-A', B-B', AND C-C' (EXISTING CONDITIONS)

ARCADIS

FIGURE
5

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL K. SINGABAUGH LD: G. STEINBERGER PIC: (Opt) PM: (Reqd) TM: C. BECKER LYR: ON=*;OFF=*REF
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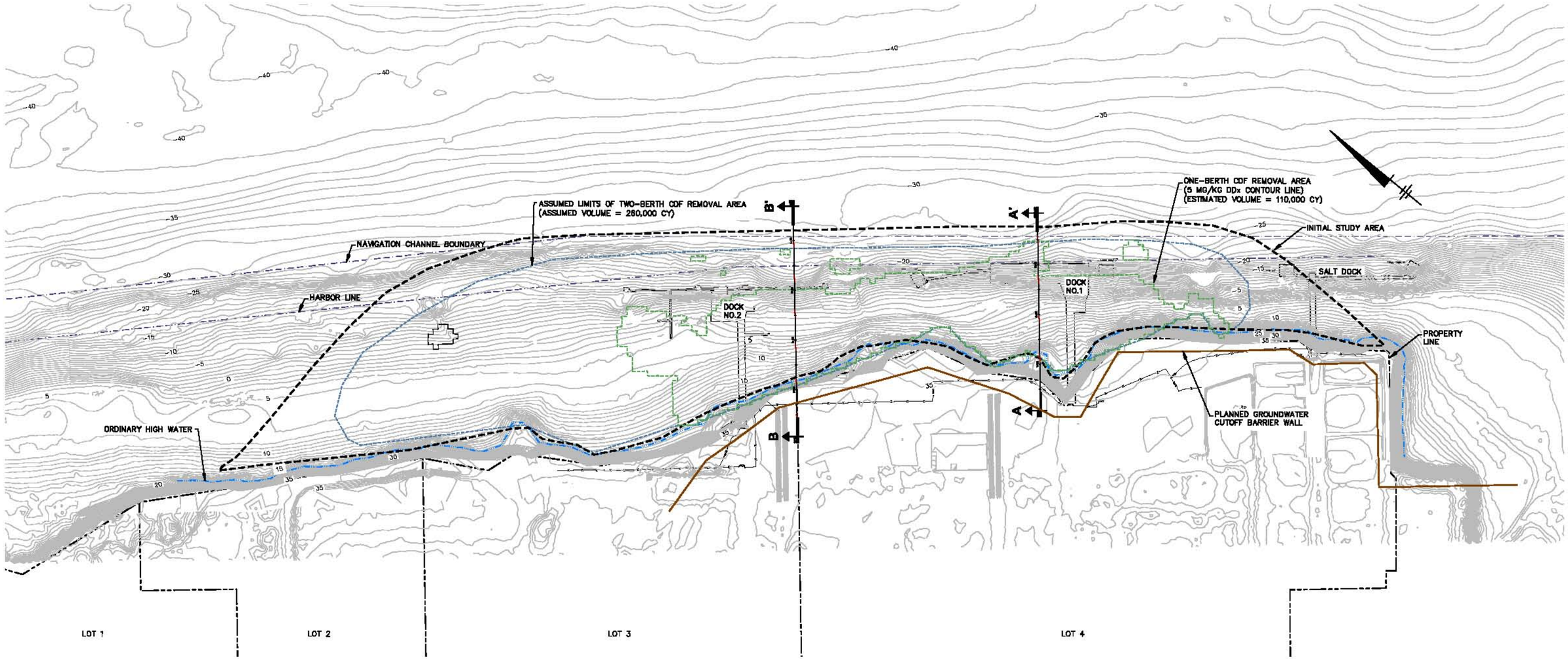

0 100' 200'
GRAPHIC SCALE

NOTES:

1. THE 5 MG/KG DDx CONTOUR LINE AND BOTTOM OF THE ASSOCIATED PRELIMINARY REMOVAL VOLUME ARE BASED ON INFORMATION THAT WAS PROVIDED TO USEPA IN A LETTER FROM LEGACY SITE SERVICES LLC DATED JULY 25, 2008 (LSS RESPONSE TO JUNE 19, 2008 LETTER RE: ARKEMA CDF EVALUATION).
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4. THE VERTICAL DATUM IS THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

ESTIMATED CDF SEDIMENT VOLUMES

ARCADIS

FIGURE
6

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL LD: G. STEINBERGER K. SINSABAUGH PIC: (Opt) PM:(Reqd) TM: C. BECKER LYR: ON=*;OFF=*REF
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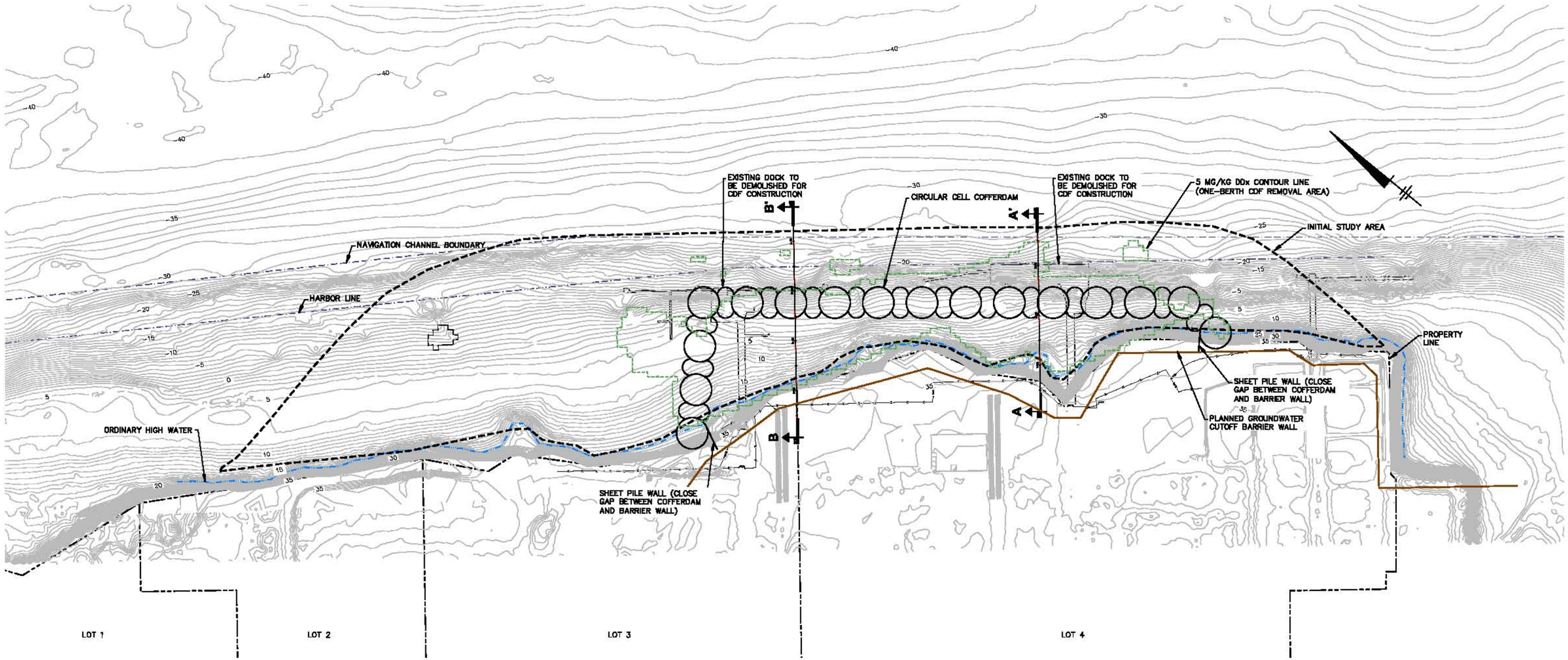

0 100' 200'
GRAPHIC SCALE

NOTES:

1. THE CIRCULAR CELL COFFERDAM STRUCTURE WILL NOT BE VISIBLE FROM ABOVE (I.E., IN PLAN VIEW) AFTER INSTALLATION OF A CAP AND PAVEMENT.
2. THE 5 MG/KG DDx CONTOUR LINE AND BOTTOM OF THE ASSOCIATED PRELIMINARY REMOVAL VOLUME ARE BASED ON INFORMATION THAT WAS PROVIDED TO USEPA IN A LETTER FROM LEGACY SITE SERVICES LLC DATED JULY 25, 2008 (LSS RESPONSE TO JUNE 19, 2008 LETTER RE: ARKEMA CDF EVALUATION).
3. BATHYMETRIC AND TOPOGRAPHIC DATA WERE COLLECTED BY DAVID EVANS AND ASSOCIATES, INC. IN FEBRUARY 2004 AND MAY 2007, RESPECTIVELY. OLDER LIDAR DATA WERE USED TO FILL IN DATA GAPS BETWEEN THE BATHYMETRY AND THE TOPOGRAPHY DATA FOR VOLUME CALCULATIONS. THE LIDAR DATA WERE COLLECTED BY SPENCER B. GROSS, INC. IN DECEMBER 2001.
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5. THE VERTICAL DATUM IS THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

CONCEPTUAL ONE-BERTH CDF LAYOUT

ARCADIS

FIGURE
7

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL LD: G. STEINBERGER K. SINSABAUGH PIC: (Opt) PM:(Reqd) TM: C. BECKER LYR: ON=*;OFF=REF
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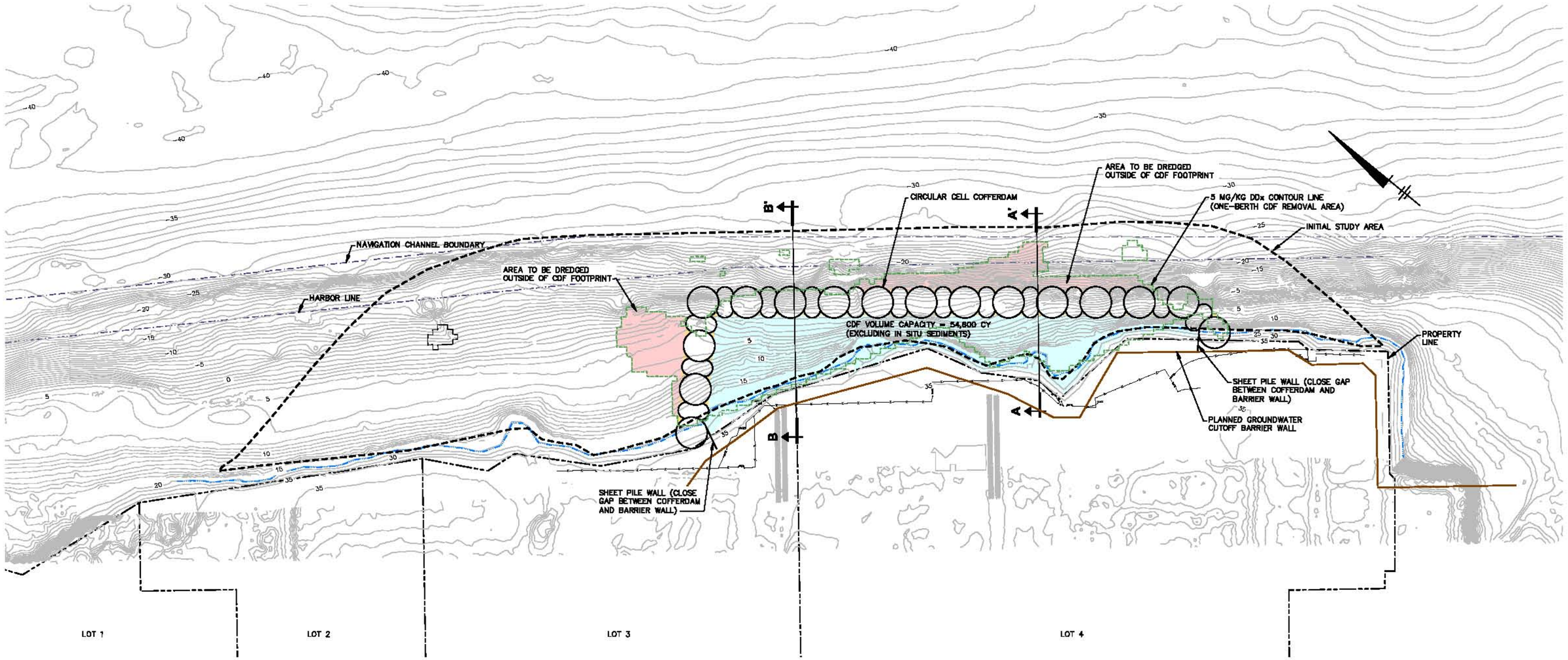

DREDGE VOLUME	=	41,900 CY
TOTAL DREDGE VOLUME INCLUDING 10% OVERDREDGE	=	46,000 CY
CDF VOLUME CAPACITY (EXCLUDING IN SITU SEDIMENTS CONTAINED WITHIN THE CDF FOOTPRINT)	=	54,600 CY
TOTAL CDF VOLUME CAPACITY	=	110,000 CY

NOTES:

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2. THE 5 MG/KG DDx CONTOUR LINE AND BOTTOM OF THE ASSOCIATED PRELIMINARY REMOVAL VOLUME ARE BASED ON INFORMATION THAT WAS PROVIDED TO USEPA IN A LETTER FROM LEGACY SITE SERVICES LLC DATED JULY 25, 2008 (LSS RESPONSE TO JUNE 19, 2008 LETTER RE: ARKEMA CDF EVALUATION).
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5. THE VERTICAL DATUM IS THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).

0 100' 200'
GRAPHIC SCALE

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

ONE-BERTH CDF VOLUMES

ARCADIS

FIGURE
8

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL K.SINSABAUGH LD: G. STEINBERGER PIC: (Opt) PM: (Reqd) TM: C. BECKER LYR: ON=*;OFF=*REF
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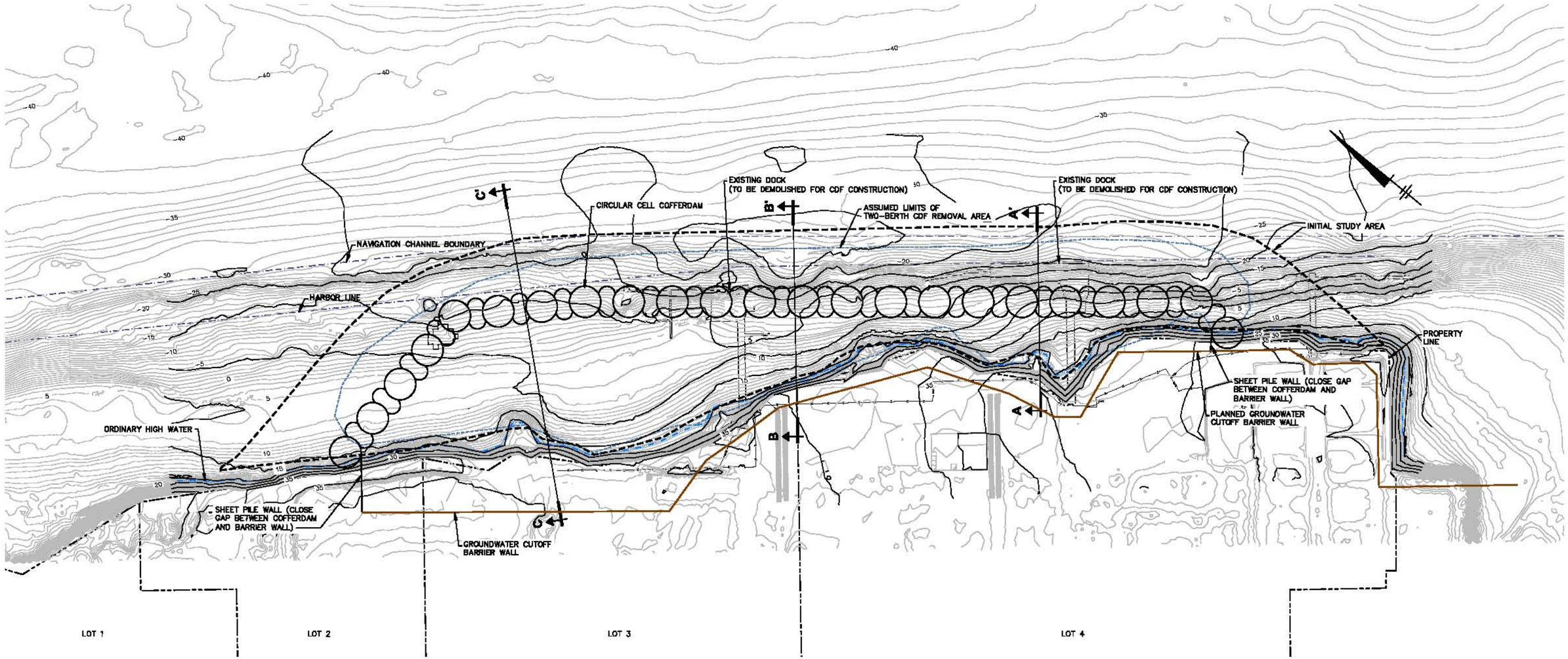

NOTES:

1. THE CIRCULAR CELL COFFERDAM STRUCTURE WILL NOT BE VISIBLE FROM ABOVE (I.E., IN PLAN VIEW) AFTER INSTALLATION OF A CAP AND PAVEMENT.
2. BATHYMETRIC AND TOPOGRAPHIC DATA WERE COLLECTED BY DAVID EVANS AND ASSOCIATES, INC. IN FEBRUARY 2004 AND MAY 2007, RESPECTIVELY. OLDER LIDAR DATA WERE USED TO FILL IN DATA GAPS BETWEEN THE BATHYMETRY AND THE TOPOGRAPHY DATA FOR VOLUME CALCULATIONS. THE LIDAR DATA WERE COLLECTED BY SPENCER B. GROSS, INC. IN DECEMBER 2001.
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LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

CONCEPTUAL TWO-BERTH CDF LAYOUT

ARCADIS

FIGURE
9

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL K.SINSABAUGH LD: G. STEINBERGER PIC: (Opt) PM: (Reqd) TM: C. BECKER LYR: ON=*;OFF=*REF
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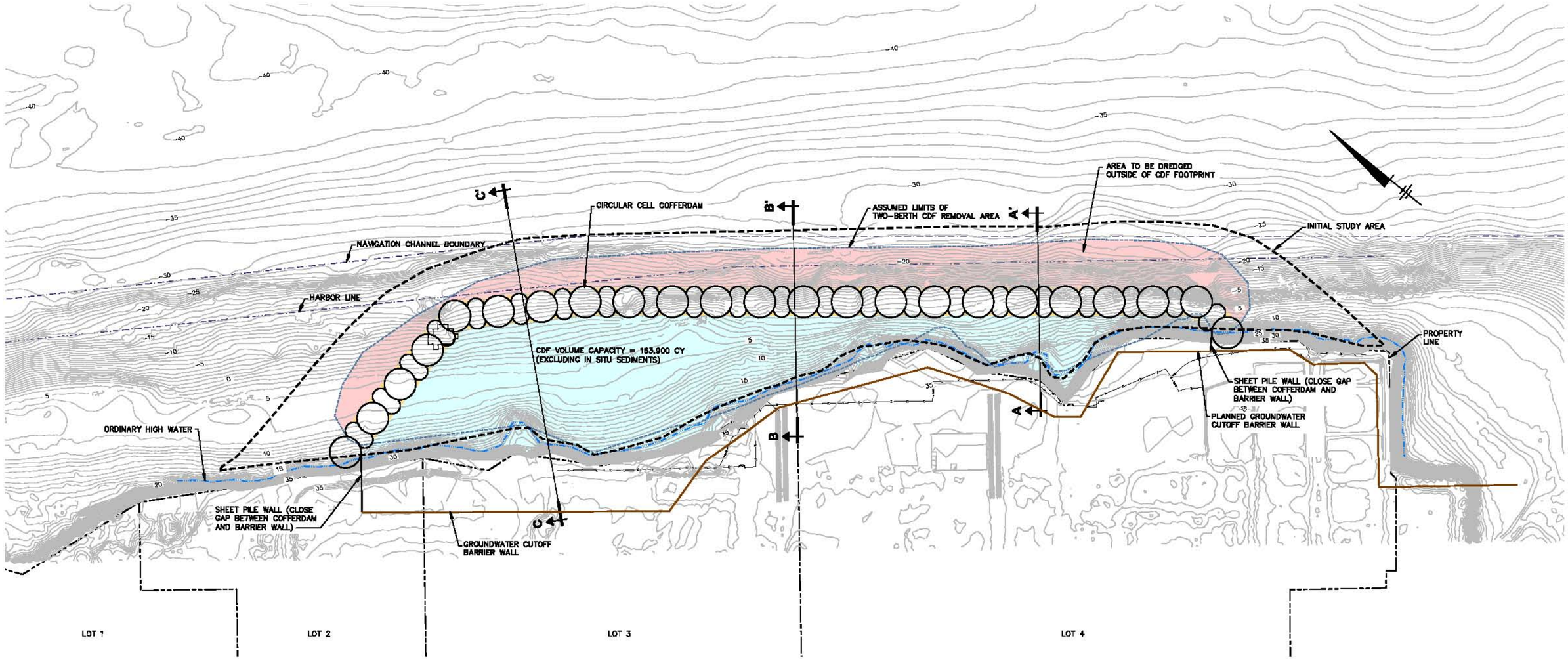

DREDGE VOLUME	= 135,500 CY
TOTAL DREDGE VOLUME INCLUDING 10% OVERDREDGE	= 149,000 CY
CDF VOLUME CAPACITY (EXCLUDING IN SITU SEDIMENTS CONTAINED WITHIN THE CDF FOOTPRINT)	= 163,900 CY
TOTAL CDF VOLUME CAPACITY	= 260,000 CY

NOTES:

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0 100' 200'
GRAPHIC SCALE

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

TWO-BERTH CDF VOLUMES

ARCADIS

FIGURE
10

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL K. SINSABAUGH LD: G. STEINBERGER PIC: (Opt) PM: (Reqd) TM: C. BECKER LYR: ON=*;OFF=*REF
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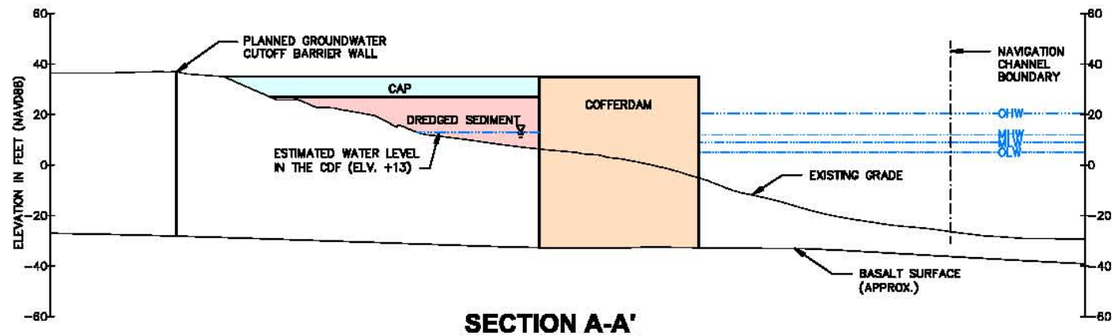
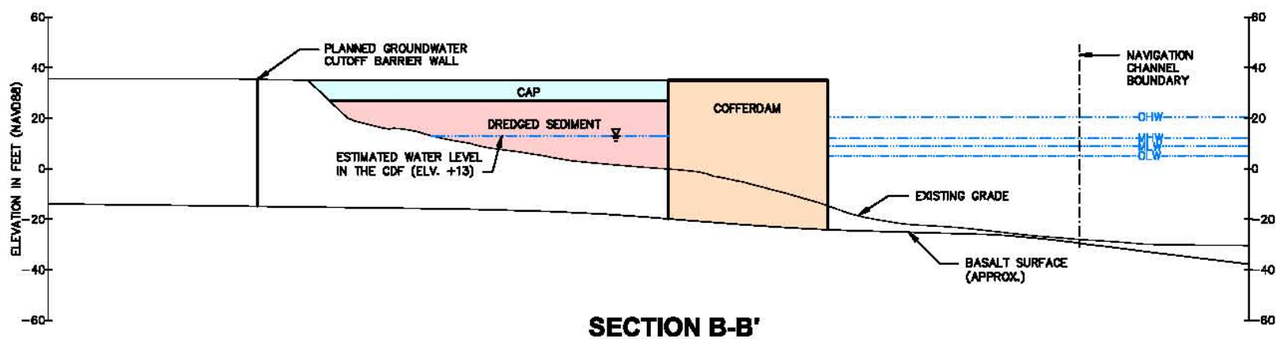
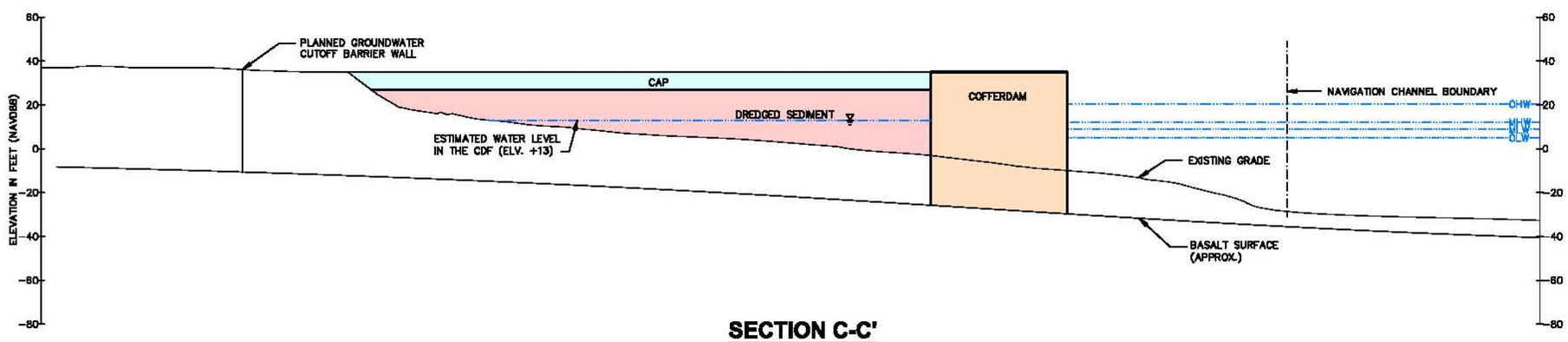


SECTION A-A'



SECTION B-B'



SECTION C-C'

NOTES:

1. WATER LEVELS IN NAVD88:
   OHW = 20.5 FEET
   MHW = 12.0 FEET
   MLW = 9.0 FEET
   OLW = 5.1 FEET
2. MEAN HIGH WATER (MHW) AND MEAN LOW WATER (MLW) WERE OBTAINED FROM THE 2007 EE/CA WORK PLAN. THE REFERENCE PROVIDED IN THE WORK PLAN IS:
   HTTP://WWW.NWD-WC.USACE.ARMY.MIL.
   MHW AND MLW ARE AVERAGES OF DAILY WATER LEVELS FROM JANUARY 1972 THROUGH DECEMBER 2005.
3. ORDINARY HIGH WATER (OHW) WAS OBTAINED FROM THE 2007 EE/CA WORK PLAN. BASED ON THE WORK PLAN, THE OHW WAS DELINEATED BY DAVID EVANS AND ASSOCIATES (DEA) IN APRIL 2006.
4. ORDINARY LOW WATER (OLW) WAS OBTAINED FROM THE WILLAMETTE RIVERBANK DESIGN NOTEBOOK: PORTLAND, OREGON, PUBLISHED BY CITY OF PORTLAND. OREGON, BUREAU OF ENVIRONMENTAL SERVICES, PORTLAND DEVELOPMENT COMMISSION (MAY 2001).

0 30' 60'
GRAPHIC SCALE

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

CDF CROSS SECTIONS A-A', B-B', AND C-C'

ARCADIS

FIGURE
11

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL K. SINGABAUGH LD: G. STEINBERGER PIC: (Opt) PM: (Reqd) TM: C. BECKER LYR: ON=*;OFF=REF
G:\ENVCAD\SYRACUSE\ACT\MN0000200\0001\00005\CTV\MN000G11.dwg LAYOUT: 11 SAVED: 5/10/2010 2:47 PM ACADVER: 17.0S (LMS TECH) PAGESETUP: ---- PLOTSTYLETABLE: PLTFULL.CTB PLOTTED: 6/10/2010 2:47 PM BY: SINGABAUGH, KATE
XREFS: MN0000001 MN0000000 MN0000002 IMAGES: PROJECTNAME: ----

LEGEND:

HEC–RAS CROSS SECTION WITH SECTION ID (SHOWING APPROXIMATE MILEAGE)

DIRECTION OF FLOW

NOTE:

1. 2005 AERIAL IMAGERY PROVIDED BY INTEGRAL CONSULTING, INC. IMAGE IN OREGON STATE PLANE NORTH HARN.

NOT TO SCALE

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

LOCATIONS OF CROSS SECTIONS PROVIDING DATA FOR HYDRAULIC MODELING

ARCADIS

FIGURE
12

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DS: K. DAVIS K.SINSABAUGH LD: G. STEINBERGER PIC: (Opt) PM: (Reqd) TM: C. BECKER LYR:ON=*;OFF=*REF*
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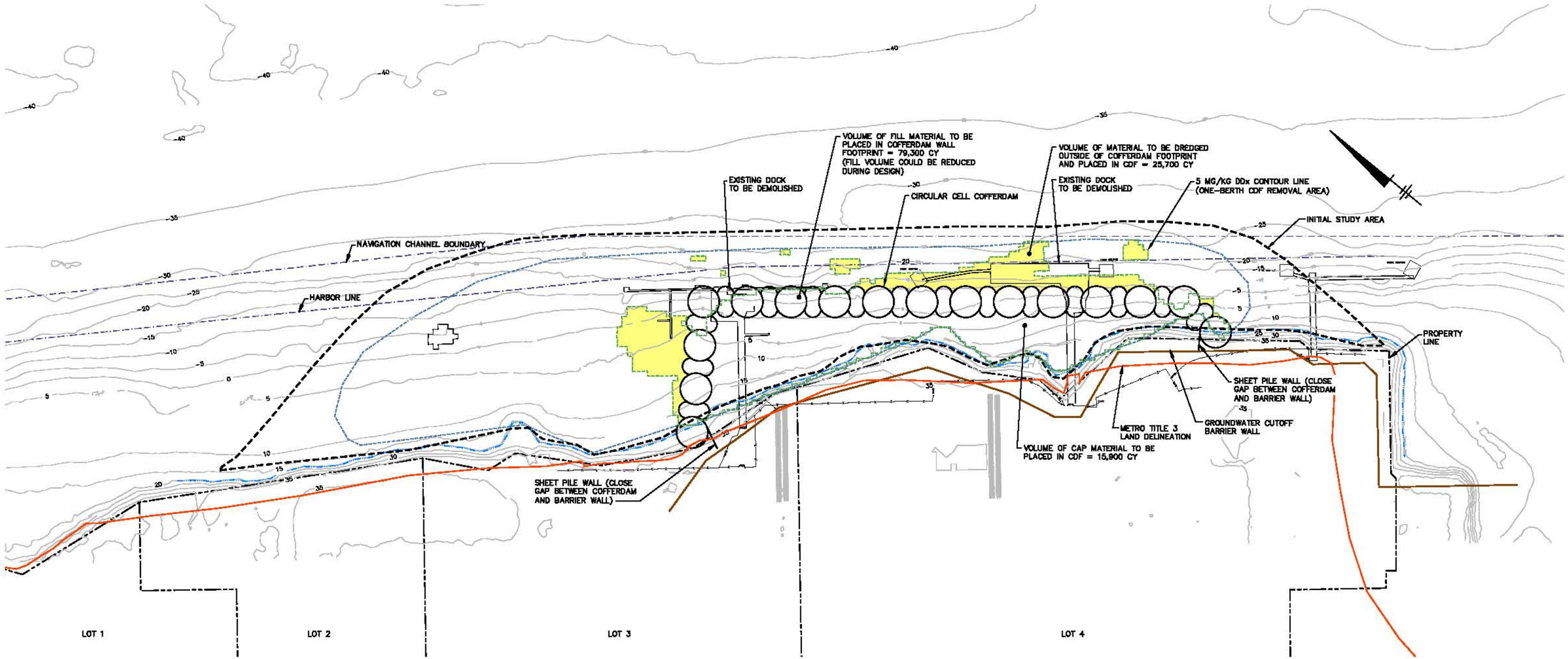

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5. THE VERTICAL DATUM IS THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).
6. METRO TITLE 3 LAND DELINEATION PROVIDED BY METRO DATA RESOURCE CENTER, PUBLISHED JULY 1, 2008.
7. FILL VOLUMES CALCULATED FROM EXISTING MUDLINE TO BASE FLOOD ELEVATION OF +31 FEET NAVD 88.
8. DREDGE VOLUMES ASSUME A REMOVAL THICKNESS OF 15 FEET WITHIN THE AREAS SHOWN.

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

BALANCED CUT AND FILL ONE-BERTH CDF

ARCADIS

FIGURE
13

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL K.DAVIS K. SINSABAUGH LD: G. STEINBERGER PIC: (Opt) PM: (Reqd) TM: C. BECKER LYR: ON*-OFF-REF*
G:\ENVCAD\SYRACUSE\EACTM\N0000609\0010000\5CVM\N0000613.dwg LAYOUT: 13 SAVED: 8/10/2010 2:48 PM ACADVER: 17.0S (LMS TECH) PAGESETUP: ---- PLOTSTYLETABLE: PLTFULL.CTB PLOTTED: 8/10/2010 2:48 PM BY: SINSABAUGH, KATE
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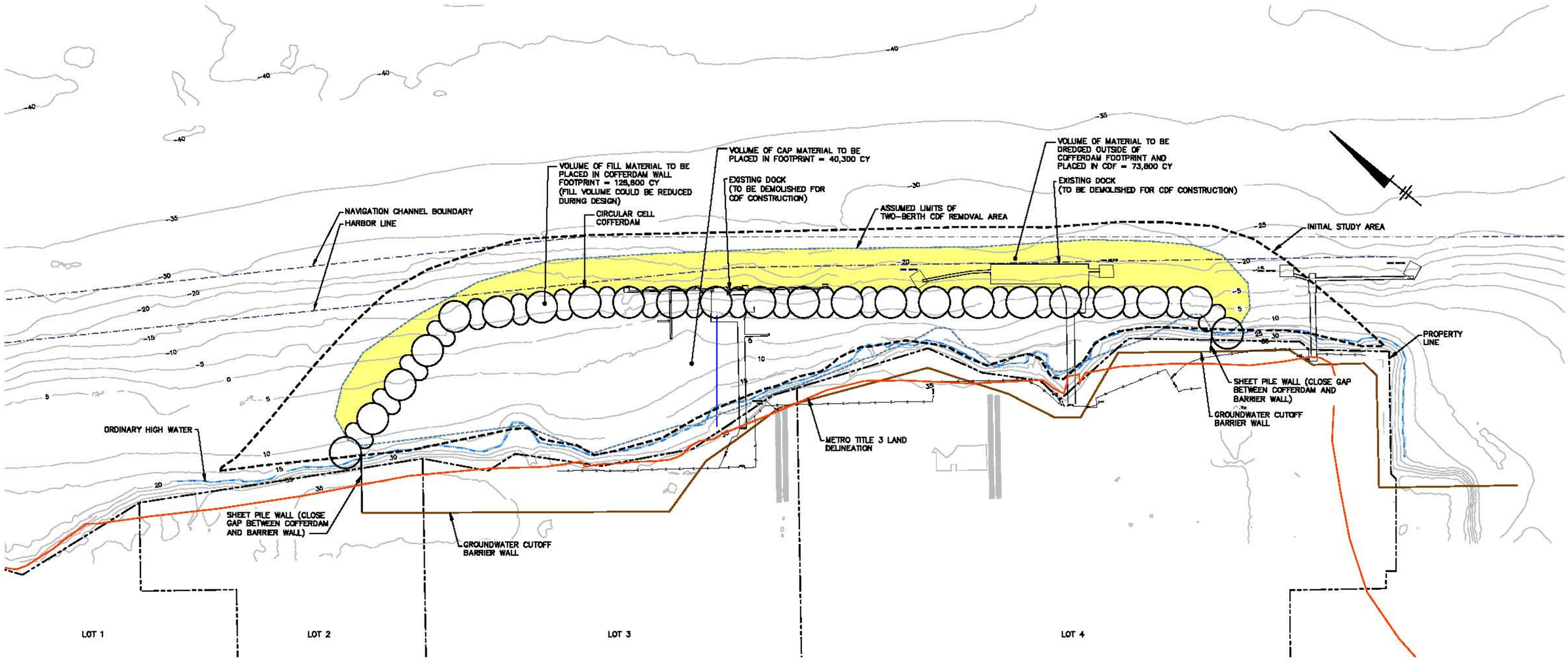

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LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

BALANCED CUT AND FILL TWO-BERTH CDF

ARCADIS

FIGURE
14

CITY: SYRACUSE, NY DIV/GROUP: ENVCAD DB: G. STEINBERGER N.SMITHGALL K.DAVIS K. SINSABAUGH LD: G. STEINBERGER PIC: (Opt) PM: (Reqd) TM: C. BECKER LYR: ON=*;OFF=*REF*
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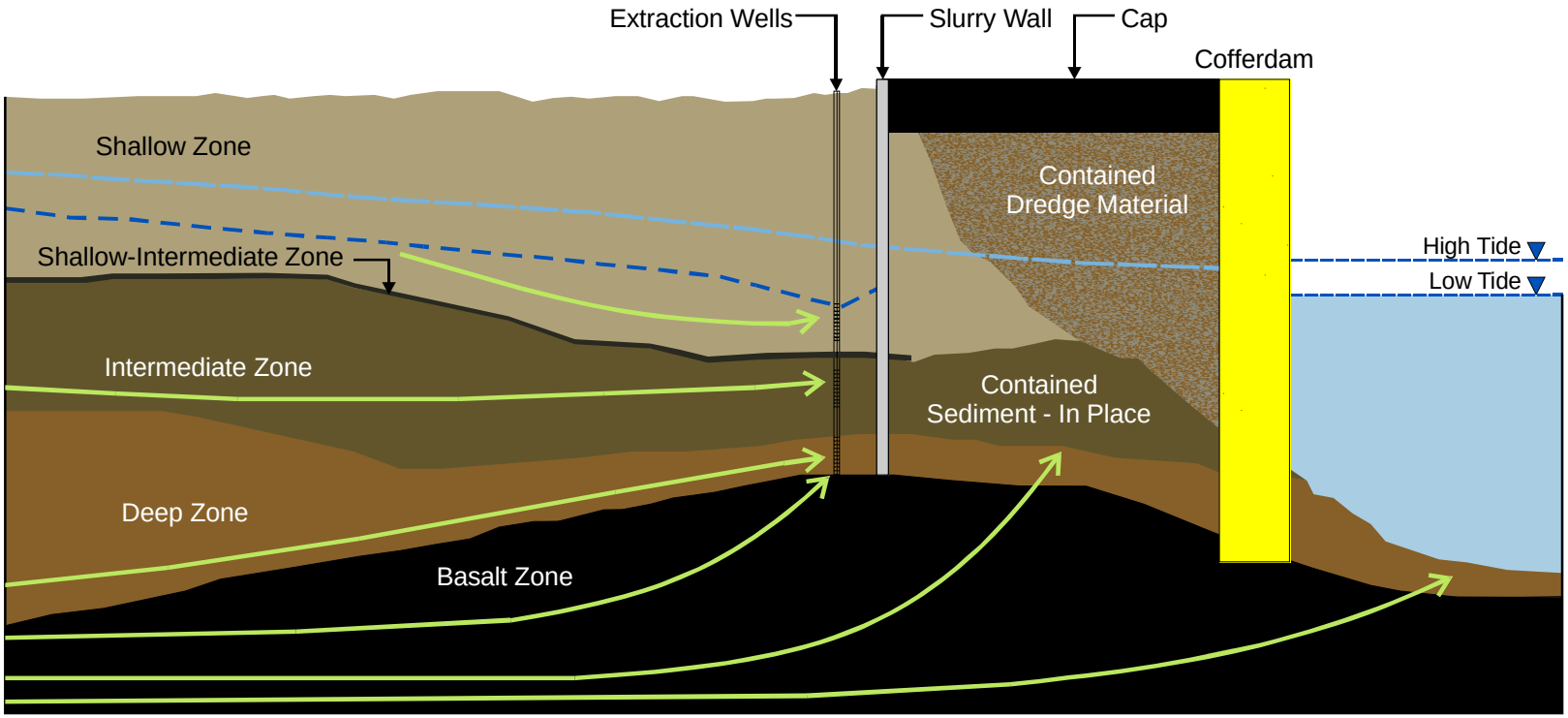

NOTE: NOT TO SCALE

LEGEND:

= POTENTIOMETRIC HEAD IN BASALT ZONE

= POTENTIOMETRIC HEAD IN SHALLOW, INTERMEDIATE, AND DEEP ZONES

= CONCEPTUAL FLOW PATHS

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

CONCEPTUAL SITE MODEL

ARCADIS

FIGURE
15

Appendix A

CDF Wall Stability Analysis

1. Introduction

In the main text of the confined disposal facility (CDF) screening evaluation, ARCADIS concluded that a feasible CDF containment structure for the Arkema Portland Site (the Site) is a circular cell cofferdam. The purpose of the preliminary, conceptual-level design analysis of CDF wall stability presented here is to determine the appropriate size for the cofferdam structure.

2. Methodology

A circular cell cofferdam essentially acts as a gravity structure, which resists lateral loads by the use of its own weight. The weight of the structure counteracts lateral loads that could result in overturning or sliding of the structure. In the conceptual-level design analysis conducted for this screening evaluation, only overturning and sliding of the structure were analyzed. These steps generally provide the effective width of the structure necessary to resist the design loads.

Sliding and overturning were analyzed using the methods provided in the Naval Facilities Engineering Command's Design Manual 7.02 (NAVFAC 1986). These methods are relatively simple limit-equilibrium analyses for gravity structures and were performed using Microsoft Excel spreadsheet calculations. Other steps in the analysis, such as interlock tension, vertical shear on centerline, tilting, and shear at the cell fill-sheet pile interface, would be performed during the design phase.

3. Assumptions

3.1 Generalized Subsurface Conditions

A subsurface investigation was performed in 2003 that included 25 direct-push explorations (Integral Consulting 2003). These explorations provided sediment descriptions and general stratigraphy, but no standard penetration test results or soil properties, such as soil shear strength and Atterberg limits. (These additional tests are being performed as part of the current site characterization work.)

The following geologic units were identified in those in-water explorations:

- **River sediment.** Based on the visual description recorded on the exploration logs, the river sediment consists of sandy silt and silty sand. The thickness of the sediment layer varies between approximately 20 and 30 feet within the CDF footprint. Sediment thickness along the CDF wall appears to range from 20 to 22 feet, with thickness decreasing significantly near the navigation channel to about 4 to 8 feet.

- **Basalt bedrock.** The river sediment is underlain by relatively shallow basalt bedrock.

3.2 Design Cross Section

A critical section along the cofferdam alignment was identified based on available bathymetry and subsurface information. The conceptual design cross section that was used for the analysis is shown on Figure A-1. ARCADIS has conservatively assumed that the sediment on the river side of the structure would be dredged to bedrock.

3.3 Soil Parameters

For the conceptual-level design analysis, ARCADIS selected soil parameters on the basis of engineering judgment and in the expectation that design-level data will be available during later design stages. Soil parameters based on engineering judgment are considered appropriate for preliminary sizing of the cofferdam. Soil parameters used in the analyses are provided in Table A-1.

Table A-1. Soil Parameters for Conceptual Cofferdam Design

Soil Unit	Sand Cap	Granular Fill	Dredged Sediment	Existing Sediment
Total Unit Weight, γ_T (pounds per cubic foot)	120	120	100	90
Angle of Internal Friction, ϕ' (degrees)	36	34	30	32

3.4 Seismic Design Criteria

The Site is located in a seismically active region of the Pacific Northwest. It is assumed that the CDF would be designed to meet the same seismic design criteria as the CDF planned for the Port of Portland's Terminal 4 (Anchor 2006), which is approximately 2.5 miles from the Site. Therefore, the conceptual-level seismic design analysis (pseudostatic analysis only) was performed for the contingency-level event (CLE), which corresponds to an earthquake with a 10 percent probability of exceedance in 50 years (i.e., a 475-year return period). During the CLE, waterfront facilities could suffer significant damage that would impair operations, and major repair work would likely be required, but no catastrophic failure should develop. Although design components such as a CDF containment structure may suffer substantial deformation, containment of the impacted sediment should not be jeopardized.

3.4.1 Estimated Seismic Hazard

A peak ground acceleration (PGA) for rock outcrop of 0.2g (g = acceleration of gravity) was used for the analysis of the proposed CDF cofferdam. This PGA was estimated using the corresponding seismic hazard maps from the 2002 U.S. Geological Survey (USGS) National Seismic Hazard Mapping Project (USGS 2002). (Although the 2008 USGS seismic hazard maps [USGS 2008] show a slightly smaller PGA for the Site of 0.185g, a PGA of 0.2g for rock outcrop was used for the conceptual-level design analysis to be conservative.) This acceleration was further modified to account for amplification using amplification factors provided in Stewart et al. (2003). Assuming Site Class D, the PGA at the top of the CDF was estimated to be 0.24g.

3.5 Factors of Safety

Factors of safety for static conditions generally were adopted from NAVFAC (1986). The selection of appropriate seismic factors of safety generally is more complex and involves some engineering judgment. For the conceptual-level design analysis, however, only a pseudostatic analysis was performed. More sophisticated analyses could be performed at more advanced design stages.

For a pseudostatic analysis, it is necessary to select an appropriate pseudostatic coefficient in combination with appropriate factors of safety. Kramer (1996) suggests that for design based on seismic pressure (i.e., a pseudostatic analysis, instead of an analysis of displacement), pseudostatic acceleration values generally are considerably smaller than anticipated PGAs. Additionally, Kramer (1996) states that values between 0.05 and 0.15g, corresponding to one-third to one-half of the PGA, are commonly used with factors of safety of 1.0 to 1.2. For the conceptual-level design analysis, a conservative approach was selected by combining the full estimated PGA with a factor of safety of 1.2 for sliding. The factor of safety for overturning is generally larger than that for sliding. Therefore, a minimum factor of safety of 2 was selected for overturning under seismic conditions. The factors of safety used in the analysis are summarized in Table A-2.

Table A-2. Factors of Safety

Loading Case	Factor of Safety
Overturning (Static)	3.0
Overturning (Seismic)	2.0
Sliding (Static)	1.5
Sliding (Seismic)	1.2

3.6 Design Loads

The following loads were applied for the conceptual-level design analysis:

- Static earth pressures
- Hydrostatic pressure

- Surcharge load
- Dynamic earth pressure due to a CLE

3.6.1 Static Earth Pressures

Static earth pressures were calculated using Rankine earth pressure theory. Only active earth pressures were used. It was assumed that the sediment on the river side of the cofferdam would be dredged to bedrock. Thus, no passive resistance was used to counteract sliding toward the river.

3.6.2 Hydrostatic Loads

Hydrostatic loads on the wall depend on the water levels within the CDF and in the river. Water level differentials that act toward the CDF wall were not considered at this time, but may need to be considered during subsequent design stages to take into account high river stages during construction. Contingency measures, such as flooding of the enclosed area, may be used to counteract large hydrostatic loads pushing toward the CDF. For the conceptual-level design analysis, only relatively common water levels were considered. During subsequent design stages, unusual and extreme events would also be considered. The use of lower factors of safety would be appropriate for events that have a low frequency of occurrence.

River stage data provided by the U.S. Army Corps of Engineers (USACE 2004) were used to select appropriate water levels for the conceptual-level design analysis. The river stages for water years 1973 through 2003 are provided in Table A-3.

Table A-3. Willamette River Stage Data at Portland, Oregon (Water Years 1973–2003

Month	Minimum Monthly Stage (feet)	Mean Monthly Stage (feet)	Maximum Monthly Stage (feet)
October	6.4	8.0	12.2
November	6.6	9.8	22.5
December	7.2	11.8	21.6
January	7.6	12.2	27.7
February	7.5	12.2	32.2
March	7.6	12.0	19.3
April	7.0	11.7	22.4
May	6.1	12.9	22.4
June	7.0	13.0	23.5
July	6.1	9.8	14.6
August	6.2	8.6	11.6
September	6.1	8.2	11.1

Source: USACE 2004
Elevations in North American Vertical Datum of 1988 (NAVD 88)

For the conceptual-level design analysis, a low river stage elevation of +6 feet NAVD 88 was combined with a water level within the CDF of +8 feet NAVD 88.

3.7 Surcharge Load

A uniform surcharge load of 1,000 pounds per square foot (psf) was assumed for the conceptual-level design analysis. This represents an average load for container facilities (Gaythwaite 2004). Live loads for general cargo facilities range from 500 to 1,000 psf. Bulk cargo typically requires the use of higher surcharge loads of 1,000 to 3,000 psf. Such materials would need to be stored farther upland to avoid movement of the cofferdam wall.

3.8 Dynamic Thrust

The dynamic thrust was calculated using the following equation developed by Seed and Whitman (1970):

$P_E = (3/8)\ (a_{max}/g)\ H^2\ \gamma_t$

Where a_{max} = maximum ground acceleration, g = acceleration of gravity, H = height of soil retained behind the cofferdam, and γ_t = total bulk density of the retained soil. The dynamic thrust was assumed to act at a height of 0.6H above the base of the wall.

The equation developed by Seed and Whitman (1970) was selected because it is relatively simple to use in a spreadsheet calculation. Dynamic thrust was also calculated using the Mononobe-Okabe method (Okabe 1926; Mononobe and Matsuo 1929) to verify that the equation by Seed and Whitman (1970) provides reasonable values of dynamic thrust. The values from these two methods generally compare well with one another.

The full PGA of 0.24g was used to calculate the dynamic thrust. As outlined above (Section 3.5), this is a conservative approach according to Kramer (1996).

4. Results and Conclusions

Based on the conceptual-level design analyses discussed here, an effective cofferdam width of 54 feet would be required to meet the minimum factors of safety for sliding and overturning provided in Table A-2. A circular cell cofferdam structure can be sized to meet the demands of the Site and is generally considered a feasible CDF option. It should be noted that these analyses are not comprehensive and design criteria and loads may change during subsequent design stages. The purpose of the conceptual-level design is only to provide some level of confidence that a suitable containment structure can be designed for the Site.

For subsequent design stages, data gaps would need to be closed and design criteria would need to be refined prior to additional analyses. Existing data gaps include engineering properties of the sediment. Additional geotechnical data have been collected as part of the site characterization work for the engineering evaluation/cost analysis to further evaluate the feasibility of the proposed CDF.

Additional analyses would need to be performed and additional load cases considered to properly size the cofferdam. If assumptions and design criteria change during subsequent design stages, the size of the structure can be adjusted to meet the load requirements.

Generally, gravity structures have performed quite well in earthquakes, which may be associated with the relatively conservative static design approach traditionally used for these structures (Kramer 1996). The potential for earthquake-induced liquefaction would be evaluated during subsequent design stages. Some liquefaction in the material retained in the CDF is not currently expected to result in significant damage to the cofferdam during design-level events. Some repair of the asphalt cap within the CDF footprint may be required following events of strong seismic shaking.

5. References

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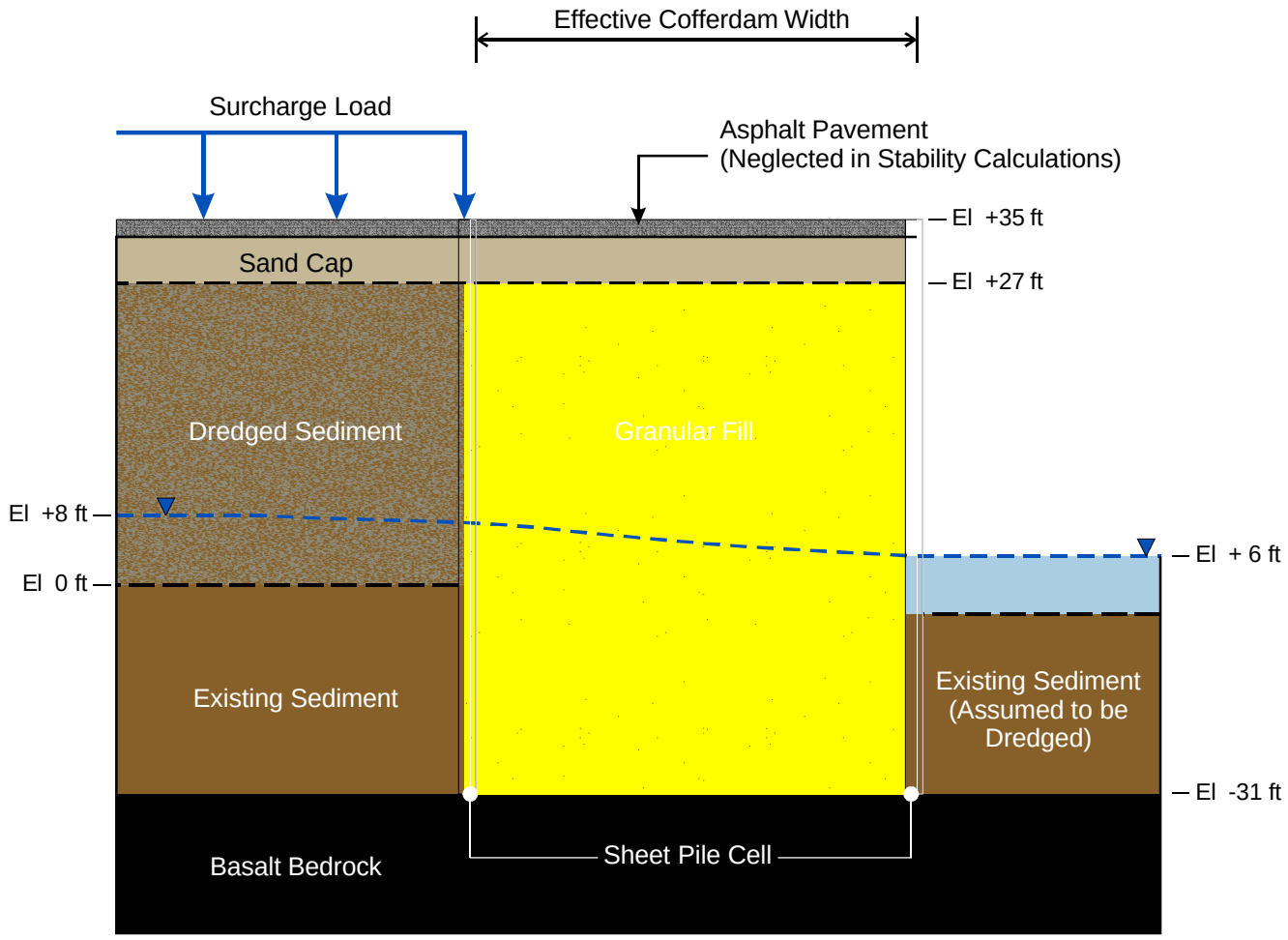


NOTES:

1. VERTICAL DATUM IS THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).

2. FIGURE IS CONCEPTUAL AND NOT TO SCALE.

LEGACY SITE SERVICES, LLC
ARKEMA EARLY ACTION, PORTLAND, OREGON
PRELIMINARY CDF SCREENING EVALUATION

CDF COFFERDAM –
CONCEPTUAL DESIGN CROSS SECTION

ARCADIS

FIGURE
A-1

07/27/09 SYRACUSE, NY-ENV/CAD-DJHOWES
MN000609/0001/00005/CDR/00609G02.CDR

Appendix B

Floodway Analysis Modeling Output

Results of HEC-RAS Analysis (Existing Conditions)
at Arkema Site in Portland, OR.

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	1.379	100	existingND	375000.00	-46.22	-6.68	8.32	45061.82	1489.24	0.27
Reach 1	1.379	100	existing0	375000.00	-46.22	2.68	6.34	59111.80	1507.88	0.18
Reach 1	1.379	100	existing15	375000.00	-46.22	16.13	4.72	79421.94	1511.39	0.11
Reach 1	1.379	100	existing30	375000.00	-46.22	30.56	3.70	101233.60	1511.39	0.08
Reach 1	1.360	100	existingND	375000.00	-45.00	-6.32	5.86	63940.56	2445.35	0.20
Reach 1	1.360	100	existing0	375000.00	-45.00	2.91	4.33	86698.05	2483.11	0.13
Reach 1	1.360	100	existing15	375000.00	-45.00	16.26	3.12	120216.90	2519.33	0.08
Reach 1	1.360	100	existing30	375000.00	-45.00	30.64	2.40	156453.70	2519.33	0.05
Reach 1	1.341	100	existingND	375000.00	-44.31	-6.45	6.35	59045.66	2413.93	0.23
Reach 1	1.341	100	existing0	375000.00	-44.31	2.86	4.59	81670.13	2444.36	0.14
Reach 1	1.341	100	existing15	375000.00	-44.31	16.24	3.27	114705.40	2474.80	0.08
Reach 1	1.341	100	existing30	375000.00	-44.31	30.63	2.49	150325.60	2474.80	0.06
Reach 1	1.322	100	existingND	375000.00	-43.30	-6.53	6.63	56530.41	2406.56	0.24
Reach 1	1.322	100	existing0	375000.00	-43.30	2.83	4.74	79189.24	2428.64	0.15
Reach 1	1.322	100	existing15	375000.00	-43.30	16.23	3.36	111727.10	2428.64	0.09
Reach 1	1.322	100	existing30	375000.00	-43.30	30.63	2.56	146697.80	2428.64	0.06
Reach 1	1.303	100	existingND	375000.00	-42.92	-6.70	7.21	52028.59	2381.20	0.27
Reach 1	1.303	100	existing0	375000.00	-42.92	2.77	5.02	74744.66	2408.03	0.16
Reach 1	1.303	100	existing15	375000.00	-42.92	16.21	3.50	107094.40	2408.03	0.09
Reach 1	1.303	100	existing30	375000.00	-42.92	30.62	2.64	141794.70	2408.03	0.06
Reach 1	1.284	100	existingND	375000.00	-43.39	-6.95	8.01	46823.32	2002.01	0.29
Reach 1	1.284	100	existing0	375000.00	-43.39	2.68	5.49	68244.21	2345.92	0.18
Reach 1	1.284	100	existing15	375000.00	-43.39	16.17	3.75	99925.02	2347.22	0.10
Reach 1	1.284	100	existing30	375000.00	-43.39	30.60	2.80	133792.80	2347.22	0.07
Reach 1	1.265	100	existingND	375000.00	-44.30	-7.00	8.09	46352.45	1657.51	0.27
Reach 1	1.265	100	existing0	375000.00	-44.30	2.56	6.00	62550.91	1727.53	0.18
Reach 1	1.265	100	existing15	375000.00	-44.30	16.09	4.32	86753.71	1798.29	0.11
Reach 1	1.265	100	existing30	375000.00	-44.30	30.55	3.33	112748.40	1798.29	0.07
Reach 1	1.246	100	existingND	375000.00	-46.62	-6.99	7.87	47643.70	1633.19	0.26
Reach 1	1.246	100	existing0	375000.00	-46.62	2.57	5.90	63567.46	1701.05	0.17
Reach 1	1.246	100	existing15	375000.00	-46.62	16.09	4.27	87864.27	1816.91	0.11
Reach 1	1.246	100	existing30	375000.00	-46.62	30.55	3.29	114128.60	1816.91	0.07
Reach 1	1.227	100	existingND	375000.00	-50.06	-6.95	7.47	50192.23	1752.39	0.25
Reach 1	1.227	100	existing0	375000.00	-50.06	2.60	5.52	67988.97	1928.83	0.16
Reach 1	1.227	100	existing15	375000.00	-50.06	16.11	3.97	94370.81	1954.51	0.10
Reach 1	1.227	100	existing30	375000.00	-50.06	30.56	3.06	122607.80	1954.51	0.07
Reach 1	1.208	100	existingND	375000.00	-52.48	-6.95	7.29	51426.54	1805.15	0.24
Reach 1	1.208	100	existing0	375000.00	-52.48	2.60	5.43	69117.12	1887.09	0.16
Reach 1	1.208	100	existing15	375000.00	-52.48	16.11	3.95	94921.78	1917.08	0.10
Reach 1	1.208	100	existing30	375000.00	-52.48	30.56	3.06	122618.20	1917.08	0.07
Reach 1	1.189	100	existingND	375000.00	-54.15	-6.99	7.36	50976.08	1736.64	0.24
Reach 1	1.189	100	existing0	375000.00	-54.15	2.58	5.48	68404.54	1859.23	0.16
Reach 1	1.189	100	existing15	375000.00	-54.15	16.10	4.00	93678.17	1871.91	0.10
Reach 1	1.189	100	existing30	375000.00	-54.15	30.55	3.11	120729.80	1871.91	0.07
Reach 1	1.170	100	existingND	375000.00	-55.89	-7.03	7.42	50532.36	1734.20	0.24
Reach 1	1.170	100	existing0	375000.00	-55.89	2.56	5.52	67934.77	1850.85	0.16
Reach 1	1.170	100	existing15	375000.00	-55.89	16.09	4.03	92974.77	1850.85	0.10
Reach 1	1.170	100	existing30	375000.00	-55.89	30.55	3.13	119728.40	1850.85	0.07
Reach 1	1.151	100	existingND	375000.00	-56.80	-7.07	7.48	50167.21	1648.47	0.24
Reach 1	1.151	100	existing0	375000.00	-56.80	2.55	5.53	67808.34	1906.21	0.16
Reach 1	1.151	100	existing15	375000.00	-56.80	16.09	4.00	93692.49	1911.90	0.10
Reach 1	1.151	100	existing30	375000.00	-56.80	30.55	3.09	121332.80	1911.90	0.07

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	1.133	100	existingND	375000.00	-57.00	-7.10	7.50	49987.25	1670.22	0.24
Reach 1	1.133	100	existing0	375000.00	-57.00	2.53	5.58	67152.48	1848.51	0.16
Reach 1	1.133	100	existing15	375000.00	-57.00	16.08	4.05	92556.16	1881.53	0.10
Reach 1	1.133	100	existing30	375000.00	-57.00	30.54	3.13	119766.10	1881.53	0.07
Reach 1	1.114	100	existingND	375000.00	-57.00	-7.15	7.59	49416.85	1614.16	0.24
Reach 1	1.114	100	existing0	375000.00	-57.00	2.51	5.65	66370.21	1834.52	0.17
Reach 1	1.114	100	existing15	375000.00	-57.00	16.07	4.10	91482.84	1855.37	0.10
Reach 1	1.114	100	existing30	375000.00	-57.00	30.54	3.17	118323.10	1855.37	0.07
Reach 1	1.095	100	existingND	375000.00	-57.00	-7.18	7.60	49348.04	1527.64	0.24
Reach 1	1.095	100	existing0	375000.00	-57.00	2.47	5.78	64893.93	1729.78	0.17
Reach 1	1.095	100	existing15	375000.00	-57.00	16.05	4.21	89085.12	1787.94	0.11
Reach 1	1.095	100	existing30	375000.00	-57.00	30.53	3.26	114963.60	1787.94	0.07
Reach 1	1.076	100	existingND	375000.00	-56.65	-7.20	7.62	49241.40	1476.72	0.23
Reach 1	1.076	100	existing0	375000.00	-56.65	2.44	5.89	63650.71	1517.49	0.16
Reach 1	1.076	100	existing15	375000.00	-56.65	16.01	4.43	84582.68	1545.70	0.11
Reach 1	1.076	100	existing30	375000.00	-56.65	30.50	3.51	106966.00	1545.70	0.07
Reach 1	1.057	100	existingND	375000.00	-56.07	-7.23	7.62	49197.87	1478.50	0.23
Reach 1	1.057	100	existing0	375000.00	-56.07	2.43	5.88	63804.27	1559.73	0.16
Reach 1	1.057	100	existing15	375000.00	-56.07	16.01	4.39	85367.85	1592.71	0.11
Reach 1	1.057	100	existing30	375000.00	-56.07	30.50	3.46	108434.90	1592.71	0.07
Reach 1	1.038	100	existingND	375000.00	-56.00	-7.27	7.69	48789.21	1459.14	0.23
Reach 1	1.038	100	existing0	375000.00	-56.00	2.41	5.93	63279.98	1535.48	0.16
Reach 1	1.038	100	existing15	375000.00	-56.00	16.00	4.44	84462.13	1564.65	0.11
Reach 1	1.038	100	existing30	375000.00	-56.00	30.49	3.50	107129.40	1564.65	0.07
Reach 1	1.019	100	existingND	375000.00	-56.00	-7.30	7.71	48607.31	1445.82	0.23
Reach 1	1.019	100	existing0	375000.00	-56.00	2.40	5.95	62980.90	1520.41	0.16
Reach 1	1.019	100	existing15	375000.00	-56.00	15.99	4.47	83930.57	1545.54	0.11
Reach 1	1.019	100	existing30	375000.00	-56.00	30.49	3.53	106326.00	1545.54	0.07
Reach 1	1.000	100	existingND	375000.00	-56.00	-7.33	7.75	48400.34	1443.28	0.24
Reach 1	1.000	100	existing0	375000.00	-56.00	2.38	5.97	62763.52	1519.70	0.16
Reach 1	1.000	100	existing15	375000.00	-56.00	15.99	4.48	83761.85	1548.04	0.11
Reach 1	1.000	100	existing30	375000.00	-56.00	30.48	3.53	106198.20	1548.04	0.08
Reach 1	0.981	100	existingND	375000.00	-55.62	-7.39	7.88	47567.33	1432.33	0.24
Reach 1	0.981	100	existing0	375000.00	-55.62	2.35	6.06	61865.78	1519.71	0.17
Reach 1	0.981	100	existing15	375000.00	-55.62	15.98	4.52	82969.91	1554.48	0.11
Reach 1	0.981	100	existing30	375000.00	-55.62	30.48	3.55	105509.00	1554.48	0.08
Reach 1	0.962	100	existingND	375000.00	-52.22	-7.53	8.32	45065.83	1436.67	0.26
Reach 1	0.962	100	existing0	375000.00	-52.22	2.29	6.29	59576.03	1505.37	0.18
Reach 1	0.962	100	existing15	375000.00	-52.22	15.95	4.68	80134.95	1505.37	0.11
Reach 1	0.962	100	existing30	375000.00	-52.22	30.46	3.68	101980.50	1505.37	0.08
Reach 1	0.943	100	existingND	375000.00	-50.00	-7.66	8.64	43398.06	1438.82	0.28
Reach 1	0.943	100	existing0	375000.00	-50.00	2.24	6.47	57958.07	1505.16	0.18
Reach 1	0.943	100	existing15	375000.00	-50.00	15.93	4.77	78697.65	1515.50	0.12
Reach 1	0.943	100	existing30	375000.00	-50.00	30.45	3.72	100706.10	1515.50	0.08
Reach 1	0.924	100	existingND	375000.00	-53.25	-7.74	8.81	42566.91	1432.00	0.28
Reach 1	0.924	100	existing0	375000.00	-53.25	2.21	6.55	57272.87	1522.10	0.19
Reach 1	0.924	100	existing15	375000.00	-53.25	15.92	4.77	78586.07	1557.97	0.12
Reach 1	0.924	100	existing30	375000.00	-53.25	30.45	3.70	101219.70	1557.97	0.08
Reach 1	0.905	100	existingND	375000.00	-56.00	-7.75	8.67	43264.71	1372.36	0.27
Reach 1	0.905	100	existing0	375000.00	-56.00	2.20	6.53	57412.53	1488.48	0.19
Reach 1	0.905	100	existing15	375000.00	-56.00	15.92	4.79	78254.88	1522.43	0.12
Reach 1	0.905	100	existing30	375000.00	-56.00	30.45	3.74	100375.60	1522.43	0.08

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	0.886	100	existingND	375000.00	-55.27	-7.78	8.67	43262.52	1365.86	0.27
Reach 1	0.886	100	existing0	375000.00	-55.27	2.19	6.52	57504.05	1494.60	0.19
Reach 1	0.886	100	existing15	375000.00	-55.27	15.91	4.80	78159.79	1505.50	0.12
Reach 1	0.886	100	existing30	375000.00	-55.27	30.44	3.75	100037.70	1505.50	0.08
Reach 1	0.867	100	existingND	375000.00	-54.70	-7.88	8.89	42167.17	1365.70	0.28
Reach 1	0.867	100	existing0	375000.00	-54.70	2.15	6.63	56519.86	1492.30	0.19
Reach 1	0.867	100	existing15	375000.00	-54.70	15.90	4.85	77266.89	1510.35	0.12
Reach 1	0.867	100	existing30	375000.00	-54.70	30.44	3.78	99227.23	1510.35	0.08
Reach 1	0.848	100	existingND	375000.00	-48.59	-8.10	9.48	39565.26	1349.90	0.31
Reach 1	0.848	100	existing0	375000.00	-48.59	2.06	6.96	53884.18	1465.05	0.20
Reach 1	0.848	100	existing15	375000.00	-48.59	15.86	5.05	74197.85	1472.29	0.13
Reach 1	0.848	100	existing30	375000.00	-48.59	30.41	3.92	95631.89	1472.29	0.09
Reach 1	0.830	100	existingND	375000.00	-48.24	-8.22	9.73	38541.45	1325.90	0.32
Reach 1	0.830	100	existing0	375000.00	-48.24	2.00	7.13	52593.91	1430.29	0.21
Reach 1	0.830	100	existing15	375000.00	-48.24	15.83	5.18	72418.70	1433.53	0.13
Reach 1	0.830	100	existing30	375000.00	-48.24	30.40	4.02	93305.20	1433.53	0.09
Reach 1	0.811	100	existingND	375000.00	-49.00	-8.32	9.89	37912.56	1310.43	0.32
Reach 1	0.811	100	existing0	375000.00	-49.00	1.96	7.22	51925.08	1406.73	0.21
Reach 1	0.811	100	existing15	375000.00	-49.00	15.81	5.25	71409.00	1406.73	0.13
Reach 1	0.811	100	existing30	375000.00	-49.00	30.39	4.08	91916.34	1406.73	0.09
Reach 1	0.792	100	existingND	375000.00	-49.18	-8.40	9.99	37530.68	1301.57	0.33
Reach 1	0.792	100	existing0	375000.00	-49.18	1.93	7.29	51469.94	1394.60	0.21
Reach 1	0.792	100	existing15	375000.00	-49.18	15.80	5.27	71095.73	1416.31	0.13
Reach 1	0.792	100	existing30	375000.00	-49.18	30.38	4.09	91752.18	1416.31	0.09
Reach 1	0.773	100	existingND	375000.00	-48.32	-8.64	10.53	35619.90	1282.51	0.35
Reach 1	0.773	100	existing0	375000.00	-48.32	1.84	7.55	49689.45	1395.74	0.22
Reach 1	0.773	100	existing15	375000.00	-48.32	15.77	5.39	69529.31	1427.34	0.14
Reach 1	0.773	100	existing30	375000.00	-48.32	30.37	4.15	90370.20	1427.34	0.09
Reach 1	0.754	100	existingND	375000.00	-46.18	-8.93	11.17	33586.68	1292.42	0.39
Reach 1	0.754	100	existing0	375000.00	-46.18	1.75	7.82	47945.18	1394.47	0.24
Reach 1	0.754	100	existing15	375000.00	-46.18	15.74	5.51	67998.80	1440.76	0.14
Reach 1	0.754	100	existing30	375000.00	-46.18	30.36	4.21	89061.43	1440.76	0.09
Reach 1	0.735	100	existingND	375000.00	-45.98	-8.95	10.98	34165.00	1282.20	0.37
Reach 1	0.735	100	existing0	375000.00	-45.98	1.73	7.76	48305.32	1357.14	0.23
Reach 1	0.735	100	existing15	375000.00	-45.98	15.73	5.55	67528.29	1377.13	0.14
Reach 1	0.735	100	existing30	375000.00	-45.98	30.35	4.28	87662.94	1377.13	0.09
Reach 1	0.716	100	existingND	375000.00	-45.92	-8.95	10.71	35016.58	1284.21	0.36
Reach 1	0.716	100	existing0	375000.00	-45.92	1.74	7.62	49215.26	1355.97	0.22
Reach 1	0.716	100	existing15	375000.00	-45.92	15.73	5.49	68355.20	1369.45	0.14
Reach 1	0.716	100	existing30	375000.00	-45.92	30.35	4.24	88376.60	1369.45	0.09
Reach 1	0.697	100	existingND	375000.00	-49.00	-8.78	9.73	38524.39	1350.47	0.32
Reach 1	0.697	100	existing0	375000.00	-49.00	1.81	7.05	53182.43	1410.21	0.20
Reach 1	0.697	100	existing15	375000.00	-49.00	15.76	5.12	73171.20	1436.55	0.13
Reach 1	0.697	100	existing30	375000.00	-49.00	30.37	3.98	94152.32	1436.55	0.09
Reach 1	0.678	100	existingND	375000.00	-49.54	-9.15	10.64	35243.75	1314.87	0.36
Reach 1	0.678	100	existing0	375000.00	-49.54	1.68	7.51	49964.69	1398.84	0.22
Reach 1	0.678	100	existing15	375000.00	-49.54	15.71	5.36	69980.38	1431.59	0.14
Reach 1	0.678	100	existing30	375000.00	-49.54	30.35	4.12	90926.03	1431.59	0.09
Reach 1	0.659	100	existingND	375000.00	-47.37	-9.47	11.33	33084.48	1237.36	0.39
Reach 1	0.659	100	existing0	375000.00	-47.37	1.54	7.97	47043.09	1299.16	0.23
Reach 1	0.659	100	existing15	375000.00	-47.37	15.65	5.67	66088.95	1364.42	0.14
Reach 1	0.659	100	existing30	375000.00	-47.37	30.31	4.36	86092.82	1364.42	0.10

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	0.640	100	existingND	375000.00	-47.46	-9.81	12.00	31246.62	1224.51	0.42
Reach 1	0.640	100	existing0	375000.00	-47.46	1.43	8.26	45409.10	1289.81	0.25
Reach 1	0.640	100	existing15	375000.00	-47.46	15.61	5.82	64401.63	1355.94	0.15
Reach 1	0.640	100	existing30	375000.00	-47.46	30.29	4.45	84308.13	1355.94	0.10
Reach 1	0.621	100	existingND	375000.00	-64.44	-9.56	10.72	34986.29	1223.02	0.35
Reach 1	0.621	100	existing0	375000.00	-64.44	1.51	7.68	48839.52	1280.39	0.22
Reach 1	0.621	100	existing15	375000.00	-64.44	15.64	5.55	67514.36	1334.54	0.14
Reach 1	0.621	100	existing30	375000.00	-64.44	30.30	4.31	87086.15	1334.54	0.09
Reach 1	0.612			Bridge						
Reach 1	0.602	100	existingND	375000.00	-57.62	-9.94	11.01	34070.61	1206.35	0.36
Reach 1	0.602	100	existing0	375000.00	-57.62	1.37	7.81	48044.46	1270.06	0.22
Reach 1	0.602	100	existing15	375000.00	-57.62	15.48	5.59	67068.02	1368.54	0.14
Reach 1	0.602	100	existing30	375000.00	-57.62	30.24	4.30	87268.35	1368.54	0.09
Reach 1	0.583	100	existingND	375000.00	-48.34	-10.38	11.96	31355.67	1182.04	0.41
Reach 1	0.583	100	existing0	375000.00	-48.34	1.27	8.08	46437.90	1787.08	0.28
Reach 1	0.583	100	existing15	375000.00	-48.34	15.53	5.14	72914.49	1867.64	0.15
Reach 1	0.583	100	existing30	375000.00	-48.34	30.29	3.73	100485.10	1867.64	0.09
Reach 1	0.564	100	existingND	375000.00	-44.87	-10.86	12.89	29086.64	1149.83	0.45
Reach 1	0.564	100	existing0	375000.00	-44.87	1.20	8.19	45764.26	1833.96	0.29
Reach 1	0.564	100	existing15	375000.00	-44.87	15.52	5.13	73041.09	1920.01	0.15
Reach 1	0.564	100	existing30	375000.00	-44.87	30.29	3.70	101398.80	1920.01	0.09
Reach 1	0.545	100	existingND	375000.00	-42.30	-11.01	12.99	28861.06	1352.78	0.50
Reach 1	0.545	100	existing0	375000.00	-42.30	1.27	7.56	49613.94	1898.82	0.26
Reach 1	0.545	100	existing15	375000.00	-42.30	15.54	4.86	77154.51	1934.69	0.14
Reach 1	0.545	100	existing30	375000.00	-42.30	30.30	3.55	105704.50	1934.69	0.08
Reach 1	0.527	100	existingND	375000.00	-41.31	-10.50	10.65	35210.72	1633.60	0.40
Reach 1	0.527	100	existing0	375000.00	-41.31	1.37	6.75	55563.58	1777.28	0.21
Reach 1	0.527	100	existing15	375000.00	-41.31	15.56	4.61	81342.29	1826.64	0.12
Reach 1	0.527	100	existing30	375000.00	-41.31	30.30	3.46	108269.80	1826.64	0.08
Reach 1	0.508	100	existingND	375000.00	-41.26	-10.47	10.19	36796.30	1691.61	0.39
Reach 1	0.508	100	existing0	375000.00	-41.26	1.39	6.54	57379.63	1776.95	0.20
Reach 1	0.508	100	existing15	375000.00	-41.26	15.56	4.53	82799.59	1796.74	0.12
Reach 1	0.508	100	existing30	375000.00	-41.26	30.30	3.43	109282.10	1796.74	0.08
Reach 1	0.489	100	existingND	375000.00	-42.00	-10.48	9.93	37746.64	1633.88	0.36
Reach 1	0.489	100	existing0	375000.00	-42.00	1.37	6.51	57604.78	1707.37	0.20
Reach 1	0.489	100	existing15	375000.00	-42.00	15.55	4.57	82019.57	1724.86	0.12
Reach 1	0.489	100	existing30	375000.00	-42.00	30.29	3.49	107447.50	1724.86	0.08
Reach 1	0.470	100	existingND	375000.00	-42.00	-10.62	10.15	36943.66	1554.84	0.37
Reach 1	0.470	100	existing0	375000.00	-42.00	1.32	6.70	55982.87	1634.71	0.20
Reach 1	0.470	100	existing15	375000.00	-42.00	15.52	4.72	79489.48	1658.48	0.12
Reach 1	0.470	100	existing30	375000.00	-42.00	30.28	3.61	103958.50	1658.48	0.08
Reach 1	0.451	100	existingND	375000.00	-43.20	-10.98	10.96	34200.69	1476.32	0.40
Reach 1	0.451	100	existing0	375000.00	-43.20	1.20	7.12	52683.09	1562.01	0.22
Reach 1	0.451	100	existing15	375000.00	-43.20	15.47	5.00	75042.20	1566.63	0.13
Reach 1	0.451	100	existing30	375000.00	-43.20	30.25	3.82	98191.76	1566.63	0.09
Reach 1	0.432	100	existingND	375000.00	-42.00	-11.40	11.85	31651.99	1399.61	0.44
Reach 1	0.432	100	existing0	375000.00	-42.00	1.07	7.56	49592.61	1482.08	0.23
Reach 1	0.432	100	existing15	375000.00	-42.00	15.42	5.25	71443.24	1533.10	0.14
Reach 1	0.432	100	existing30	375000.00	-42.00	30.22	3.98	94137.10	1533.10	0.09
Reach 1	0.413	100	existingND	375000.00	-42.00	-11.66	12.27	30569.12	1213.09	0.43
Reach 1	0.413	100	existing0	375000.00	-42.00	0.97	7.84	47816.04	1445.23	0.24
Reach 1	0.413	100	existing15	375000.00	-42.00	15.39	5.41	69342.11	1507.43	0.14

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	0.413	100	existing30	375000.00	-42.00	30.21	4.09	91683.54	1507.43	0.09
Reach 1	0.394	100	existingND	375000.00	-43.10	-11.80	12.40	30248.81	1185.37	0.43
Reach 1	0.394	100	existing0	375000.00	-43.10	0.91	7.98	46986.16	1407.90	0.24
Reach 1	0.394	100	existing15	375000.00	-43.10	15.36	5.51	68066.39	1474.63	0.14
Reach 1	0.394	100	existing30	375000.00	-43.10	30.19	4.17	89939.75	1474.63	0.09
Reach 1	0.375	100	existingND	375000.00	-45.56	-11.83	12.22	30688.28	1157.74	0.42
Reach 1	0.375	100	existing0	375000.00	-45.56	0.89	7.97	47036.29	1391.16	0.24
Reach 1	0.375	100	existing15	375000.00	-45.56	15.35	5.52	67928.68	1453.96	0.14
Reach 1	0.375	100	existing30	375000.00	-45.56	30.19	4.19	89500.80	1453.96	0.09
Reach 1	0.356	100	existingND	375000.00	-47.94	-11.86	12.01	31213.33	1177.18	0.41
Reach 1	0.356	100	existing0	375000.00	-47.94	0.87	7.92	47319.70	1359.72	0.24
Reach 1	0.356	100	existing15	375000.00	-47.94	15.34	5.54	67746.27	1424.84	0.14
Reach 1	0.356	100	existing30	375000.00	-47.94	30.18	4.22	88890.84	1424.84	0.09
Reach 1	0.337	100	existingND	375000.00	-46.78	-11.92	11.97	31318.38	1162.73	0.41
Reach 1	0.337	100	existing0	375000.00	-46.78	0.83	7.98	46964.95	1315.12	0.24
Reach 1	0.337	100	existing15	375000.00	-46.78	15.31	5.63	66654.17	1367.97	0.14
Reach 1	0.337	100	existing30	375000.00	-46.78	30.16	4.31	86965.68	1367.97	0.10
Reach 1	0.318	100	existingND	375000.00	-43.84	-12.73	13.61	27550.22	1145.83	0.49
Reach 1	0.318	100	existing0	375000.00	-43.84	0.63	8.61	43560.09	1281.15	0.26
Reach 1	0.318	100	existing15	375000.00	-43.84	15.24	5.96	62923.60	1334.44	0.15
Reach 1	0.318	100	existing30	375000.00	-43.84	30.13	4.53	82787.70	1334.44	0.10
Reach 1	0.299	100	existingND	375000.00	-44.19	-13.20	14.37	26105.09	1114.02	0.52
Reach 1	0.299	100	existing0	375000.00	-44.19	0.53	8.86	42319.54	1239.71	0.27
Reach 1	0.299	100	existing15	375000.00	-44.19	15.20	6.11	61337.90	1314.70	0.16
Reach 1	0.299	100	existing30	375000.00	-44.19	30.11	4.63	80935.66	1314.70	0.10
Reach 1	0.280	100	existingND	375000.00	-42.62	-13.49	14.69	25532.99	1097.75	0.54
Reach 1	0.280	100	existing0	375000.00	-42.62	0.46	8.98	41736.87	1220.90	0.27
Reach 1	0.280	100	existing15	375000.00	-42.62	15.17	6.22	60308.70	1273.82	0.16
Reach 1	0.280	100	existing30	375000.00	-42.62	30.09	4.73	79312.68	1273.82	0.11
Reach 1	0.261	100	existingND	375000.00	-41.22	-13.86	15.13	24788.13	1090.66	0.56
Reach 1	0.261	100	existing0	375000.00	-41.22	0.38	9.14	41026.77	1184.70	0.27
Reach 1	0.261	100	existing15	375000.00	-41.22	15.13	6.33	59234.91	1251.85	0.16
Reach 1	0.261	100	existing30	375000.00	-41.22	30.07	4.81	77931.18	1251.85	0.11
Reach 1	0.242	100	existingND	375000.00	-42.00	-14.16	15.42	24324.12	1082.42	0.57
Reach 1	0.242	100	existing0	375000.00	-42.00	0.31	9.27	40438.16	1147.48	0.28
Reach 1	0.242	100	existing15	375000.00	-42.00	15.10	6.44	58238.07	1226.96	0.16
Reach 1	0.242	100	existing30	375000.00	-42.00	30.05	4.90	76581.55	1226.96	0.11
Reach 1	0.223	100	existingND	375000.00	-42.26	-14.30	15.38	24381.20	1075.84	0.57
Reach 1	0.223	100	existing0	375000.00	-42.26	0.28	9.25	40522.98	1138.55	0.27
Reach 1	0.223	100	existing15	375000.00	-42.26	15.09	6.45	58107.03	1208.60	0.16
Reach 1	0.223	100	existing30	375000.00	-42.26	30.04	4.92	76181.77	1208.60	0.11
Reach 1	0.205	100	existingND	375000.00	-44.60	-14.49	15.45	24276.33	1067.59	0.57
Reach 1	0.205	100	existing0	375000.00	-44.60	0.25	9.25	40531.30	1140.44	0.27
Reach 1	0.205	100	existing15	375000.00	-44.60	15.07	6.47	57930.72	1181.37	0.16
Reach 1	0.205	100	existing30	375000.00	-44.60	30.03	4.96	75602.70	1181.37	0.11
Reach 1	0.186	100	existingND	375000.00	-44.62	-14.85	15.83	23682.43	1059.40	0.59
Reach 1	0.186	100	existing0	375000.00	-44.62	0.20	9.31	40295.38	1154.97	0.28
Reach 1	0.186	100	existing15	375000.00	-44.62	15.06	6.49	57790.88	1181.48	0.16
Reach 1	0.186	100	existing30	375000.00	-44.62	30.03	4.97	75473.86	1181.48	0.11
Reach 1	0.167	100	existingND	375000.00	-45.00	-14.97	15.71	23869.27	1071.23	0.59
Reach 1	0.167	100	existing0	375000.00	-45.00	0.19	9.20	40746.79	1162.79	0.27
Reach 1	0.167	100	existing15	375000.00	-45.00	15.06	6.41	58467.08	1197.63	0.16

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	0.167	100	existing30	375000.00	-45.00	30.03	4.91	76393.69	1197.63	0.11
Reach 1	0.148	100	existingND	375000.00	-45.99	-15.46	16.29	23024.43	1043.58	0.61
Reach 1	0.148	100	existing0	375000.00	-45.99	0.11	9.36	40049.53	1153.58	0.28
Reach 1	0.148	100	existing15	375000.00	-45.99	15.04	6.48	57906.30	1201.63	0.16
Reach 1	0.148	100	existing30	375000.00	-45.99	30.02	4.94	75909.82	1201.63	0.11
Reach 1	0.129	100	existingND	375000.00	-47.25	-15.85	16.64	22529.29	1044.55	0.63
Reach 1	0.129	100	existing0	375000.00	-47.25	0.07	9.40	39895.67	1141.75	0.28
Reach 1	0.129	100	existing15	375000.00	-47.25	15.02	6.49	57784.14	1215.64	0.17
Reach 1	0.129	100	existing30	375000.00	-47.25	30.02	4.93	76009.37	1215.64	0.11
Reach 1	0.110	100	existingND	375000.00	-47.79	-16.39	17.23	21758.80	1042.47	0.66
Reach 1	0.110	100	existing0	375000.00	-47.79	0.02	9.44	39708.28	1145.44	0.28
Reach 1	0.110	100	existing15	375000.00	-47.79	15.02	6.47	57925.84	1235.62	0.17
Reach 1	0.110	100	existing30	375000.00	-47.79	30.01	4.90	76459.20	1235.62	0.11
Reach 1	0.091	100	existingND	375000.00	-48.00	-16.60	17.24	21752.67	1031.98	0.66
Reach 1	0.091	100	existing0	375000.00	-48.00	0.00	9.39	39957.17	1165.43	0.28
Reach 1	0.091	100	existing15	375000.00	-48.00	15.00	6.50	57722.76	1186.27	0.16
Reach 1	0.091	100	existing30	375000.00	-48.00	30.00	4.97	75516.81	1186.27	0.11

Plan name	Description
Arkema_existing_ND	Existing Conditions Model with normal depth downstream WSE (0.0021)
Arkema_upper_bound_ND	Proposed Conditions Model with normal depth downstream WSE (0.0021)
Arkema_existing_0	Existing Conditions Model with 0 ft NGVD downstream WSE
Arkema_upper_bound_0	Proposed Conditions Model with 0 ft NGVD downstream WSE
Arkema_existing_15	Existing Conditions Model with 15 ft NGVD downstream WSE
Arkema_upper_bound_15	Proposed Conditions Model with 15 ft NGVD downstream WSE
Arkema_existing_30	Existing Conditions Model with 30 ft NGVD downstream WSE
Arkema_upper_bound_30	Proposed Conditions Model with 30 ft NGVD downstream WSE

Notes:
1. NGVD = National Geodetic Vertical Datum
2. WSE = Water Surface Elevation

Results of HEC-RAS Analysis (Proposed Conditions)
at Arkema Site in Portland, OR.

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	1.379	100	upper_bound_ND	375000.00	-46.22	-6.68	8.32	45057.17	1489.23	0.27
Reach 1	1.379	100	upper_bound_0	375000.00	-46.22	2.68	6.35	59098.90	1507.87	0.18
Reach 1	1.379	100	upper_bound_15	375000.00	-46.22	16.12	4.72	79417.26	1511.39	0.11
Reach 1	1.379	100	upper_bound_30	375000.00	-46.22	30.56	3.70	101231.40	1511.39	0.08
Reach 1	1.360	100	upper_bound_ND	375000.00	-45.00	-6.33	5.87	63933.11	2445.34	0.20
Reach 1	1.360	100	upper_bound_0	375000.00	-45.00	2.90	4.33	86676.99	2483.08	0.13
Reach 1	1.360	100	upper_bound_15	375000.00	-45.00	16.26	3.12	120209.10	2519.33	0.08
Reach 1	1.360	100	upper_bound_30	375000.00	-45.00	30.64	2.40	156450.00	2519.33	0.05
Reach 1	1.341	100	upper_bound_ND	375000.00	-44.31	-6.45	6.35	59038.20	2413.92	0.23
Reach 1	1.341	100	upper_bound_0	375000.00	-44.31	2.85	4.59	81649.38	2444.34	0.14
Reach 1	1.341	100	upper_bound_15	375000.00	-44.31	16.24	3.27	114697.80	2474.80	0.08
Reach 1	1.341	100	upper_bound_30	375000.00	-44.31	30.63	2.49	150322.10	2474.80	0.06
Reach 1	1.322	100	upper_bound_ND	375000.00	-43.30	-6.54	6.63	56522.85	2406.55	0.24
Reach 1	1.322	100	upper_bound_0	375000.00	-43.30	2.82	4.74	79168.45	2428.64	0.15
Reach 1	1.322	100	upper_bound_15	375000.00	-43.30	16.22	3.36	111719.60	2428.64	0.09
Reach 1	1.322	100	upper_bound_30	375000.00	-43.30	30.63	2.56	146694.30	2428.64	0.06
Reach 1	1.303	100	upper_bound_ND	375000.00	-42.92	-6.70	7.21	52020.97	2381.19	0.27
Reach 1	1.303	100	upper_bound_0	375000.00	-42.92	2.76	5.02	74724.00	2408.03	0.16
Reach 1	1.303	100	upper_bound_15	375000.00	-42.92	16.20	3.50	107086.90	2408.03	0.09
Reach 1	1.303	100	upper_bound_30	375000.00	-42.92	30.62	2.64	141791.20	2408.03	0.06
Reach 1	1.284	100	upper_bound_ND	375000.00	-43.39	-6.95	8.01	46816.77	2001.87	0.29
Reach 1	1.284	100	upper_bound_0	375000.00	-43.39	2.67	5.50	68223.88	2345.89	0.18
Reach 1	1.284	100	upper_bound_15	375000.00	-43.39	16.17	3.75	99917.82	2347.22	0.10
Reach 1	1.284	100	upper_bound_30	375000.00	-43.39	30.60	2.80	133789.30	2347.22	0.07
Reach 1	1.265	100	upper_bound_ND	375000.00	-44.30	-7.01	8.09	46347.07	1657.48	0.27
Reach 1	1.265	100	upper_bound_0	375000.00	-44.30	2.56	6.00	62535.95	1727.46	0.18
Reach 1	1.265	100	upper_bound_15	375000.00	-44.30	16.09	4.32	86748.16	1798.29	0.11
Reach 1	1.265	100	upper_bound_30	375000.00	-44.30	30.54	3.33	112745.70	1798.29	0.07
Reach 1	1.246	100	upper_bound_ND	375000.00	-46.62	-7.00	7.87	47638.41	1633.16	0.26
Reach 1	1.246	100	upper_bound_0	375000.00	-46.62	2.56	5.90	63552.75	1700.98	0.17
Reach 1	1.246	100	upper_bound_15	375000.00	-46.62	16.09	4.27	87858.63	1816.91	0.11
Reach 1	1.246	100	upper_bound_30	375000.00	-46.62	30.54	3.29	114125.90	1816.91	0.07
Reach 1	1.227	100	upper_bound_ND	375000.00	-50.06	-6.96	7.47	50186.60	1752.24	0.25
Reach 1	1.227	100	upper_bound_0	375000.00	-50.06	2.59	5.52	67972.25	1928.77	0.16
Reach 1	1.227	100	upper_bound_15	375000.00	-50.06	16.11	3.97	94364.69	1954.51	0.10
Reach 1	1.227	100	upper_bound_30	375000.00	-50.06	30.56	3.06	122604.90	1954.51	0.07
Reach 1	1.208	100	upper_bound_ND	375000.00	-52.48	-6.95	7.29	51420.71	1805.12	0.24
Reach 1	1.208	100	upper_bound_0	375000.00	-52.48	2.59	5.43	69100.78	1887.04	0.16
Reach 1	1.208	100	upper_bound_15	375000.00	-52.48	16.11	3.95	94915.84	1917.08	0.10
Reach 1	1.208	100	upper_bound_30	375000.00	-52.48	30.56	3.06	122615.40	1917.08	0.07
Reach 1	1.189	100	upper_bound_ND	375000.00	-54.15	-7.00	7.36	50970.47	1736.53	0.24
Reach 1	1.189	100	upper_bound_0	375000.00	-54.15	2.57	5.48	68388.42	1859.21	0.16
Reach 1	1.189	100	upper_bound_15	375000.00	-54.15	16.10	4.00	93672.34	1871.91	0.10
Reach 1	1.189	100	upper_bound_30	375000.00	-54.15	30.55	3.11	120727.00	1871.91	0.07
Reach 1	1.170	100	upper_bound_ND	375000.00	-55.89	-7.04	7.42	50526.72	1734.13	0.24
Reach 1	1.170	100	upper_bound_0	375000.00	-55.89	2.56	5.52	67918.70	1850.85	0.16
Reach 1	1.170	100	upper_bound_15	375000.00	-55.89	16.09	4.03	92969.04	1850.85	0.10
Reach 1	1.170	100	upper_bound_30	375000.00	-55.89	30.55	3.13	119725.70	1850.85	0.07
Reach 1	1.151	100	upper_bound_ND	375000.00	-56.80	-7.08	7.48	50161.84	1648.32	0.24
Reach 1	1.151	100	upper_bound_0	375000.00	-56.80	2.54	5.53	67791.80	1906.17	0.16
Reach 1	1.151	100	upper_bound_15	375000.00	-56.80	16.09	4.00	93686.55	1911.90	0.10
Reach 1	1.151	100	upper_bound_30	375000.00	-56.80	30.55	3.09	121330.00	1911.90	0.07
Reach 1	1.133	100	upper_bound_ND	375000.00	-57.00	-7.11	7.50	49981.84	1670.16	0.24
Reach 1	1.133	100	upper_bound_0	375000.00	-57.00	2.52	5.59	67097.62	1848.46	0.16
Reach 1	1.133	100	upper_bound_15	375000.00	-57.00	16.08	4.07	92194.27	1881.53	0.10

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	1.133	100	upper_bound_30	375000.00	-57.00	30.54	3.15	119055.30	1881.53	0.07
Reach 1	1.114	100	upper_bound_ND	375000.00	-57.00	-7.15	7.59	49411.57	1613.99	0.24
Reach 1	1.114	100	upper_bound_0	375000.00	-57.00	2.50	5.66	66267.02	1834.48	0.17
Reach 1	1.114	100	upper_bound_15	375000.00	-57.00	16.07	4.11	91133.23	1855.37	0.10
Reach 1	1.114	100	upper_bound_30	375000.00	-57.00	30.53	3.19	117705.20	1855.37	0.07
Reach 1	1.095	100	upper_bound_ND	375000.00	-57.00	-7.18	7.60	49343.04	1527.61	0.24
Reach 1	1.095	100	upper_bound_0	375000.00	-57.00	2.46	5.79	64754.87	1729.65	0.17
Reach 1	1.095	100	upper_bound_15	375000.00	-57.00	16.05	4.23	88641.32	1787.94	0.11
Reach 1	1.095	100	upper_bound_30	375000.00	-57.00	30.52	3.28	114190.70	1787.94	0.07
Reach 1	1.076	100	upper_bound_ND	375000.00	-56.65	-7.21	7.62	49236.57	1476.71	0.23
Reach 1	1.076	100	upper_bound_0	375000.00	-56.65	2.43	5.91	63502.36	1517.42	0.16
Reach 1	1.076	100	upper_bound_15	375000.00	-56.65	16.00	4.49	83606.93	1545.70	0.11
Reach 1	1.076	100	upper_bound_30	375000.00	-56.65	30.49	3.57	105055.10	1545.70	0.07
Reach 1	1.057	100	upper_bound_ND	375000.00	-56.07	-7.23	7.62	49193.04	1478.48	0.23
Reach 1	1.057	100	upper_bound_0	375000.00	-56.07	2.42	5.90	63560.27	1559.63	0.16
Reach 1	1.057	100	upper_bound_15	375000.00	-56.07	16.00	4.47	83823.02	1592.71	0.11
Reach 1	1.057	100	upper_bound_30	375000.00	-56.07	30.49	3.56	105432.90	1592.71	0.07
Reach 1	1.038	100	upper_bound_ND	375000.00	-56.00	-7.27	7.69	48783.66	1459.12	0.23
Reach 1	1.038	100	upper_bound_0	375000.00	-56.00	2.40	5.96	62958.85	1535.42	0.16
Reach 1	1.038	100	upper_bound_15	375000.00	-56.00	15.99	4.52	82935.98	1564.65	0.11
Reach 1	1.038	100	upper_bound_30	375000.00	-56.00	30.48	3.60	104232.40	1564.65	0.08
Reach 1	1.019	100	upper_bound_ND	375000.00	-56.00	-7.30	7.72	48602.64	1445.80	0.23
Reach 1	1.019	100	upper_bound_0	375000.00	-56.00	2.38	5.98	62678.82	1520.35	0.16
Reach 1	1.019	100	upper_bound_15	375000.00	-56.00	15.98	4.55	82488.23	1545.54	0.11
Reach 1	1.019	100	upper_bound_30	375000.00	-56.00	30.47	3.62	103598.90	1545.54	0.08
Reach 1	1.000	100	upper_bound_ND	375000.00	-56.00	-7.33	7.75	48375.84	1443.25	0.23
Reach 1	1.000	100	upper_bound_0	375000.00	-56.00	2.37	6.02	62281.12	1519.60	0.16
Reach 1	1.000	100	upper_bound_15	375000.00	-56.00	15.97	4.58	81809.02	1548.04	0.11
Reach 1	1.000	100	upper_bound_30	375000.00	-56.00	30.47	3.65	102613.40	1548.04	0.08
Reach 1	0.981	100	upper_bound_ND	375000.00	-55.62	-7.39	7.90	47479.47	1432.29	0.24
Reach 1	0.981	100	upper_bound_0	375000.00	-55.62	2.34	6.12	61274.03	1519.55	0.16
Reach 1	0.981	100	upper_bound_15	375000.00	-55.62	15.96	4.65	80685.25	1554.48	0.11
Reach 1	0.981	100	upper_bound_30	375000.00	-55.62	30.46	3.70	101349.80	1554.48	0.08
Reach 1	0.962	100	upper_bound_ND	375000.00	-52.22	-7.54	8.33	45011.48	1436.63	0.26
Reach 1	0.962	100	upper_bound_0	375000.00	-52.22	2.28	6.35	59089.46	1505.37	0.17
Reach 1	0.962	100	upper_bound_15	375000.00	-52.22	15.94	4.76	78800.52	1505.37	0.11
Reach 1	0.962	100	upper_bound_30	375000.00	-52.22	30.45	3.76	99745.47	1505.37	0.08
Reach 1	0.943	100	upper_bound_ND	375000.00	-50.00	-7.66	8.65	43328.10	1438.78	0.28
Reach 1	0.943	100	upper_bound_0	375000.00	-50.00	2.22	6.53	57470.13	1505.04	0.18
Reach 1	0.943	100	upper_bound_15	375000.00	-50.00	15.91	4.86	77084.40	1515.50	0.12
Reach 1	0.943	100	upper_bound_30	375000.00	-50.00	30.44	3.83	97896.98	1515.50	0.08
Reach 1	0.924	100	upper_bound_ND	375000.00	-53.25	-7.75	8.83	42451.64	1431.92	0.28
Reach 1	0.924	100	upper_bound_0	375000.00	-53.25	2.19	6.64	56493.86	1521.85	0.19
Reach 1	0.924	100	upper_bound_15	375000.00	-53.25	15.90	4.93	76057.59	1557.97	0.12
Reach 1	0.924	100	upper_bound_30	375000.00	-53.25	30.43	3.87	96793.59	1557.97	0.08
Reach 1	0.905	100	upper_bound_ND	375000.00	-56.00	-7.75	8.68	43186.83	1372.31	0.27
Reach 1	0.905	100	upper_bound_0	375000.00	-56.00	2.18	6.62	56658.48	1488.23	0.18
Reach 1	0.905	100	upper_bound_15	375000.00	-56.00	15.89	4.96	75535.57	1522.43	0.12
Reach 1	0.905	100	upper_bound_30	375000.00	-56.00	30.42	3.92	95546.88	1522.43	0.08
Reach 1	0.886	100	upper_bound_ND	375000.00	-55.27	-7.78	8.67	43228.02	1365.83	0.27
Reach 1	0.886	100	upper_bound_0	375000.00	-55.27	2.16	6.61	56752.09	1494.34	0.18
Reach 1	0.886	100	upper_bound_15	375000.00	-55.27	15.88	4.96	75586.38	1505.50	0.12
Reach 1	0.886	100	upper_bound_30	375000.00	-55.27	30.42	3.92	95545.87	1505.50	0.08
Reach 1	0.867	100	upper_bound_ND	375000.00	-54.70	-7.88	8.90	42124.21	1365.66	0.28

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	0.867	100	upper_bound_0	375000.00	-54.70	2.12	6.73	55720.40	1492.10	0.19
Reach 1	0.867	100	upper_bound_15	375000.00	-54.70	15.87	5.03	74598.47	1510.35	0.12
Reach 1	0.867	100	upper_bound_30	375000.00	-54.70	30.41	3.96	94580.51	1510.35	0.08
Reach 1	0.848	100	upper_bound_ND	375000.00	-48.59	-8.10	9.48	39565.26	1349.90	0.31
Reach 1	0.848	100	upper_bound_0	375000.00	-48.59	2.04	7.01	53492.50	1464.95	0.20
Reach 1	0.848	100	upper_bound_15	375000.00	-48.59	15.84	5.16	72627.55	1472.29	0.13
Reach 1	0.848	100	upper_bound_30	375000.00	-48.59	30.40	4.04	92829.24	1472.29	0.09
Reach 1	0.830	100	upper_bound_ND	375000.00	-48.24	-8.22	9.73	38541.45	1325.90	0.32
Reach 1	0.830	100	upper_bound_0	375000.00	-48.24	2.00	7.13	52593.91	1430.29	0.21
Reach 1	0.830	100	upper_bound_15	375000.00	-48.24	15.83	5.18	72418.70	1433.53	0.13
Reach 1	0.830	100	upper_bound_30	375000.00	-48.24	30.40	4.02	93305.20	1433.53	0.09
Reach 1	0.811	100	upper_bound_ND	375000.00	-49.00	-8.32	9.89	37912.56	1310.43	0.32
Reach 1	0.811	100	upper_bound_0	375000.00	-49.00	1.96	7.22	51925.08	1406.73	0.21
Reach 1	0.811	100	upper_bound_15	375000.00	-49.00	15.81	5.25	71409.00	1406.73	0.13
Reach 1	0.811	100	upper_bound_30	375000.00	-49.00	30.39	4.08	91916.34	1406.73	0.09
Reach 1	0.792	100	upper_bound_ND	375000.00	-49.18	-8.40	9.99	37530.68	1301.57	0.33
Reach 1	0.792	100	upper_bound_0	375000.00	-49.18	1.93	7.29	51469.94	1394.60	0.21
Reach 1	0.792	100	upper_bound_15	375000.00	-49.18	15.80	5.27	71095.73	1416.31	0.13
Reach 1	0.792	100	upper_bound_30	375000.00	-49.18	30.38	4.09	91752.18	1416.31	0.09
Reach 1	0.773	100	upper_bound_ND	375000.00	-48.32	-8.64	10.53	35619.90	1282.51	0.35
Reach 1	0.773	100	upper_bound_0	375000.00	-48.32	1.84	7.55	49689.45	1395.74	0.22
Reach 1	0.773	100	upper_bound_15	375000.00	-48.32	15.77	5.39	69529.31	1427.34	0.14
Reach 1	0.773	100	upper_bound_30	375000.00	-48.32	30.37	4.15	90370.20	1427.34	0.09
Reach 1	0.754	100	upper_bound_ND	375000.00	-46.18	-8.93	11.17	33586.68	1292.42	0.39
Reach 1	0.754	100	upper_bound_0	375000.00	-46.18	1.75	7.82	47945.18	1394.47	0.24
Reach 1	0.754	100	upper_bound_15	375000.00	-46.18	15.74	5.51	67998.80	1440.76	0.14
Reach 1	0.754	100	upper_bound_30	375000.00	-46.18	30.36	4.21	89061.43	1440.76	0.09
Reach 1	0.735	100	upper_bound_ND	375000.00	-45.98	-8.95	10.98	34165.00	1282.20	0.37
Reach 1	0.735	100	upper_bound_0	375000.00	-45.98	1.73	7.76	48305.32	1357.14	0.23
Reach 1	0.735	100	upper_bound_15	375000.00	-45.98	15.73	5.55	67528.29	1377.13	0.14
Reach 1	0.735	100	upper_bound_30	375000.00	-45.98	30.35	4.28	87662.94	1377.13	0.09
Reach 1	0.716	100	upper_bound_ND	375000.00	-45.92	-8.95	10.71	35016.58	1284.21	0.36
Reach 1	0.716	100	upper_bound_0	375000.00	-45.92	1.74	7.62	49215.26	1355.97	0.22
Reach 1	0.716	100	upper_bound_15	375000.00	-45.92	15.73	5.49	68355.20	1369.45	0.14
Reach 1	0.716	100	upper_bound_30	375000.00	-45.92	30.35	4.24	88376.60	1369.45	0.09
Reach 1	0.697	100	upper_bound_ND	375000.00	-49.00	-8.78	9.73	38524.39	1350.47	0.32
Reach 1	0.697	100	upper_bound_0	375000.00	-49.00	1.81	7.05	53182.43	1410.21	0.20
Reach 1	0.697	100	upper_bound_15	375000.00	-49.00	15.76	5.12	73171.20	1436.55	0.13
Reach 1	0.697	100	upper_bound_30	375000.00	-49.00	30.37	3.98	94152.32	1436.55	0.09
Reach 1	0.678	100	upper_bound_ND	375000.00	-49.54	-9.15	10.64	35243.75	1314.87	0.36
Reach 1	0.678	100	upper_bound_0	375000.00	-49.54	1.68	7.51	49964.69	1398.84	0.22
Reach 1	0.678	100	upper_bound_15	375000.00	-49.54	15.71	5.36	69980.38	1431.59	0.14
Reach 1	0.678	100	upper_bound_30	375000.00	-49.54	30.35	4.12	90926.03	1431.59	0.09
Reach 1	0.659	100	upper_bound_ND	375000.00	-47.37	-9.47	11.33	33084.48	1237.36	0.39
Reach 1	0.659	100	upper_bound_0	375000.00	-47.37	1.54	7.97	47043.09	1299.16	0.23
Reach 1	0.659	100	upper_bound_15	375000.00	-47.37	15.65	5.67	66088.95	1364.42	0.14
Reach 1	0.659	100	upper_bound_30	375000.00	-47.37	30.31	4.36	86092.82	1364.42	0.10
Reach 1	0.640	100	upper_bound_ND	375000.00	-47.46	-9.81	12.00	31246.62	1224.51	0.42
Reach 1	0.640	100	upper_bound_0	375000.00	-47.46	1.43	8.26	45409.10	1289.81	0.25
Reach 1	0.640	100	upper_bound_15	375000.00	-47.46	15.61	5.82	64401.63	1355.94	0.15
Reach 1	0.640	100	upper_bound_30	375000.00	-47.46	30.29	4.45	84308.13	1355.94	0.10
Reach 1	0.621	100	upper_bound_ND	375000.00	-64.44	-9.56	10.72	34986.29	1223.02	0.35
Reach 1	0.621	100	upper_bound_0	375000.00	-64.44	1.51	7.68	48839.52	1280.39	0.22
Reach 1	0.621	100	upper_bound_15	375000.00	-64.44	15.64	5.55	67514.36	1334.54	0.14
Reach 1	0.621	100	upper_bound_30	375000.00	-64.44	30.30	4.31	87086.15	1334.54	0.09

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	0.612			Bridge						
Reach 1	0.602	100	upper_bound_ND	375000.00	-57.62	-9.94	11.01	34070.61	1206.35	0.36
Reach 1	0.602	100	upper_bound_0	375000.00	-57.62	1.37	7.81	48044.46	1270.06	0.22
Reach 1	0.602	100	upper_bound_15	375000.00	-57.62	15.48	5.59	67068.02	1368.54	0.14
Reach 1	0.602	100	upper_bound_30	375000.00	-57.62	30.24	4.30	87268.35	1368.54	0.09
Reach 1	0.583	100	upper_bound_ND	375000.00	-48.34	-10.38	11.96	31355.67	1182.04	0.41
Reach 1	0.583	100	upper_bound_0	375000.00	-48.34	1.27	8.08	46437.90	1787.08	0.28
Reach 1	0.583	100	upper_bound_15	375000.00	-48.34	15.53	5.14	72914.49	1867.64	0.15
Reach 1	0.583	100	upper_bound_30	375000.00	-48.34	30.29	3.73	100485.10	1867.64	0.09
Reach 1	0.564	100	upper_bound_ND	375000.00	-44.87	-10.86	12.89	29086.64	1149.83	0.45
Reach 1	0.564	100	upper_bound_0	375000.00	-44.87	1.20	8.19	45764.26	1833.96	0.29
Reach 1	0.564	100	upper_bound_15	375000.00	-44.87	15.52	5.13	73041.09	1920.01	0.15
Reach 1	0.564	100	upper_bound_30	375000.00	-44.87	30.29	3.70	101398.80	1920.01	0.09
Reach 1	0.545	100	upper_bound_ND	375000.00	-42.30	-11.01	12.99	28861.06	1352.78	0.50
Reach 1	0.545	100	upper_bound_0	375000.00	-42.30	1.27	7.56	49613.94	1898.82	0.26
Reach 1	0.545	100	upper_bound_15	375000.00	-42.30	15.54	4.86	77154.51	1934.69	0.14
Reach 1	0.545	100	upper_bound_30	375000.00	-42.30	30.30	3.55	105704.50	1934.69	0.08
Reach 1	0.527	100	upper_bound_ND	375000.00	-41.31	-10.50	10.65	35210.72	1633.60	0.40
Reach 1	0.527	100	upper_bound_0	375000.00	-41.31	1.37	6.75	55563.58	1777.28	0.21
Reach 1	0.527	100	upper_bound_15	375000.00	-41.31	15.56	4.61	81342.29	1826.64	0.12
Reach 1	0.527	100	upper_bound_30	375000.00	-41.31	30.30	3.46	108269.80	1826.64	0.08
Reach 1	0.508	100	upper_bound_ND	375000.00	-41.26	-10.47	10.19	36796.30	1691.61	0.39
Reach 1	0.508	100	upper_bound_0	375000.00	-41.26	1.39	6.54	57379.63	1776.95	0.20
Reach 1	0.508	100	upper_bound_15	375000.00	-41.26	15.56	4.53	82799.59	1796.74	0.12
Reach 1	0.508	100	upper_bound_30	375000.00	-41.26	30.30	3.43	109282.10	1796.74	0.08
Reach 1	0.489	100	upper_bound_ND	375000.00	-42.00	-10.48	9.93	37746.64	1633.88	0.36
Reach 1	0.489	100	upper_bound_0	375000.00	-42.00	1.37	6.51	57604.78	1707.37	0.20
Reach 1	0.489	100	upper_bound_15	375000.00	-42.00	15.55	4.57	82019.57	1724.86	0.12
Reach 1	0.489	100	upper_bound_30	375000.00	-42.00	30.29	3.49	107447.50	1724.86	0.08
Reach 1	0.470	100	upper_bound_ND	375000.00	-42.00	-10.62	10.15	36943.66	1554.84	0.37
Reach 1	0.470	100	upper_bound_0	375000.00	-42.00	1.32	6.70	55982.87	1634.71	0.20
Reach 1	0.470	100	upper_bound_15	375000.00	-42.00	15.52	4.72	79489.48	1658.48	0.12
Reach 1	0.470	100	upper_bound_30	375000.00	-42.00	30.28	3.61	103958.50	1658.48	0.08
Reach 1	0.451	100	upper_bound_ND	375000.00	-43.20	-10.98	10.96	34200.69	1476.32	0.40
Reach 1	0.451	100	upper_bound_0	375000.00	-43.20	1.20	7.12	52683.09	1562.01	0.22
Reach 1	0.451	100	upper_bound_15	375000.00	-43.20	15.47	5.00	75042.20	1566.63	0.13
Reach 1	0.451	100	upper_bound_30	375000.00	-43.20	30.25	3.82	98191.76	1566.63	0.09
Reach 1	0.432	100	upper_bound_ND	375000.00	-42.00	-11.40	11.85	31651.99	1399.61	0.44
Reach 1	0.432	100	upper_bound_0	375000.00	-42.00	1.07	7.56	49592.61	1482.08	0.23
Reach 1	0.432	100	upper_bound_15	375000.00	-42.00	15.42	5.25	71443.24	1533.10	0.14
Reach 1	0.432	100	upper_bound_30	375000.00	-42.00	30.22	3.98	94137.10	1533.10	0.09
Reach 1	0.413	100	upper_bound_ND	375000.00	-42.00	-11.66	12.27	30569.12	1213.09	0.43
Reach 1	0.413	100	upper_bound_0	375000.00	-42.00	0.97	7.84	47816.04	1445.23	0.24
Reach 1	0.413	100	upper_bound_15	375000.00	-42.00	15.39	5.41	69342.11	1507.43	0.14
Reach 1	0.413	100	upper_bound_30	375000.00	-42.00	30.21	4.09	91683.54	1507.43	0.09
Reach 1	0.394	100	upper_bound_ND	375000.00	-43.10	-11.80	12.40	30248.81	1185.37	0.43
Reach 1	0.394	100	upper_bound_0	375000.00	-43.10	0.91	7.98	46986.16	1407.90	0.24
Reach 1	0.394	100	upper_bound_15	375000.00	-43.10	15.36	5.51	68066.39	1474.63	0.14
Reach 1	0.394	100	upper_bound_30	375000.00	-43.10	30.19	4.17	89939.75	1474.63	0.09
Reach 1	0.375	100	upper_bound_ND	375000.00	-45.56	-11.83	12.22	30688.28	1157.74	0.42
Reach 1	0.375	100	upper_bound_0	375000.00	-45.56	0.89	7.97	47036.29	1391.16	0.24
Reach 1	0.375	100	upper_bound_15	375000.00	-45.56	15.35	5.52	67928.68	1453.96	0.14
Reach 1	0.375	100	upper_bound_30	375000.00	-45.56	30.19	4.19	89500.80	1453.96	0.09

HEC-RAS River: Willamette Reach: Reach 1 Profile: 100 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	0.356	100	upper_bound_ND	375000.00	-47.94	-11.86	12.01	31213.33	1177.18	0.41
Reach 1	0.356	100	upper_bound_0	375000.00	-47.94	0.87	7.92	47319.70	1359.72	0.24
Reach 1	0.356	100	upper_bound_15	375000.00	-47.94	15.34	5.54	67746.27	1424.84	0.14
Reach 1	0.356	100	upper_bound_30	375000.00	-47.94	30.18	4.22	88890.84	1424.84	0.09
Reach 1	0.337	100	upper_bound_ND	375000.00	-46.78	-11.92	11.97	31318.38	1162.73	0.41
Reach 1	0.337	100	upper_bound_0	375000.00	-46.78	0.83	7.98	46964.95	1315.12	0.24
Reach 1	0.337	100	upper_bound_15	375000.00	-46.78	15.31	5.63	66654.17	1367.97	0.14
Reach 1	0.337	100	upper_bound_30	375000.00	-46.78	30.16	4.31	86965.68	1367.97	0.10
Reach 1	0.318	100	upper_bound_ND	375000.00	-43.84	-12.73	13.61	27550.22	1145.83	0.49
Reach 1	0.318	100	upper_bound_0	375000.00	-43.84	0.63	8.61	43560.09	1281.15	0.26
Reach 1	0.318	100	upper_bound_15	375000.00	-43.84	15.24	5.96	62923.60	1334.44	0.15
Reach 1	0.318	100	upper_bound_30	375000.00	-43.84	30.13	4.53	82787.70	1334.44	0.10
Reach 1	0.299	100	upper_bound_ND	375000.00	-44.19	-13.20	14.37	26105.09	1114.02	0.52
Reach 1	0.299	100	upper_bound_0	375000.00	-44.19	0.53	8.86	42319.54	1239.71	0.27
Reach 1	0.299	100	upper_bound_15	375000.00	-44.19	15.20	6.11	61337.90	1314.70	0.16
Reach 1	0.299	100	upper_bound_30	375000.00	-44.19	30.11	4.63	80935.66	1314.70	0.10
Reach 1	0.280	100	upper_bound_ND	375000.00	-42.62	-13.49	14.69	25532.99	1097.75	0.54
Reach 1	0.280	100	upper_bound_0	375000.00	-42.62	0.46	8.98	41736.87	1220.90	0.27
Reach 1	0.280	100	upper_bound_15	375000.00	-42.62	15.17	6.22	60308.70	1273.82	0.16
Reach 1	0.280	100	upper_bound_30	375000.00	-42.62	30.09	4.73	79312.68	1273.82	0.11
Reach 1	0.261	100	upper_bound_ND	375000.00	-41.22	-13.86	15.13	24788.13	1090.66	0.56
Reach 1	0.261	100	upper_bound_0	375000.00	-41.22	0.38	9.14	41026.77	1184.70	0.27
Reach 1	0.261	100	upper_bound_15	375000.00	-41.22	15.13	6.33	59234.91	1251.85	0.16
Reach 1	0.261	100	upper_bound_30	375000.00	-41.22	30.07	4.81	77931.18	1251.85	0.11
Reach 1	0.242	100	upper_bound_ND	375000.00	-42.00	-14.16	15.42	24324.12	1082.42	0.57
Reach 1	0.242	100	upper_bound_0	375000.00	-42.00	0.31	9.27	40438.16	1147.48	0.28
Reach 1	0.242	100	upper_bound_15	375000.00	-42.00	15.10	6.44	58238.07	1226.96	0.16
Reach 1	0.242	100	upper_bound_30	375000.00	-42.00	30.05	4.90	76581.55	1226.96	0.11
Reach 1	0.223	100	upper_bound_ND	375000.00	-42.26	-14.30	15.38	24381.20	1075.84	0.57
Reach 1	0.223	100	upper_bound_0	375000.00	-42.26	0.28	9.25	40522.98	1138.55	0.27
Reach 1	0.223	100	upper_bound_15	375000.00	-42.26	15.09	6.45	58107.03	1208.60	0.16
Reach 1	0.223	100	upper_bound_30	375000.00	-42.26	30.04	4.92	76181.77	1208.60	0.11
Reach 1	0.205	100	upper_bound_ND	375000.00	-44.60	-14.49	15.45	24276.33	1067.59	0.57
Reach 1	0.205	100	upper_bound_0	375000.00	-44.60	0.25	9.25	40531.30	1140.44	0.27
Reach 1	0.205	100	upper_bound_15	375000.00	-44.60	15.07	6.47	57930.72	1181.37	0.16
Reach 1	0.205	100	upper_bound_30	375000.00	-44.60	30.03	4.96	75602.70	1181.37	0.11
Reach 1	0.186	100	upper_bound_ND	375000.00	-44.62	-14.85	15.83	23682.43	1059.40	0.59
Reach 1	0.186	100	upper_bound_0	375000.00	-44.62	0.20	9.31	40295.38	1154.97	0.28
Reach 1	0.186	100	upper_bound_15	375000.00	-44.62	15.06	6.49	57790.88	1181.48	0.16
Reach 1	0.186	100	upper_bound_30	375000.00	-44.62	30.03	4.97	75473.86	1181.48	0.11
Reach 1	0.167	100	upper_bound_ND	375000.00	-45.00	-14.97	15.71	23869.27	1071.23	0.59
Reach 1	0.167	100	upper_bound_0	375000.00	-45.00	0.19	9.20	40746.79	1162.79	0.27
Reach 1	0.167	100	upper_bound_15	375000.00	-45.00	15.06	6.41	58467.08	1197.63	0.16
Reach 1	0.167	100	upper_bound_30	375000.00	-45.00	30.03	4.91	76393.69	1197.63	0.11
Reach 1	0.148	100	upper_bound_ND	375000.00	-45.99	-15.46	16.29	23024.43	1043.58	0.61
Reach 1	0.148	100	upper_bound_0	375000.00	-45.99	0.11	9.36	40049.53	1153.58	0.28
Reach 1	0.148	100	upper_bound_15	375000.00	-45.99	15.04	6.48	57906.30	1201.63	0.16
Reach 1	0.148	100	upper_bound_30	375000.00	-45.99	30.02	4.94	75909.82	1201.63	0.11
Reach 1	0.129	100	upper_bound_ND	375000.00	-47.25	-15.85	16.64	22529.29	1044.55	0.63
Reach 1	0.129	100	upper_bound_0	375000.00	-47.25	0.07	9.40	39895.67	1141.75	0.28
Reach 1	0.129	100	upper_bound_15	375000.00	-47.25	15.02	6.49	57784.14	1215.64	0.17
Reach 1	0.129	100	upper_bound_30	375000.00	-47.25	30.02	4.93	76009.37	1215.64	0.11
Reach 1	0.110	100	upper_bound_ND	375000.00	-47.79	-16.39	17.23	21758.80	1042.47	0.66
Reach 1	0.110	100	upper_bound_0	375000.00	-47.79	0.02	9.44	39708.28	1145.44	0.28
Reach 1	0.110	100	upper_bound_15	375000.00	-47.79	15.02	6.47	57925.84	1235.62	0.17

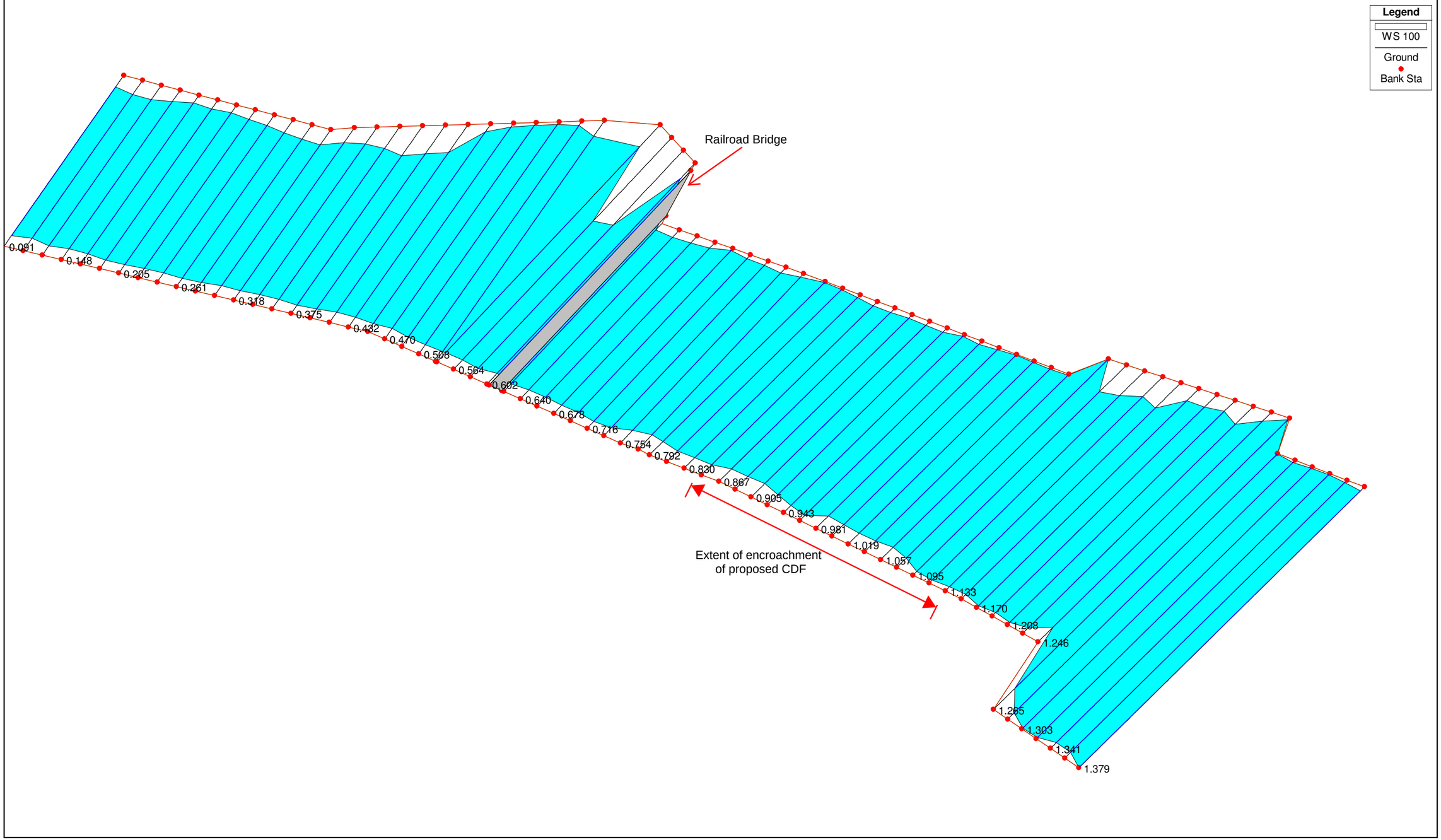
HEC-RAS River: Willamette Reach: Reach 1 Profile: 100 (Continued)

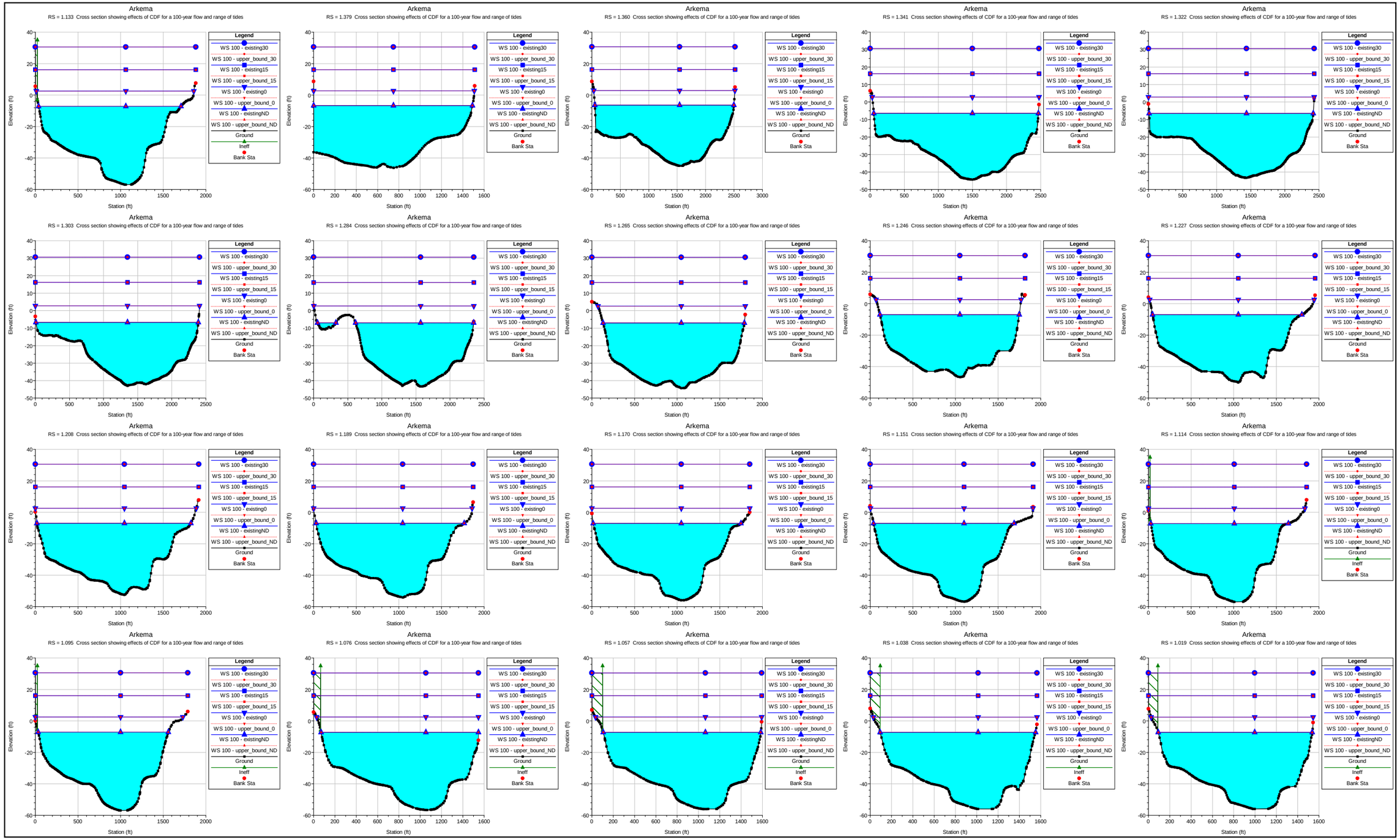
Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	
Reach 1	0.110	100	upper_bound_30	375000.00	-47.79	30.01	4.90	76459.20	1235.62	0.11
Reach 1	0.091	100	upper_bound_ND	375000.00	-48.00	-16.60	17.24	21752.67	1031.98	0.66
Reach 1	0.091	100	upper_bound_0	375000.00	-48.00	0.00	9.39	39957.17	1165.43	0.28
Reach 1	0.091	100	upper_bound_15	375000.00	-48.00	15.00	6.50	57722.76	1186.27	0.16
Reach 1	0.091	100	upper_bound_30	375000.00	-48.00	30.00	4.97	75516.81	1186.27	0.11

Plan name	Description
Arkema_existing_ND	Existing Conditions Model with normal depth downstream WSE (0.0021)
Arkema_upper_bound_ND	Proposed Conditions Model with normal depth downstream WSE (0.0021)
Arkema_existing_0	Existing Conditions Model with 0 ft NGVD downstream WSE
Arkema_upper_bound_0	Proposed Conditions Model with 0 ft NGVD downstream WSE
Arkema_existing_15	Existing Conditions Model with 15 ft NGVD downstream WSE
Arkema_upper_bound_15	Proposed Conditions Model with 15 ft NGVD downstream WSE
Arkema_existing_30	Existing Conditions Model with 30 ft NGVD downstream WSE
Arkema_upper_bound_30	Proposed Conditions Model with 30 ft NGVD downstream WSE

Notes:
1. NGVD = National Geodetic Vertical Datum
2. WSE = Water Surface Elevation

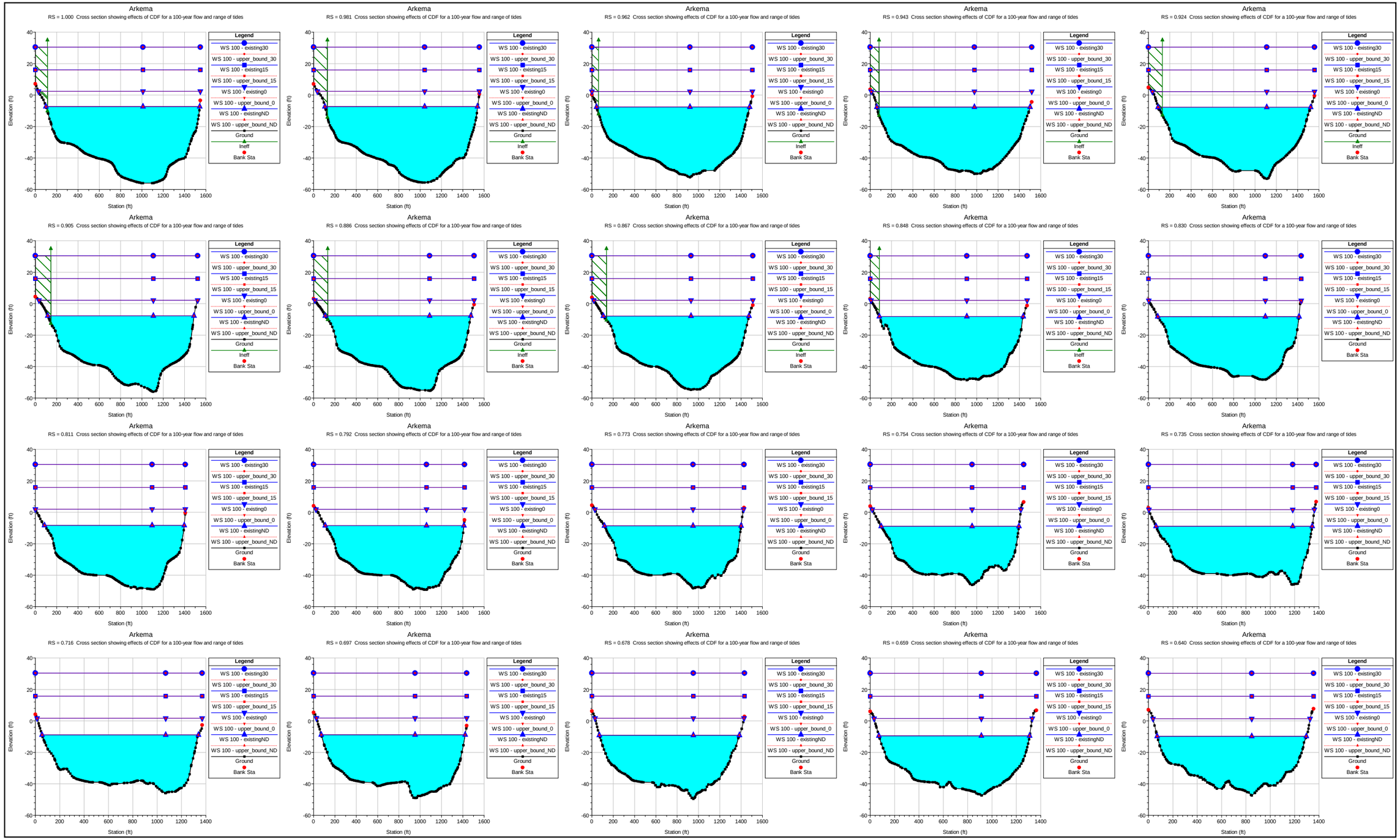
Arkema XYZ plot showing layout of HEC-RAS model





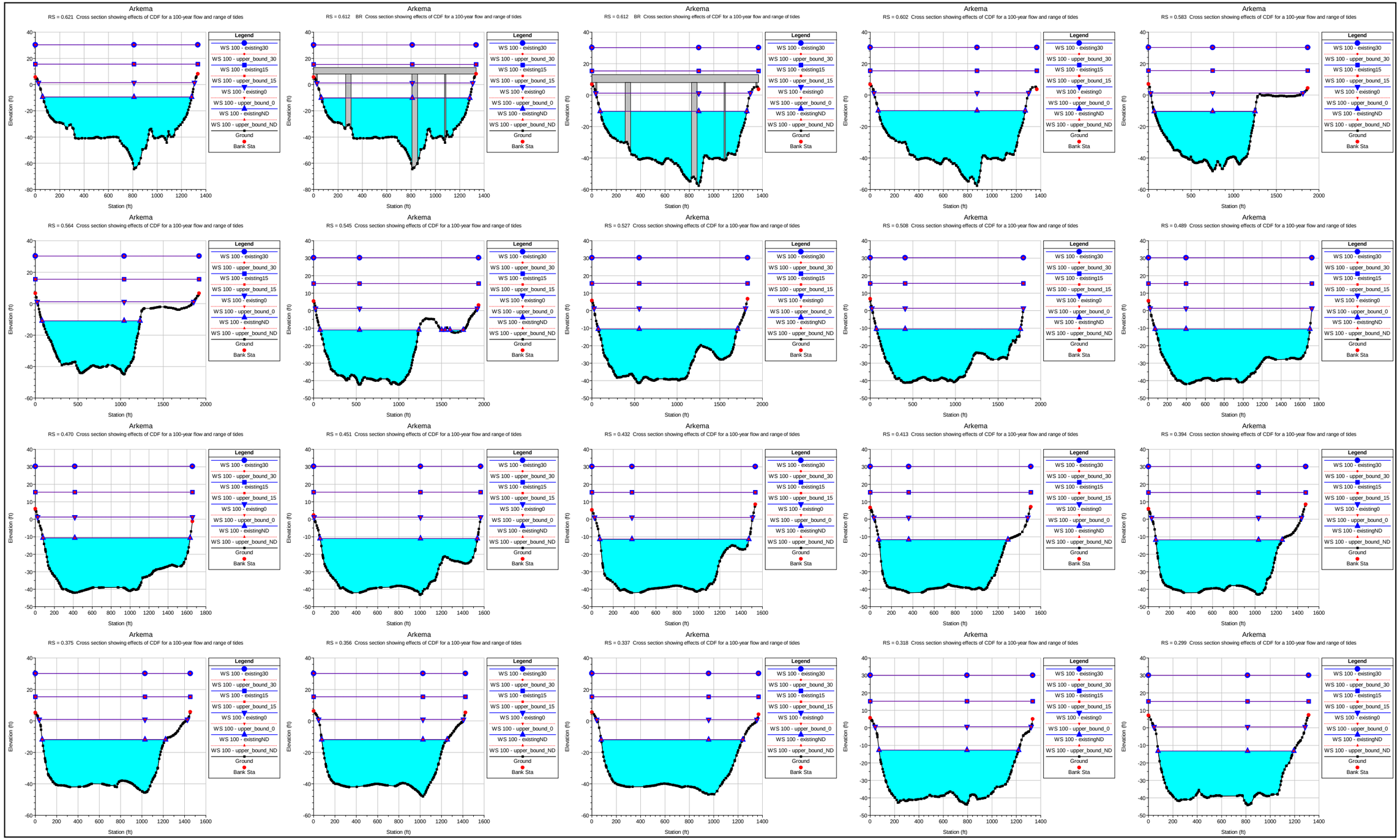
Notes

1. Existing Conditions shown in Blue; Proposed Conditions shown in Red
2. Ineffective flow areas indicate extent of CDF encroachment into channel



Notes

1. Existing Conditions shown in Blue; Proposed Conditions shown in Red
2. Ineffective flow areas indicate extent of CDF encroachment into channel

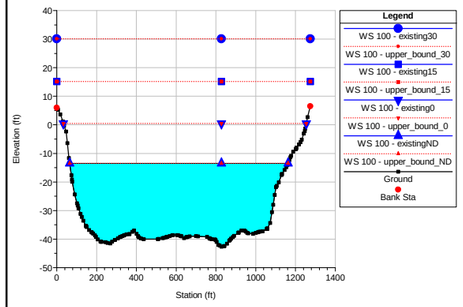


Notes

1. Existing Conditions shown in Blue; Proposed Conditions shown in Red

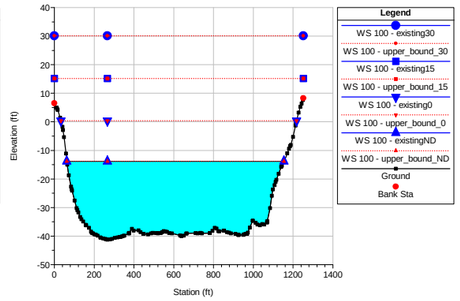
Arkema

RS = 0.280 Cross section showing effects of CDF for a 100-year flow and range of tides



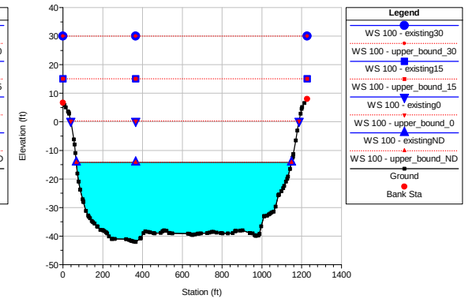
Arkema

RS = 0.261 Cross section showing effects of CDF for a 100-year flow and range of tides



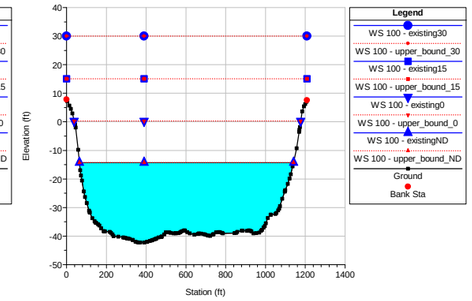
Arkema

RS = 0.242 Cross section showing effects of CDF for a 100-year flow and range of tides



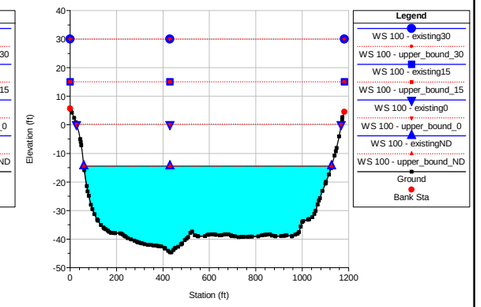
Arkema

RS = 0.223 Cross section showing effects of CDF for a 100-year flow and range of tides



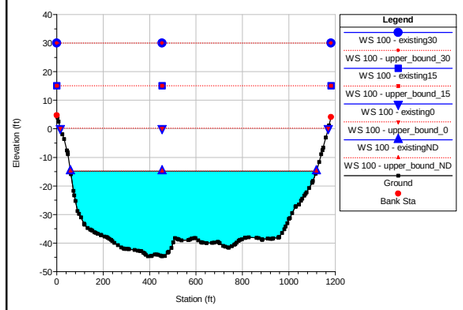
Arkema

RS = 0.205 Cross section showing effects of CDF for a 100-year flow and range of tides



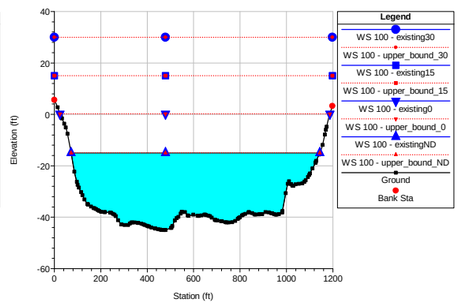
Arkema

RS = 0.186 Cross section showing effects of CDF for a 100-year flow and range of tides



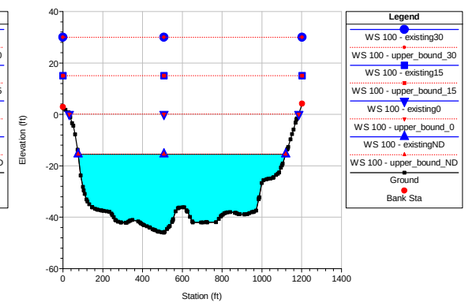
Arkema

RS = 0.167 Cross section showing effects of CDF for a 100-year flow and range of tides



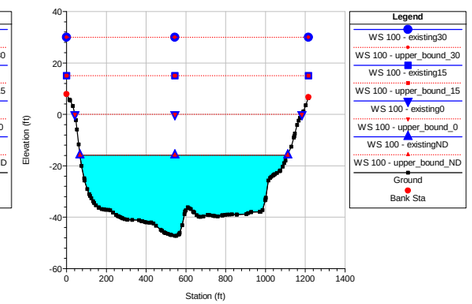
Arkema

RS = 0.148 Cross section showing effects of CDF for a 100-year flow and range of tides



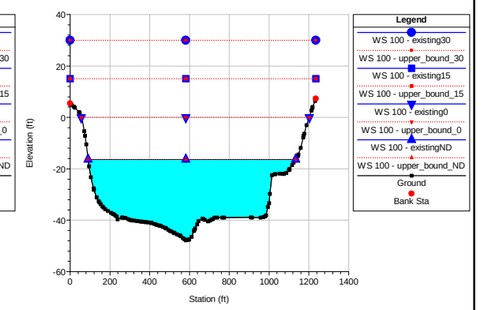
Arkema

RS = 0.129 Cross section showing effects of CDF for a 100-year flow and range of tides



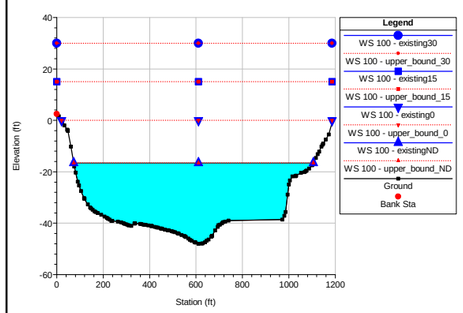
Arkema

RS = 0.110 Cross section showing effects of CDF for a 100-year flow and range of tides



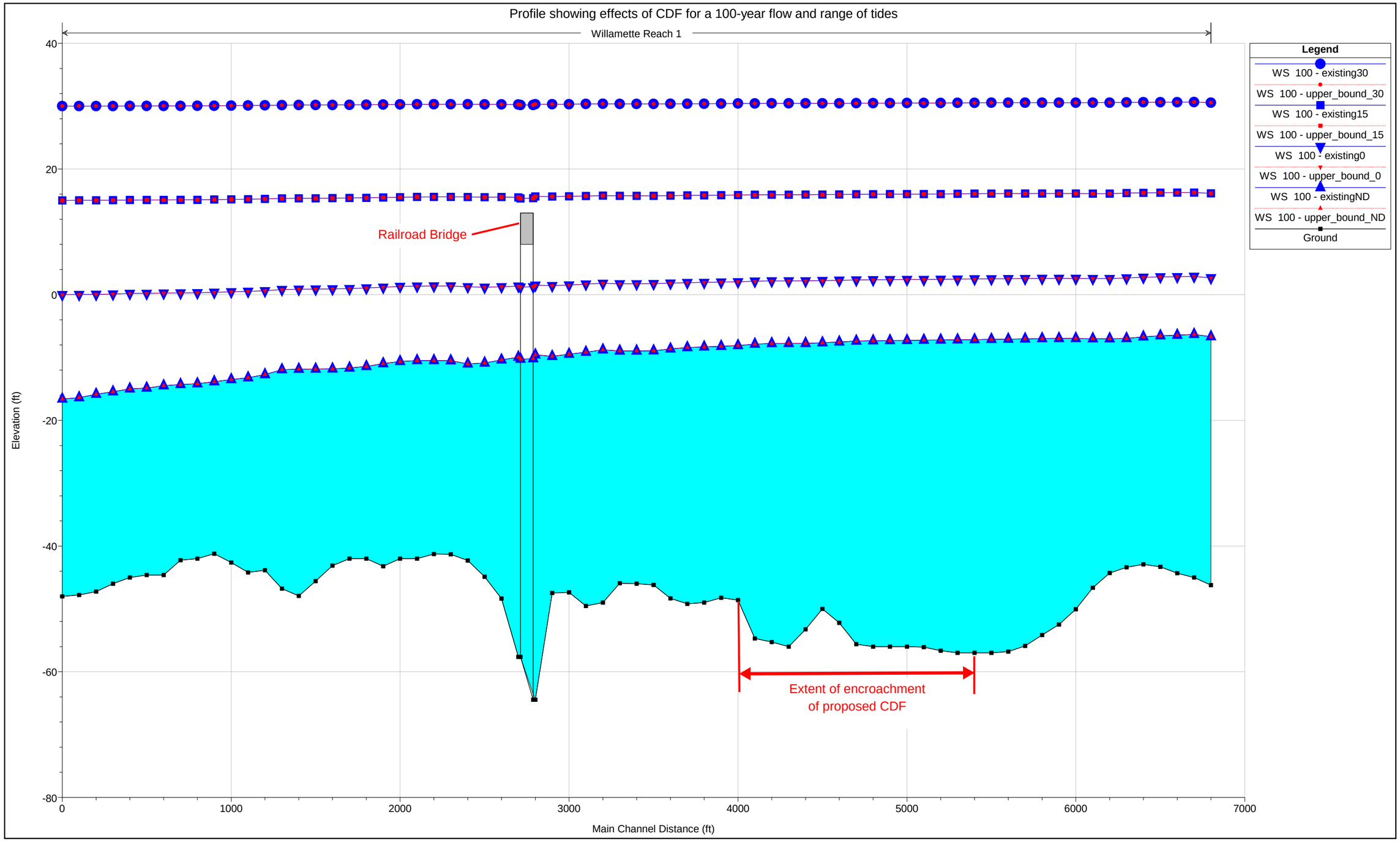
Arkema

RS = 0.091 Cross section showing effects of CDF for a 100-year flow and range of tides

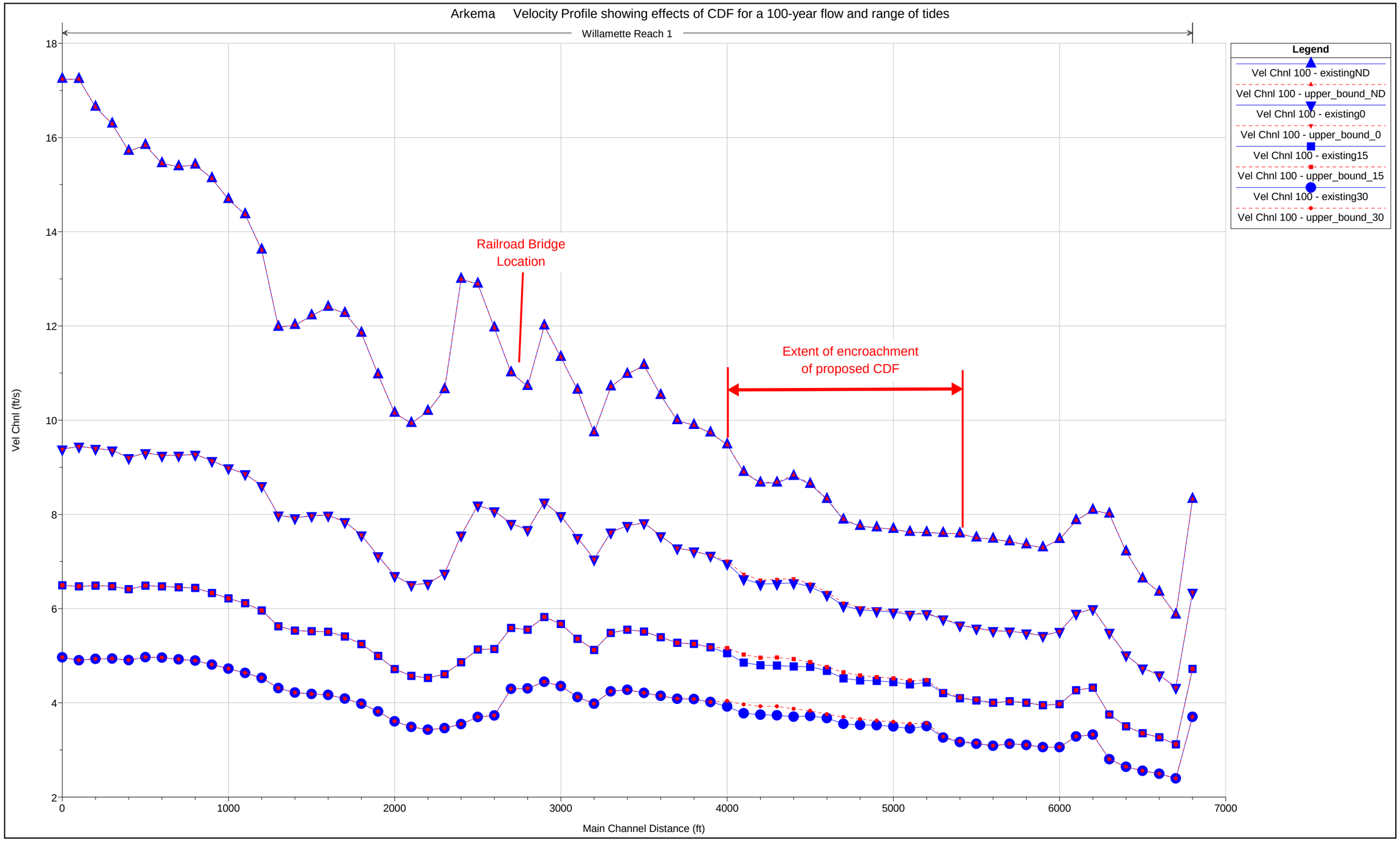


Notes

1. Existing Conditions shown in Blue; Proposed Conditions shown in Red



Notes
1. Existing Conditions shown in Blue; Proposed Conditions shown in Red



Notes

1. Existing Conditions shown in Blue; Proposed Conditions shown in Red

Appendix C

Balanced Cut and Fill Analysis

1. Metro Title 3 Delineation

Two shapefiles were obtained from the City of Portland Bureau of Technology Services and Corporate Geographic Information Services office on July 20, 2009:

- 1996_Flood_metro—A delineation of the areas of inundation near the mainstream and major tributaries of the Willamette River during the February 1996 floods

- Potential_Flood_Hazard_pdx—A delineation of the Title 3 Lands within urban Clackamas, Multnomah, and Washington counties, Oregon

The shapefiles are shown on Figure C-1 (Attachment C-1).

In addition, the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) was obtained from the FEMA Flood Map website (www.msc.fema.gov) for the vicinity of the Arkema Portland Site. The FIRM is provided as Attachment C-2.

1.1 1996 Flood Shapefile

This shapefile was developed using aerial photographs of the region during the floods that occurred from February 9 to 11, 1996. The flood inundation line was digitized directly from the aerial photographs. This shapefile represents areas of observed inundation during the flood, not a measured or calculated elevation line. The metadata for this shapefile is provided as Attachment C-3.

1.2 Title 3 Lands Shapefile

This shapefile delineates areas protected by the Stream and Floodplain Protection Plan by combining data from various sources. The following data are contained in the Title 3 Lands shapefile:

- WetBuf—Water Quality Resource Areas (as defined by Title 3) that were created by buffering wetlands. Buffer widths are 50 feet for all wetlands.

- Riparian—Water Quality Resource Areas (as defined by Title 3) that were created by buffering streams. Buffer widths vary depending on the size of the stream.

- Title3—Title 3 Land designation not defined by one of the other categories listed here.

- Flood96—February 1996 flood inundation areas, protected as Title 3 Flood Management Areas.

- FEMA—FEMA 100-year floodplain, protected as Title 3 Flood Management Areas.

The Title 3 Lands shapefile within the vicinity of the Site is shown on Figure C-1 (Attachment C-1), with each of the data types labeled.

The Title 3 Lands shapefile defines an area in the horizontal plane. There is no elevation associated with the Title 3 Lands delineation. The metadata for this shapefile is provided as Attachment C-4.

1.3 FEMA FIRM

The FEMA FIRM provides the 100-year base flood elevation for the Site vicinity, as well as the Flood Hazard Area zone designation. The 100-year base flood elevation for the Site vicinity is +31 feet North American Vertical Datum of 1988 (NAVD 88) and the Flood Hazard Area zone designation is Zone AE.

1.4 Balanced Cut and Fill Analysis

The most upland points from the Flood 1996 and Title 3 Land delineation shapefiles were used to establish one continuous Title 3 Land delineation, shown on the balanced cut and fill figures (Figures 13 and 14) in the CDF screening evaluation document. The smaller subarea designations that fell within the footprint of the Title 3 Land delineation, such as WetBuf and Riparian, were removed. The Title 3 Land delineation was overlaid onto the one-berth confined disposal facility (CDF) and two-berth CDF layouts to determine whether the layouts fall within the Title 3 Land delineation. The entire one-berth CDF and two-berth conceptual CDF footprints both fell within the Title 3 Land delineation. The FEMA 100-year base flood elevation of +31 feet NAVD 88 was then used to determine applicable cut and fill volumes below the base flood elevation, per the Title 3 regulation. The following volumes were calculated:

- **Dredged material.** Dredging is not considered a cut, as defined by the Title 3 regulation, which states that excavation will not be counted as compensation for fill in areas that are filled with water in non-storm conditions. Dredged material

volumes were calculated to determine the quantity of dredged material to be placed within the CDF, because placement of this material is considered fill per the Title 3 regulation. Dredged material volumes were calculated using the one-berth and two-berth CDF dredging areas and an assumed dredging thickness of 15 feet.

- **Cofferdam walls.** Material placed between the existing mudline elevation and the base flood elevation of +31 feet NAVD 88 would be considered fill per the Title 3 regulation. The volume of material to be placed between these two elevations was calculated using the existing mudline and proposed cofferdam wall footprints for the one-berth and two-berth CDF layouts.

- **CDF cap material.** The CDF would include a cap placed over the dredged material. An 8-foot cap is proposed, extending from +27 to +35 feet NAVD 88. For the purposes of the Title 3 regulation, the fill quantity of interest is the volume of fill placed between +27 and +31 feet NAVD 88. This volume was calculated for both the one-berth and two-berth CDF layouts, using the area of the footprint between the interior wall of the cofferdam to elevation +31 feet NAVD 88 and a cap thickness of 4 feet.

Appendix D

Treatment Technology Evaluation

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1. Treatment Technology Evaluation

1.1 Summary of Existing Sediment Chemistry

Varied organic and inorganic constituents of interest (COIs) are present within the sediment of the Willamette River adjacent to the Arkema Portland Site (the Site). While there are specific COIs associated with Site activities, many of the COIs originate from upstream and regional sources in this highly industrial area. Table D-1 provides an overview of the 56 COIs (42 organic and 14 inorganic) identified in historical sediment sampling and the feasibility of the potential technologies available to treat these COIs.

The Administrative Order on Consent focuses the non-time-critical removal action at the Site on impacts associated with the Site, and the detailed evaluation in the work plan for the engineering evaluation/cost analysis (EE/CA) identifies DDx (the sum of the DDE, DDD, and DDT isomers) as the focus for the Site. For these reasons, emphasis was placed on DDx in the preliminary evaluation of treatment technologies. These COIs are high-molecular-weight, low-solubility compounds with elevated partitioning coefficients. Given these characteristics, the compounds will tend to partition to organic materials and fine grains within the silty sand sediment matrix and have limited mobility[1]. These compounds are also characterized by low vapor pressure, low Henry's law coefficients, and high boiling points. As such, they are not volatile or strippable and will require moderately high temperatures to be desorbed and mobilized from the sediment, particularly as vapor. In addition, DDx is resistant to biodegradation, but capable of dechlorination in anaerobic conditions, particularly for the more chlorinated parent compounds (as compared to intermediates and daughter products of dechlorination). Aerobic biodegradation is more appropriate for the intermediate products.

Other COIs present in river sediment from upstream and regional sources adjacent to the Site possess similar characteristics and, for this reason, it is important to understand how they will interact with a potential treatment technology. These COIs include the following:

- Polychlorinated biphenyls (PCBs) and PCB Aroclors (1242, 1248, 1254, and 1260)
- Dioxins (which can also be produced through the combustion of other COIs)

[1] The fraction of organic carbon (F_{oc}) of the sediments is needed to further quantify adsorption-desorption kinetics of these compounds.

- Other pesticides, such as aldrin, dieldrin, endrin, heptachlor epoxide, lindane, and chlordanes

Several semivolatile organic compounds (SVOCs) are also present in the river sediment from upstream and regional sources adjacent to the Site. These are also low-mobility compounds that will tend to partition to the sediment and degrade very slowly. The lower-molecular-weight polycyclic aromatic hydrocarbons (PAHs), such as naphthalene, are amenable to aerobic biodegradation and are more mobile; the higher-molecular-weight PAHs, such as benzo(a)pyrene, are more resistant to biodegradation and adsorb very strongly to soil and sediment F_{oc} (fraction of organic carbon). The PAHs are likely more typical of upstream sources and regional industrial impacts (including, but not limited to, combustion and airborne deposition and releases from other industrial and petro-chemical activities). PAH compounds on the COI list are as follows:

- acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene

Other SVOCs include some compounds that are also present in the river sediment upstream and from regional sources adjacent to the Site. These include:

- hexachlorobenzene, hexachlorobutadiene, and hexachloropentadiene

Several phenols and phthalates on the COI list are also present in the river sediment upstream and from regional sources adjacent to the Site. These COIs will not partition as strongly to the sediment, but they tend to be more biodegradable aerobically and sometimes anaerobically. They include:

- phenol, pentachlorophenol (PCP), bis(2-ethylhexyl)phthalate, and dibutyl phthalate

PCP is an exception in that it is a highly chlorinated, high-molecular-weight compound that is susceptible to initial anaerobic dechlorination (similar to DDT and PCBs), with the intermediates being more susceptible to aerobic biodegradation.

Several metals are also present in the river sediment upstream and either from regional sources adjacent to the Site or, in most cases, from geogenic sources, including:

- arsenic, cadmium, copper, iron, lead, mercury, nickel, selenium, thallium, vanadium, and zinc

The metals generally are not susceptible to treatment with most of the treatment technologies presented here, where the focus is mainly on DDx at the Site. The mobility of metals will be influenced by reduction-oxidation (redox) environments (with most being mobilized in oxidizing environments) and pH conditions. Arsenic can be immobilized using some biological, chemical oxidation, and reduction technologies. Mercury (organic form) is the only metal that may be addressed via thermal technology. Only stabilization/solidification or other soil mixing techniques would reduce the permeability and leachability of the treated sediment.

For this evaluation, the treatment technologies under consideration were evaluated primarily on their ability to treat DDx and secondarily on their ability to potentially treat other, harborwide COIs. It was also important to identify whether any of the proposed technologies could exacerbate issues with the underlying harborwide COIs—possibly creating a worse situation, even if effective at treating DDx.

The following treatment technologies were considered in the evaluation:

- Low-temperature thermal desorption (LTTD)
- Chemical oxidation (persulfate, ozone, permanganate, and hydrogen peroxide)
- Soil mixing (solidification/stabilization and zero-valent iron [ZVI] clay)
- Bioremediation (in-situ and ex-situ anaerobic and aerobic)
- Chemical reduction (dithionate, polysulfide, and ZVI)

These technologies are described below, with the treatability analysis focused primarily on DDx. Treatment of harborwide COIs is mentioned where appropriate, as are potential adverse effects on the harborwide COIs.

2. Thermal Technology

2.1 Low-Temperature Thermal Desorption

LTTD, also known as low-temperature thermal volatilization, thermal stripping, or soil roasting, is an ex-situ remedial technology for the treatment of contaminated soil and sediment. LTTD removes organic constituents from soil and sediment by raising the temperature of the contaminated material to a sufficiently high level for contaminant volatilization and transfer to a gas stream. Off-gas treatment and treated soil/sediment stabilization may be required as post-treatment processes.

Prior to being fed to the LTTD treatment unit, dredged sediment would first be screened to remove large objects, such as gravels, soil aggregates, and debris. The dredged sediment would also require dewatering to lower the moisture content to between 5 and 25 percent to achieve minimum operating conditions and higher removal efficiency in the LTTD unit (USEPA 1998a).

Two general classes of low-temperature thermal desorber units are available for full-scale applications: indirect fired unit and direct fired unit. The unit is selected based on the properties of the contaminants and treatment requirements. In an indirect fired unit, heat is conducted to the contaminated material through metal walls or with a medium of heated gas. In the direct fired unit, the burner gases are directly mixed with the contaminated materials. Off-gas stream management is much simpler for the indirect fired unit, because burner gases are separated from the off-gas stream, while the direct fired unit has higher heat transfer efficiency and potential to reach a higher desorption temperature range when needed. Typical thermal desorbers include thermal screw, asphalt aggregate dryer, rotary dryer, and conveyor furnace. LTTD is applicable to chemicals that are volatile at temperatures as high as 750 degrees Fahrenheit (°F) to a maximum of 800 °F (FRTR 2009). LTTD was originally designed for removing petroleum hydrocarbons from soil, but full-scale implementations at a variety of Superfund sites indicated that LTTD is also effective and efficient for removal of organic chlorinated pesticides, including DDT and its breakdown products DDD and DDE, and other contaminants such as PCBs, PAHs, and chlorinated hydrocarbons (USEPA 1995a, 1995b, 1998b, 2003, 2005b).

The off-gas stream needs to be treated to remove particles, organics, and carbon monoxide using equipment such as cyclones, afterburner, baghouse, catalytic oxidizer, and/or vapor-phase activated carbon. Afterburners are designed so that the exit gas temperatures reach 1400 to 1600 °F for complete organic compound destruction.

Organic destruction efficiency in an afterburner typically ranges from 95 percent to greater than 99 percent (USEPA 1994). Condensation needs to be treated with condensers and liquid-phase activated carbon before proper disposal. Treated materials may need to be cooled, moisturized to reduce dusting, and stabilized to reduce metal leachate prior to on-Site disposal.

Advantages of LTTD (if appropriate for treatment of DDx) for the treatment of soil and sediment include the availability of equipment from pilot to full scale, the fact that treatment can be conducted on site, and a treatment time that is faster than some other in-situ and ex-situ technologies. However, the applicability and implementability of LTTD need to be evaluated on a case-by-case basis to address site-specific conditions and treatment goals.

Pilot studies typically are needed to determine the operating parameters for a full-scale unit design, including treatment temperature, residence time, and selection of off-gas treatment and treated material stabilization technologies. When chlorinated organics (e.g., DDx) are present in the contaminated sediment, dioxin formation at an elevated treatment temperature above 650 °F (minimum temperature shown to be effective for volatilization of DDx) at long residence times should be considered (Interstate Technology and Regulatory Council [ITRC] 1998). In addition, PCBs and dioxin (harborwide COIs) in the sediment would not only go untreated (temperatures necessary for volatilization of these COIs are well above the limits for LTTD), but as mentioned in ITRC (1998), these COIs would most likely be exacerbated (through the creation of additional dioxins) due to the high temperature and extended residence time in the unit. Lastly, if metals such as mercury, chromium, lead, and cadmium are present in the contaminated sediment, they may also exist in the off-gas due to soil particle dusting or vapor-liquid phase partitioning. These metals could also leach out during the stabilization of treated materials.

For this treatment option, the exacerbation of harborwide COIs from lower-toxicity compounds to higher-toxicity compounds is to be avoided. Therefore, LTTD is considered technically infeasible. In addition, metals stabilization and removal technologies would need to be selected to address the off-gas and leachate treatment and material stabilization prior to disposal. The appropriate handling and disposal of the residuals generated by the various treatment processes associated with an operating LTTD system would also need to be arranged. Dewatering is another critical item that can impact multiple aspects of the LTTD system, including removal effectiveness, efficiency, and energy consumption. In addition, water content or

moisture can significantly impact energy consumption (evaporating water and lowering moisture) and soil particle properties, which impact compound sorption and desorption.

This treatment option requires a relatively large area of land for LTTD equipment and staging of the off-gas treatment system, temporary stockpiling of pretreated and treated soil and sediment, and temporary on-site storage of residuals. The cost of implementing LTTD is typically higher than other soil/sediment treatment technologies (USEPA 1995a, 1995b, 1998b, 2003, 2005b). Given its certain potential to exacerbate adverse conditions, its excessive energy use, and its large carbon dioxide (CO_2) footprint, LTTD would not be considered a sustainable and green alternative as defined in the USEPA's recent directive and primer for green remediation (USEPA 2008a).

2.1.1 Applicability to the Conceptual CDF

LTTD has demonstrated effectiveness in the removal of DDx compounds and other chlorinated organics. However, given its certain potential to exacerbate adverse conditions, its excessive energy use, and its large CO2 footprint, the LTTD process is not considered a feasible technology at this Site.

3. Chemical Oxidation

Chemical oxidation is an advantageous treatment option, because the mechanisms tend to be rapid, aggressive, and independent of contaminant characteristics and concentrations (Groundwater Remediation Technologies Analysis Center [GWRTAC] 1999). The treatment of contamination through chemical oxidation involves first introducing an oxidant to the impacted media. The oxidant chemicals then react with the contaminant to produce benign end products such as water, carbon dioxide, and chloride. The process of contaminant oxidation can take place either directly through the chemical's oxidation potential or indirectly through the formation of radical intermediates (ITRC 2005a). A list of oxidant species and their associated oxidation potentials is presented in Table D-2.

Four principal oxidants used for environmental remediation are persulfate, permanganate, peroxide, and ozone (ITRC 2005a; USEPA 2006a, 2008b). The effectiveness of the chosen oxidant is dependent on many variables, including individual oxidation potential, type of intermediate radicals produced, persistence of the oxidant, target compounds, type of substrate targeted (soil, groundwater, vadose zone), and the intrinsic properties of the targeted substrate, such as pH, temperature, and organic content. The levels of reactivity of individual oxidants with DDx for the Site are shown in Table D-3.

Based on the above, persulfate appears to be most applicable for chemical oxidation at the Site due to its high level of reactivity with DDx and multiple activation methods, followed by ozone, permanganate, and hydrogen peroxide. The following sections describe the processes in which these individual chemicals oxidize targeted compounds.

3.1.1 Persulfate

This chemical oxidant is typically used as an aqueous solution of the sodium persulfate salt. Oxidation via persulfate is usually a slow process unless it is first activated with ferrous iron or heated to produce sulfate free radicals ($\cdot SO_4^-$). Iron activation of persulfate can be through addition of ferrous iron to the reagent solution prior to introduction or through the reaction with naturally occurring ferrous iron in the subsurface. Heat activation requires temperatures of at least 40 degrees Celsius (°C) through direct heating of the subsurface or through the heat of hydration created by mixing the reagent solution with quick lime (ITRC 2005a; USEPA 2006a).

During heat activation of persulfate, the chain-initiating reaction is as follows:

$$S_2O_8^{2-} \rightarrow \cdot SO_4^- + \cdot SO_4^-$$

Activation of persulfate via the ferrous iron pathway proceeds as follows:

$$Fe^{2+} + S_2O_8^{2-} \rightarrow \cdot SO_4^- + \cdot SO_4^- + Fe^{3+}$$

In addition to the chain-initiating reactions and formation of sulfate free radicals, there are a number of chain-propagating reactions that can lead to the formation of other strongly oxidizing species, such as hydroxyl radicals and organic radicals. The formation of these multiple free radicals compounds the effectiveness of using persulfate to oxidize contaminant mass (ITRC 2005a). Examples of the chain-propagating reactions are given below:

$$\cdot SO_4 + H_2O \rightarrow \cdot OH + HSO_4^-$$

$$\cdot OH + RH \rightarrow \cdot R + H_2O$$

$$\cdot SO_4^- + RH \rightarrow \cdot R + HSO_4^-$$

Persulfate has an advantage over other available oxidants in that the persulfate anion is slow in oxidizing contaminants and the sulfate free radicals have a lower affinity for natural organic matter than those of hydrogen peroxide or permanganate. As a result, the optimal loading requirement when using persulfate will be lower than for any of the other applicable oxidants for DDx degradation. A potential disadvantage of using persulfate is that dissolved chloride, bicarbonate, and carbonate anions will scavenge the persulfate, thus increasing the loading demand in environments where these species exist at elevated concentrations (ITRC 2005a; USEPA 2006a).

3.1.2 Ozone

Ozone is a strong oxidant that is typically introduced to a contaminant mass through gaseous injections and for this reason is more beneficial in the treatment of unsaturated materials (USEPA 2008b; GWRTAC 1999). Ozone can also be used as a liquid reagent by sparging ozone through water to create ozonated water with a concentration ranging from between 5 and 30 milligrams per liter (mg/L) of ozone. Another liquid reagent using ozone is a mixture with hydrogen peroxide, which is considered one of the most aggressive forms of chemical oxidation (ITRC 2005a).

Oxidation using ozone can proceed along two major pathways: direct or indirect oxidation. In direct oxidation, the ozone gas attacks organic compounds without relying on the formation of free radicals. An example of this is shown in the equation below:

$$O_3 + RC{=}CR \rightarrow RCOCR + O_2$$

Indirect oxidation pathways involve the interaction of ozone with hydroxide ions or water to form the hydroxyl free radicals. The indirect pathways typically require either neutral to basic pH ranges or the presence of ultraviolet light (ITRC 2005a; USEPA 2006a). Examples of these pathways are shown below:

$$O_3 + OH^- \rightarrow O_2 + \cdot OH$$

$$O_3 + H_2O \rightarrow O_2 + \cdot OH + \cdot OH$$

Although ozone is known to be a strong oxidizer, there are limitations associated with its use. One is that its gaseous state coupled with its short stability time once introduced in the subsurface requires longer treatment times than other oxidants.

3.1.3 Permanganate

Permanganate is used as an aqueous solution of either the potassium or sodium permanganate salts. Although sodium permanganate is more reactive than the potassium salt, it has been used to a lesser degree due to the potential for exothermic release upon contact with reductants (ITRC 2005a). Potassium permanganate has been used for treatment of contamination for decades with proven effect (GWRTAC 1999). Permanganate is useful over a wide pH range and is particularly effective at treating contaminants with a low redox potential and a high soil oxidant demand. One advantage of permanganate over other common oxidants is that it has the potential to remain in the subsurface over a much longer time period, allowing the reagent to come into contact with more contaminant mass as the soil oxidant demand is consumed and mass is released into the dissolved phase (USEPA 2006a). Unlike the other oxidants, there is no formation of free radical intermediates and the treatment of contaminants is through direct electron transfer (ITRC 2005a). The half-cell reaction for most typical environmental conditions (pH 3.5 to 12) is provided below:

$$MnO_4^- + 2H_2O + 3e^- \rightarrow MnO_2(s) + 4OH^-$$

As shown in the above reaction, as permanganate oxidizes organic compounds, solid manganese oxides will precipitate from solution. This can have a positive effect on subsurface pore space as the precipitates continue to form and consume the permeability (GWRTAC 1999; ITRC 2005a; USEPA 2006a). A potentially negative impact is associated with metal impurities of the permanganate salts. For sites that have metals contamination issues, it is important to evaluate how these impurities would affect the current concentrations of dissolved metals (ITRC 2005a; USEPA 2006a).

3.1.4 Hydrogen Peroxide

Hydrogen peroxide can be used as a stand-alone oxidant or in conjunction with ferrous iron as either Fenton's or modified Fenton's reagent (GWRTAC 1999; ITRC 2005a; USEPA 2006a). When used by itself, hydrogen peroxide is consumed rapidly in the subsurface and is therefore not suitable to contaminants in low-permeability sediments (USEPA 2006a). Fenton's or modified Fenton's reagent uses hydrogen peroxide in the presence of ferrous iron to produce hydroxyl radicals that are capable of oxidizing contaminants (GWRTAC 1999; USEPA 2006a). The primary reaction involved in Fenton's reagent is shown below:

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \cdot OH + OH^-$$

As shown above, this reaction forms ferric iron, which then precipitates, potentially consuming sediment permeability.

3.1.5 Implementation of In-situ Chemical Oxidation

In-situ oxidation can be conducted within the confines of the CDF through the subsurface introduction of liquids, gases, or colloidal substances, such as those discussed above. The introduction of these chemicals can be through conventional injection well techniques or through more innovative techniques such as deep soil mixing (GWRTAC 1999). When considering which option would achieve better reagent distribution, and therefore effective contaminant treatment, the nature of the targeted substrate must be considered. In the case of the Site, the targeted substrate is impacted sediment from the Willamette River. River sediment has been described as comprising silty sands, which increases the difficulty of adequately distributing the reagents in a cost-effective manner. It is likely that the nature of the silty sands would limit the injection rates, leading to elevated injection backpressures having geotechnical implications (i.e., the potential to blow out a seal or a wall) and thus

requiring a large network of injection wells, increasing both capital and operation and maintenance costs significantly.

A potentially more effective alternative would be in-situ deep soil mixing, in which large-diameter augers or excavator-mounted articulated mixing (see Section 4.1 below) are used to mix the chosen oxidant into the contaminated sediment. This would provide improved contact with the sediment, allowing for more complete oxidation of the contaminant mass. To design a soil mixing program, bench- or field-scale pilot testing may be necessary to determine the optimum oxidant loading required to overcome the soil oxidant demand and any other potential oxidant scavengers present in the sediment or pore water.

Lastly, a significant challenge with regard to using in-situ chemical oxidation within the CDF itself is the material compatibility of various oxidants with the CDF materials (carbon steel, jointing material) and the upland concrete barrier wall. Persulfate has the best likelihood of success (in terms of DDx treatment), but the sulfate radical can be corrosive toward metals and the sulfur itself can also deteriorate concrete.

3.1.6 Ex-situ Chemical Oxidation

Ex-situ chemical oxidation would involve dredging sediment, placing it into a confined treatment cell, and mixing it with a chemical oxidant. While this method can allow for controlled treatment, it involves additional risks associated with handling and may still pose material compatibility risks to the CDF.

3.1.7 Applicability to the Conceptual CDF

Although there is some evidence in existing literature that chemical oxidation is capable of treating DDx, there are several issues associated with oxidation, its compatibility with a carbon steel CDF, and potential metals mobilization. Persulfate is the preferred oxidant for remediation of DDx and has been used effectively in a groundwater interim remedial measure at the Site. The next applicable oxidant that could be used at the Site is permanganate. Both of these chemicals are highly corrosive and are therefore not compatible with the proposed structure of the carbon steel CDF. Oxidants, with a few exceptions, are also not capable of treating the heavy metals. However, metals are not the focus at the Site, although the EE/CA should further consider these harborwide COIs. Oxidation of metals such as chromium could result in increases in the mobility and leachability of certain metals species using certain oxidants in the sediment. However, these leachability/mobility issues are of

minor concern because they would be conducted within the confines of the CDF, i.e., in a controlled environment.

4. Soil Mixing

4.1 In-situ Implementation

In-situ soil mixing is also an established treatment approach for soil and sediment. With this approach, the contaminated sediment would remain within the constructed CDF. The CDF would be dewatered as necessary, and treatment would be performed by mixing reagents with the sediment in place. Different approaches could be used to mix the reagents into the sediment, including (1) rotary soil blending using crane- or track-mounted, large-diameter augers to create overlapping vertical columns of treated sediment or (2) shallow soil mass mixing using excavator-mounted soil mixing tools. The equipment used is dependent on the required treatment depth for the soil or sediment and how easily the equipment can access the work area. As with ex-situ soil mixing, various reagents can be mixed into the sediment to achieve the necessary physical and chemical requirements for treatment. Following in-situ mixing, the treated sediment would be left in place within the CDF to allow the mixed material time to cure and react.

In-situ soil mixing generally offers less certainty about the uniformity of the treatment than ex-situ mixing, because it is more difficult to monitor and homogenize the material. As with ex-situ mixing, the physical and chemical characteristics of the reagents and the material to be treated can affect the selection of mixing equipment and the level of effort needed for adequate mixing. An in-situ mixing operation would not require the potentially large operating footprint associated with an ex-situ mixing operation, but in-situ mixing may also require more time to complete than ex-situ mixing.

Dust and odor controls, such as a dust collection hood installed over a large-diameter auger, could have to be implemented as exposure control measures during the work, but generally there is less exposure risk than with ex-situ soil mixing because the sediment remains within the CDF during treatment. In addition, because in-situ mixing does not require the additional material handling that ex-situ mixing does, engineering and operating costs generally are lower, as are fuel use and vehicle and equipment air emissions.

4.2 Ex-situ Implementation

Ex-situ soil mixing treatment technologies will be specifically evaluated in the EE/CA per a directed change from the USEPA (USEPA 2010).

Ex-situ soil mixing is a fully developed treatment approach applicable to contaminated soil and sediment. In this approach, contaminated sediment would be dredged or excavated (and then placed in a designated area on Site where it would be treated). The sediment would be dewatered as needed to improve the workability of the sediment before applying any reagents in the treatment area. Various reagents can be mixed into the sediment ex-situ to achieve the necessary physical and chemical requirements for stabilization and/or treatment, including Portland cement, lime, cement kiln dust, persulfate, and ZVI. These reagents can either immobilize or destroy contaminants present in the sediment. Mixing these reagents into the sediment would be accomplished using equipment such as pug mills, excavator buckets, or rotovators. The treated sediment would then be placed back into the CDF to allow the treated material time to cure and react.

Ex-situ soil mixing generally provides a higher degree of certainty about the uniformity of the treatment as compared to in-situ soil mixing, because it typically is easier to monitor and homogenize the material. Ex-situ mixing can also require less time to complete than in-situ mixing, but the equipment used and effort expended in mixing is dependent on the physical and chemical characteristics of the reagents and the material to be treated. Ex-situ mixing would also require a large operating footprint on Site to provide adequate space to perform dewatering, staging, and mixing efficiently. The size of the staging area would be related to the amount of sediment removed, the rate of removal, and the rates of dewatering and mixing that could be achieved on Site.

Dust, odor, and other exposure control measures would need to be implemented as health and safety measures, because the removal, staging, dewatering, and mixing operations would increase the exposure risks associated with the contaminated sediment. Ex-situ mixing would involve additional material handling steps that could lead to increased engineering and operating costs and could result in greater fuel use and more vehicle/equipment air emissions because of the additional work.

Two categories of soil mixing treatments were evaluated: solidification/stabilization (S/S) and ZVI clay. Each is discussed below.

4.3 Solidification/Stabilization

S/S is one of the top five most commonly implemented source control treatment technologies used at Superfund sites (USEPA 2000a). Solidification involves encapsulating the contaminated sediment, forming a more physically strong and solid material that can reduce contaminant mobility by decreasing the surface area exposed

to potential leaching, coating the sediment with low-permeability material, and generally making the contaminated sediment less likely to disperse. Stabilization involves the conversion of contaminants into less soluble/mobile or less toxic forms. The goal of S/S is primarily to reduce contaminant mobility through physical and chemical means within the sediment rather than destroying the contaminants with chemical or physical treatments. Leachability testing is typically performed to measure the degree of immobilization of the contaminants in the treated material. Depending on the reagents used, contaminant stabilization and material solidification typically occur simultaneously, although in some instances it may be possible for stabilization to be performed without solidification. S/S can be used alone or in combination with other treatment technologies to yield a material with the required physical and chemical properties.

The treatment of organic contaminants generally depends on encapsulation of those compounds, the ability to solidify material by binding free water, reducing hydraulic conductivity, and creating a material that has more physical integrity. Generally, organic contaminants with relatively low aqueous solubilities, such as DDx compounds[2], are candidates for S/S treatment, while organic compounds with relatively high aqueous solubilities may be more difficult to treat (Suthersan 2002). Pretreatment of the sediment, such as the application of ZVI clay, can also be performed to destroy or otherwise treat organic contaminants. Additionally, organic binding agents, such as activated carbon or organoclays, can be added to the S/S reagents to decrease the leachability of organic contaminants within the treated sediment. These organic binding agents generally have higher cost compared to inorganic binders (USEPA 1997).

S/S technologies have generally shown varied effectiveness in treating pesticides and other organic contaminants, and over 35 percent of the S/S remedies implemented at Superfund sites are treating organic contaminants, including pesticides and PAHs, either alone or in combination with other types of contaminants (USEPA 2000a). The results of 1995 bench-scale S/S studies on the impacted sediments at the New Bedford Harbor Superfund Site indicated that while metals leachability generally decreased in all the admixtures tested, including Portland cement, adsorbent clay, and several proprietary reagents, there was no appreciable decrease in the leachability of

[2] Ranging from approximately 0.160 mg/L for DDD to approximately 0.0004 mg/L for DDT at room temperature.

SVOCs, including pyrene and acenaphthene, in any of the mixtures, and all the mixtures showed increased PCB leachability (USEPA 2000c).

In October 2005, the Center for Advanced Infrastructure & Transportation (CAIT) at Rutgers University issued a report documenting a successful demonstration project using in-situ S/S technology to treat highly contaminated harbor sediments using cement deep soil mixing (CDSM). The study demonstrated that the sediments could be effectively solidified/stabilized in-situ and that the resulting treated sediments showed strength gains, that the treated sediments are able to remain in place indefinitely, and that they may be able to remain in place to be properly capped (CAIT 2005).

S/S approaches have demonstrated effectiveness in the treatment of metals contamination in soil and sediments. Metals immobilization can be accomplished via a variety of stabilization reactions, including precipitation, sorption, complexation, redox potential control, and pH control (USEPA 1997). The stabilizing reactions observed are dependent on the reagents added to the material, the water content of the material, and the chemistry of the contaminants and the material itself.

4.3.1 Applicability to the Conceptual CDF

Sediment testing may be necessary to evaluate such properties as the organic content and moisture content to determine the type and amount of cementitious reagents for bench-scale testing, because sediments with high organic content or high concentrations of oils and greases may slow or prevent cement hydration by coating cement particles. Sediment bench-scale studies using several admixtures of solidification/stabilization reagents may have to be performed prior to field implementation to assess the potential of various mix designs to stabilize and solidify the sediments and the COIs present in the sediments. The pre- and post-treatment leachability of COIs would be tested for each mix design, along with pre- and post-treatment geotechnical characteristics to evaluate material handling and placement in the CDF.

S/S is an appropriate option to evaluate for a CDF application because solidified, stabilized sediment would be more physically stable and less permeable than untreated sediment. Typical cementitious S/S reagents are commonly available and relatively inexpensive and could be easily obtained and transported to the Site. Cementitious S/S reagents are also compatible with the proposed construction materials for the CDF. Because S/S can result in a net increase in treated material volume, typically between 5 and 10 percent depending on the sediment characteristics

and reagent mix, the CDF would need to be designed to accommodate the anticipated increased volume, as determined during bench testing. Cementitious S/S could be used to reduce the mobility and leachability of the relatively low-solubility organic COIs present in the sediment, including DDx, as well as harborwide COIs, PAHs and heavy metals, in the sediment. Sediment treated with cementitious reagents would likely exhibit increased shear strength and an improvement in its material workability and handling characteristics, and the solidified sediment would be less likely to be churned up and dispersed into a body of water in the event of a catastrophic structural failure of the CDF. The treated sediment also could be readily capped in a CDF, because sediment treated by cementitious S/S would not require time to consolidate and would have the compressive strength necessary for capping. An additional benefit to S/S technology in a CDF application is the decrease in hydraulic conductivity of the treated sediment, which if necessary would significantly decrease the amount of water that would require handling as part of anticipated long-term hydraulic head control.

4.4 ZVI Clay

ZVI clay is a patented technology developed by DuPont and the University of Waterloo beginning in the 1990s. In 2003, DuPont donated the patents for the technology to Colorado State University.

ZVI can cause the degradation of chlorinated organic compounds through abiotic reductive dechlorination. ZVI is a strong reductant and its use has been a common treatment technology for chlorinated solvent contamination in soil and groundwater since the 1990s. The reduction of chlorinated organics (RCl) by ZVI is driven by a corrosion reaction with the ZVI:

$$Fe^{0} + RCl + H^{+} \rightarrow Fe^{2+} + RH + Cl^{-}$$

The rate of reaction is driven by the reactivity of the particular chlorinated compound and the amount of available reactive surface area on the ZVI particles. Greater surface areas can be attained using smaller ZVI particles, such as ZVI colloids, and the resulting faster reaction kinetics can allow for a lower ZVI mass loading by lowering the residence time and increasing the reactivity required for complete treatment (Suthersan 2002).

The addition of a stabilizing agent, such as clay, along with a ZVI mixture with sediment can have several benefits, including reducing the hydraulic conductivity of the treated material and increasing the residence time for reactions to proceed. Cementitious

reagents can also be mixed into the treated material to enhance certain geotechnical properties of the material, but the addition of cementitious materials typically is done some time after the addition of ZVI, because the high pH conditions associated with cement chemistry can inhibit the dechlorination reactions.

Powdered ZVI has also been shown to be capable of reductively dechlorinating DDT, DDE, and DDD in laboratory testing. Because DDx compounds have very low aqueous solubilities, a surfactant, such as Triton X-114, which can greatly increase the apparent solubility of DDx compounds, may be used to solubilize DDx compounds to allow those compounds to adsorb and react at the ZVI particle surface, thereby increasing the reaction rate. Without a surfactant, the reaction process may slow after DDT is reduced to DDD (Sayles et al. 1997). However, the use of surfactants could also mobilize DDx compounds from their primary state of sorption to the sediment.

In addition to being able to degrade a variety of chlorinated organic solvents, certain aromatic compounds, including benzene, toluene, and ethylbenzene, are also treatable by ZVI (Suthersan 2002). Many dissolved heavy metals species can also be treated by the application of ZVI through adsorption to the ZVI particle surfaces and co-precipitation with iron corrosion products (Wilkin and McNeil 2003). Application of nanoscale (particles less than one micron in size) ZVI has also been demonstrated to be a feasible method for soil remediation of pyrene in the laboratory (Chang et al. 2005).

The use of ZVI as a means to remediate chlorinated solvent contamination via a variety of approaches (e.g., permeable reactive barriers, micro/nanoparticle solution injection) is an established and proven technology in the field. The application of ZVI-clay soil mixing as a remediation approach in the field has primarily been performed utilizing conventional in-situ soil mixing technologies, such as large-diameter auger soil mixing, to introduce and mix a ZVI-clay slurry into the soil being treated. However, given the nature of the ZVI and clay reagent materials, the application of ex-situ soil mixing utilizing ZVI or ZVI-clay reagents would be performed in a similar manner and using the same conventional equipment as mixing of cementitious reagents into soil and sediment. In-situ ZVI-clay soil mixing has been used successfully as a full-scale remedy at several sites in the U.S. to treat source zones of chlorinated solvents. At a former nylon manufacturing facility, in-situ ZVI-clay soil mixing was used to remediate approximately 8,000 cubic yards (cy) of soil to a depth of 35 feet that was contaminated with an estimated 20 tons of carbon tetrachloride and other chlorinated solvents, achieving an estimated 99 percent removal of the chlorinated organic compounds in one year and reducing permeability in the treatment zone by

approximately four to five orders of magnitude (USEPA 2006b). At Camp Lejeune, North Carolina, in-situ ZVI-clay soil mixing was used to remediate 7,000 cy of soil impacted by perchloroethylene (PCE), achieving average post-treatment reduction in PCE concentrations of 82 percent after one year and reducing hydraulic conductivity by one to two orders of magnitude (Bozzini et al. 2006).

4.4.1 Applicability to the Conceptual CDF

Bench-scale studies on sediment utilizing several admixtures of ZVI-clay reagents would have to be performed prior to possible field implementation to assess the potential of various mix designs for treating the COIs in Site sediment. Pre- and post-treatment samples would be tested for each mix design to evaluate the effectiveness of the treatments at COI removal over time, along with pre- and post-treatment evaluation of changes in hydraulic conductivity and geotechnical characteristics to evaluate material handling and placement in the CDF.

ZVI-clay soil mixing could provide several benefits. The treated sediment placed into the CDF would become less permeable through the addition of the clay, thereby decreasing the potential and/or scale of hydraulic head control within the CDF itself. The treated sediment in the CDF could exhibit significant decreases in certain COIs over time from the various degradation reactions that could take place. ZVI added to the sediment has the potential to degrade the organic pesticides and the PAHs, provided those compounds can react with the surfaces of the ZVI particles. Certain heavy metals species could also be treated using ZVI. The ZVI-clay-treated sediment material could also be solidified/stabilized post-treatment by utilizing cementitious reagents (discussed above) mixed into the treated sediment to improve its geotechnical properties. The addition of cementitious agents generally results in increased soil strength and bearing capacity as well as reduced compressibility.

5. Bioremediation Technology

5.1 In-situ Anaerobic Bioremediation

In-situ anaerobic bioremediation is a well-documented remedial strategy. Through periodic subsurface injections of a substrate, indigenous microorganisms in a contaminated aquifer are utilized to transform the contaminant to benign end products. These injection areas are known as in-situ reactive zones (IRZs). The microbial mechanism responsible for the remediation is contingent on the contaminants present. At the Site, DDx would require enhanced reductive dechlorination (ERD), a common form of IRZ implementation. Briefly, hydrogenolysis or reductive dechlorination of chlorinated hydrocarbons relies on hydrogen generated from the anaerobic fermentation of a readily degradable carbon source to replace chlorine atoms bonded to the contaminants (Suthersan 2002). This process can occur naturally, as some hydrocarbon and ketone contaminants, if present, can serve as electron donors to facilitate the reductive dechlorination process. ERD is considered an enhanced process as the injected organic substrate is generally preferentially utilized by the microorganisms due to more favorable thermodynamics. ERD can be limited or slowed somewhat by the solubility of the contaminant, i.e., low solubility may limit the bioavailability of the contaminant. Solubility at ambient temperature for DDT and its daughter products is low (0.0004-0.160 mg/L).

Establishing an ERD is partially contingent upon subsurface soil permeability (hydrogeology), the nature and extent of contamination, and remedial goals. The frequency of injection, carbon dosing, and site injectability are all parameters that are determined during pre-remedial efforts such as tracer, bench, and pilot-scale testing, as needed. Various organic substrates are available, and selection of a substrate takes into consideration cost, length of remediation, site hydrogeology, and available materials. Implementing an IRZ technology imposes less of an environmental footprint on a site in comparison to more invasive extraction techniques. In most scenarios, gravity-fed injections are sufficient and utilize little energy.

Anaerobic bioremediation of DDT has been studied previously (Pfaender and Alexander 1972; You et al. 1996; Corona-Cruz et al. 1999; Seech et al. 2008; Purnomo et al. 2008) and demonstrated to be effective at the laboratory, bench-scale, and full-scale field applications. Anaerobic kinetics suggest slow decreases in DDT, with some organisms partially dechlorinating DDT to its daughter product DDD. Insufficient dechlorination of DDT to DDD is not desirable. According to fungi-mediated reductive dechlorination work by Purnomo et al. (2008), complete dechlorination of DDT to 4,4-

dichlorobenzophenone (DBP) may involve iron limitations. You et al. (1996) examined adding surfactants and excess reductive material to microcosm studies with some improvement in dechlorination rate and decrease in DDD generation. As an added benefit to the IRZ technology, some metals can be immobilized by dissimilatory metal-reducing bacteria and other geochemical processes as a result of the shift in reductive poise caused by the addition of a degradable organic substrate. As a caution, IRZ byproducts can also result in the mobilization of some metals (i.e., arsenic) if the IRZ is not supplemented with an additional reactant such as ZVI.

5.2 In-situ Aerobic Bioremediation

In-situ aerobic bioremediation is a form of IRZ technology that utilizes aerobic respiration to biologically degrade contaminants. Aerobic respiration is defined as microbial processes that use oxygen as a terminal electron acceptor. Oxygen is generally present as dissolved oxygen (DO) in groundwater and as a gas close to the ground surface. In-situ aerobic bioremediation is usually limited by the availability of oxygen in an aquifer. Generally speaking, DO concentrations in an aquifer at equilibrium are less than 4 mg/L. In a location where light hydrocarbon and ketone contamination is present and natural reductive dechlorination is occurring, the DO can be less than 1 mg/L (Suthersan 2002). Therefore, the challenge of in-situ aerobic bioremediation is to completely oxidize the contaminated area.

There are several options for increasing the oxygen concentration of an aquifer, such as in-situ air sparging (with or without oxygen-enhanced air), injection of oxygen-saturated water, ozone injection, hydrogen peroxide injection, and bioventing. These processes can become costly if the aquifer has a high chemical oxygen demand. Another potential complication with aerobic bioremediation is the growth kinetics associated with aerobic metabolisms; bio-fouling of wells can be significant if the growth rate is not controlled. Implementing an IRZ technology imposes less of an environmental footprint on a site in comparison to more invasive extraction techniques. Aqueous additions of DO can be performed under gravity, whereas air sparging requires more infrastructure, pumps, and a larger footprint.

Aerobic bioremediation of DDT has been demonstrated previously (Nadeau et al. 1994; Corona-Cruz et al. 1999; Bidlan and Manonmani 2002; Seech et al. 2008) in a laboratory microcosm setting. Notably, Bidlan and Manonmani (2002) utilized a consortium of microorganism cultures in an effort to increase the kinetics of aerobic bioremediation of DDT with some success; however, only the decrease in DDT was discussed and no reporting of DDD and DDE concentrations was included. An

additional consideration of in-situ aerobic bioremediation is potential metals precipitation and fouling as a result of an increased reduction-oxidation potential.

5.3 Ex-situ Bioremediation

There are four primary means of ex-situ bioremediation deployment: bio-piles, composting, landfarming, and slurry-phase biological treatment. These technologies use or combine both aerobic and anaerobic mechanisms to degrade contaminants.

Bio-pile technology requires that soil be excavated and containerized in an aboveground enclosure. Soil amendments may be used to accelerate the biodegradation, but essentially the main electron acceptor is oxygen, which is provided to the pile with blowers or vacuum pumps. The pile is typically underlain by a liner or some sort of leachate collection system to prevent seepage into the groundwater. Piles may be covered in polyethylene to prevent contact with stormwater and promote solar heating. Bio-pile technology has been demonstrated for non-halogenated volatile organic compounds (VOCs) and fuel hydrocarbons, although halogenated VOCs and SVOCs and pesticides are expected to be remediated in this manner as well (Federal Remediation Technologies Roundtable [FRTR] 2009).

Landfarming is a form of ex-situ aerobic bioremediation that is most applicable for light hydrocarbons and small chain PAHs. Briefly, landfarming involves placing contaminated soil in lined beds in approximately 12- to 18-inch lifts. The lifts of contaminated soil are routinely churned to aerate the soil and supply sufficient oxygen to the indigenous microorganisms, which utilize aerobic mechanisms to biodegrade the contaminants. Bulking agents and nutrients may also be added to optimize the microbial activity. Liners are required to prevent leachate seepage into the groundwater. Once the desired level of remediation is completed, the soil is removed and disposed of or replaced in the excavation, depending on remediation goals. This technology exploits the volatility of a contaminant; the larger and more massive a contaminant becomes, the more difficult it is to successfully implement landfarming (FRTR 2009).

Composting is an ex-situ biological remedial technique that incorporates both aerobic and anaerobic biological mechanisms to degrade contaminants. Soil is excavated and combined with bulking agents and organic amendments such that favorable growth conditions exist for thermophilic microbes. Composting can be implemented similarly to bio-piles and landfarming, i.e., in piles that are aerated with vacuum pumps and blowers or in lined beds. The major difference between composting and the other ex-

situ bioremediation strategies is the temperature. Typical remedial temperatures for composting are maintained from 55 to 65 °C (FRTR 2009). Composting has been demonstrated to be effective for explosives and PAHs.

Lastly, slurry-phase biological treatment is the most potentially effective ex-situ bioremediation strategy in terms of DDx. This form of ex-situ biological treatment creates a slurry of excavated contaminated soil with water, nutrients, and other additives in a large mixing tank. Mixing the slurry maintains soil particles in solution and in contact with microorganisms. The pH is controlled through titration of the mixing tank. Pre-washing of the material is usually required to separate stones and debris from the contaminated soil. Bioaugmentation of the mixing tank may be required if characteristic DNA samples do not indicate an appropriate biological community to degrade the contaminants. Dewatering of the treated sediments can be complicated by excessive fines and may be enhanced with centrifuges or pressure filters (FRTR 2009).

5.4 Sequenced Anaerobic-Aerobic Technology

Sequenced anaerobic-aerobic bioremediation has been shown to be able to treat organochlorine pesticides and other persistent organic pollutants in soil, including DDx compounds. The technology works by first creating anaerobic and reducing conditions in soils to encourage the dechlorination of chlorinated organic compounds by native soil microorganisms. The more chlorinated parent compounds are generally more susceptible to anaerobic dechlorination than the lightly chlorinated daughter products. Therefore, the anaerobic pre-treatment is followed by an aerobic approach, whereby oxidizing conditions are created in the soils to encourage the degradation of the dechlorinated organic reaction byproducts by native soil microorganisms. Two proprietary technologies are most commonly used for sequenced anaerobic-aerobic bioremediation of organochlorine pesticides and other persistent organic pollutants: DARAMEND® from Adventus and Xenorem® from AstraZeneca. Sequencing other, non-proprietary, aerobic and anaerobic bioremediation technologies may be feasible but would require bench-scale testing to demonstrate the potential effectiveness followed by possible pilot-scale testing, depending on the results.

DARAMEND is a biological treatment technology for treating persistent organic pollutants in soil and sediment. The DARAMEND treatment process starts with the addition of DARAMEND organic amendments and ZVI to the material to be treated. The DARAMEND organic amendment is composed of biodegradable carbon from processed plant material and has a specific size distribution and formulation that can be varied to better suit the contaminants being treated. The organic amendment

supports microbial growth and provides for the carbon sources needed for microbial dechlorination reactions. The ZVI mediates direct abiotic reductive dechlorination and the corrosion of ZVI consumes dissolved oxygen. These biotic and abiotic reactions to the amendments create anaerobic, reducing conditions that are favorable for microbial dechlorination reactions (Seech et al. 2008).

For sequenced anaerobic-aerobic approaches for organochlorine pesticides, DARAMEND amendments are typically 60 to 80 percent by weight organic material and 20 to 40 percent by weight microscale ZVI. The cycling typically consists of a five- to ten-day anaerobic phase followed by a one- to two-day aerobic phase. This cycling period may be repeated over several months to achieve treatment targets. The number and length of cycles can depend on the initial concentrations, the responsiveness of the soil to treatment, and the amount of amendments added. The anaerobic phase involves the addition of DARAMEND amendments, mixing, and moisture control to approximately 90 percent of the soil's water-holding capacity. The aerobic phase involves aerating the soil and introducing atmospheric air via mixing (Seech et al. 2008). DARAMEND can be applied both ex-situ and in-situ, but an in-situ approach is applicable using deep mixing equipment, including (1) rotary soil blending using crane- or track-mounted, large-diameter augers to create overlapping vertical columns of treated sediment or (2) shallow soil mass mixing using excavator-mounted soil mixing tools. The equipment used depends on the required treatment depth for the soil or sediment and how easily the equipment can access the work area.

DARAMEND has been demonstrated to be an effective treatment technology for DDx in soil at several sites. In 1995, a pilot-scale study of the technology was implemented at the W.R. Grace Superfund Site in Charleston, South Carolina, to treat 250 tons of soil contaminated with an average of 89.7 milligrams per kilogram (mg/kg) of DDT. After an operational period of eight months, the average DDT concentration of the soil in the pilot study was reduced approximately 82 percent to 16.5 mg/kg (USEPA 2005a). In 2003, a full-scale implementation of the technology was performed at the T.H. Agriculture and Nutrition Superfund Site in Montgomery, Alabama. The full-scale system treated 4,500 tons of soil with an average initial DDT concentration of 84.5 mg/kg. After a five-month treatment period, the average DDT soil concentration had been reduced by almost 90 percent to 8.65 mg/kg (USEPA 2005a).

Xenorem is an ex-situ composting bioremediation technology that uses sequenced anaerobic-aerobic cycles to bioremediate pesticides and other persistent organic compounds. The Xenorem process uses an initial aerobic cycle using high levels of nutrients, followed by an anaerobic cycle, and is covered by several patents. In the

1990s, Stauffer Management Company (SMC), an affiliate of AstraZeneca Group PLC, conducted laboratory studies of the process, and the results indicated that the process could degrade DDT without the buildup of DDE and DDD metabolites. A field demonstration of the Xenorem technology was conducted at the SMC Superfund Site in Tampa, Florida, from June 1997 to September 1998. The field demonstration treated 500 cy of soil contaminated with DDT (initial concentration 88.4 mg/kg), DDE (initial concentration 11.3 mg/kg), DDD (initial concentration 162.5 mg/kg), and other chlorinated pesticides. The organic amendments chosen for the field demonstration were cow manure and straw; 405 cy of amendments were initially added to the soil pile. Amendments were also added at several points during the treatment process, resulting in a total of 1,193 cy of combined material after 48 weeks into the process. Anaerobic conditions were achieved using a tarp to cover the pile and aerobic conditions were created by mechanical mixing/tilling or injections of compressed air (USEPA 2000b).

At the end of the Xenorem field demonstration, DDT concentrations in the soil pile had been reduced by 98 percent, DDE concentrations were reduced by 40 percent, and DDD concentrations were reduced by 86 percent. Based on these results, a large-scale use of the ex-situ Xenorem technology was implemented at the SMC Superfund Site to treat 4,000-cy batches of contaminated soil beginning in June 2000 (USEPA 2000b). By the end of 2003, three batches of contaminated soil had been treated using cow manure, chicken litter, and wood chips as amendments. The first batch met the site cleanup goals for DDx compounds (8.91 mg/kg for DDT, 8.91 mg/kg for DDE, and 12.6 mg/kg for DDD), but required a year of treatment time. The second batch was also treated for one year, but failed to meet the cleanup goal for DDD. The third batch was also treated for one year and failed to meet the cleanup goal for DDT (SMC 2005; USEPA 2005a). Because of the unpredictable performance of the Xenorem process in large-scale applications, SMC concluded that Xenorem was not a viable remediation technology for the site (SMC 2005).

5.5 Applicability to the Conceptual CDF

At the time of this writing, there is very little regarding full-scale implementation of a stand-alone in-situ anaerobic bioremediation or aerobic bioremediation of DDx documented in the literature. It is likely that an anaerobic-only bioremediation application would achieve only partial mass removal and be focused only on the most chlorinated targets. In general, aerobic bioremediation would be better suited to the byproducts of DDT dechlorination than the parent compounds themselves.

As described above, slurry-phase bioremediation may be the most potentially effective ex-situ aerobic bioremediation approach that could be implemented at the Site to degrade DDx. Bioaugmentation may be required if there is not an appropriate biological community or there is a desire to enhance the community to degrade the COIs. Following completion of the remedy, the slurry would be dewatered and the treated sediments would be placed into the CDF. The leachate from the dewatering operations would have to be treated before it is discharged according to the appropriate permitting. An in-situ (within the CDF) slurry-phase treatment would be the preferred approach.

Regarding the potential applicability of a sequenced bioremediation approach to DDx at the Site, bench-scale studies on sediment utilizing DARAMEND, Xenorem, or other sequenced anaerobic-aerobic approaches may have to be performed prior to possible field implementation to assess the full-scale field operating parameters, such as the type and amount of amendments to use, sequencing periods, and estimated treatment period, which would be used to estimate the cost of the application of this treatment technology for sediments at the Site. In particular, the bench-scale studies could identify the volume of additional materials necessary to employ one of these sequenced techniques.

A large operational footprint would be necessary for ex-situ sequenced treatment due to the depth limitations of tilling equipment. Treating 110,000 cy at one time would require over 30 acres of treatment area assuming a 2-foot sediment depth for treatment. In contrast, an in-situ mixing approach using excavator-mounted mixing equipment could be applied sequentially toward smaller batches of sediment without the need for a large operational footprint on Site. The treatment times required for this technology, on the order of months, would also increase the exposure risk posed by an ex-situ approach. Odor and dust controls would have to be implemented to manage the removed sediment. These concerns would be minimized with an in-situ mixing approach. While a sequenced biological treatment approach shows merit in its ability to treat DDx, the DARAMEND with its ZVI component will also have a beneficial effect on heavy metals leachability.

6. Chemical Reduction

Chemical reduction systems aim to degrade or reduce the mobility of contamination through direct or indirect mechanisms. Direct reduction of contamination is achieved by reaction of the contaminant with the reductant (dechlorination of organics by ZVI), while indirect reduction is achieved by creating chemical changes to the aqueous system (for example, redox manipulation with dithionate). Quite a few materials have been identified for the purpose of chemical reduction. The reagents can be introduced as a liquid, gas, colloid, or solid depending on the target compounds, the subsurface materials, and the method of introduction (GWRTAC 1999; ITRC 2005b). Table D-4 provides examples of some of these materials and the constituents that they can treat.

Of the chemical reductants listed above, ZVI has potential for treating DDx at the Site. In addition, dithionate and polysulfide are effective at treating metals and have some implications of also reducing nitrates and sulfates (ITRC 2005b). ZVI is a strong chemical reductant that has been shown to effectively treat chlorinated organic compounds, including DDx (Sayles et al. 1997; ITRC 2005b; Elliot et al. 2009). ZVI has the added benefit of also being capable of reducing and immobilizing many oxidized metal species such as the hexavalent chromium species, chromate arsenic (GWRTAC 1999). Because dithionite and polysulfide do not appear to have the capability to effectively treat DDx, these reagents are not considered viable options for chemical reduction at the Site. ZVI has been shown to degrade DDx in laboratory-scale experiments (Sayles et al. 1997; Pirnie et al. 2006; Elliot et al. 2009). For DDT, it was shown that > 90 percent of the original mass was degraded by nanoscale ZVI over a time frame of 20 days. The amount of DDT degraded was increased to > 98 percent of the original mass when a surfactant was used to enhance the dissolution of DDT from soil material (Sayles et al. 1997). The pathway for reductive dechlorination of DDx is complex, with numerous possible intermediates before reaching the end stage of either biphenyl formation or aromatic ring opening (Sayles et al. 1997).

Bench-scale studies have shown that reduction of organic compounds is proportional to the specific iron surface area, suggesting that the reduction occurs via electron transport at the iron surface. As the available surface area for electron transfer plays an important role in reduction, the most efficient method of contaminant treatment would be through injection or deep in-situ mixing of nanoscale colloidal ZVI (Sayles et al. 1997). Other factors that determine the effectiveness of reduction using ZVI include the sediment size and sorting, the solubility of the target contaminants, and potential interferences with the reactive surface of ZVI. A major issue with nanoscale ZVI is that the particles tend to agglomerate, causing a reduction in surface area along with an

increase in particle size (Elliot et al. 2009). This tends to decrease the effectiveness of the ZVI, and it can also make distribution into fine sediments such as silty sands difficult via injection methods. The introduction of ZVI may cause a loss of permeability of the sediments, but this could help in reducing leachability of the sediments and the amount of water that may need to be handled via longer-term hydraulic controls. The solubility of the target compounds plays an important role, as the dechlorination will occur only when dissolved species come into contact with the iron surface. DDT has a low solubility in water (0.4 micrograms per liter), which may make it necessary to use a surfactant to enhance the dissolution of DDT and its dechlorination (Sayles et al. 1997). Other considerations for the effectiveness of ZVI implementation involve the intrinsic chemistry of the sediment pore water, specifically nitrate and dissolved organic carbon, which have the ability to reduce the reactivity of the ZVI surface (ITRC 2005b).

6.1 Applicability to the Conceptual CDF

ZVI is typically utilized in terrestrial applications by placing it within a permeable reactive barrier (PRB) (entrenchment of ZVI into lower-permeability sediments or soil perpendicular to groundwater flow) or through injection of micro- or nanoscale ZVI colloids. Trenching and PRB applications are likely not applicable to the Site. However, in-situ mixing using equipment similar to that described for the stabilization technology would allow for placement of the ZVI (or a combination of ZVI clay or ZVI DARAMEND, etc.) within the confines of the CDF. The sediment of the Willamette River, however, has been described as a silty sand. It is likely that the pore space adjacent to the injection wells would be consumed prior to adequate distribution of the ZVI. For this reason, injection methods of reductive dechlorination do not appear to be the most favorable ZVI application. It would seem that in-situ soil mixing with ZVI (or a combination of ZVI clay or ZVI DARAMEND, etc.) would be the most beneficial treatment technology utilizing chemical reduction.

7. Evaluation of Treatment Options

The following sections summarize some of the key factors in screening technologies discussed in this appendix. The objective is to move toward a short list of technologies or hybrid technologies that can be further evaluated in the EE/CA.

If a CDF and treatment are selected as a recommended option for the removal action, many or most technologies would require bench-scale or field testing to gather necessary data that can be used to design and scale up a larger-scale application or, for more innovative approaches, for proof of process. Some technologies, such as chemical oxidation, may not be applicable or have limited applicability based on the current CDF construction (materials, layout, size, and volume). Some technologies, such as LTTD, should not be attempted due to the exacerbation of chlorinated organic compounds to more toxic chlorinated compounds (i.e., creation of dioxins and furans), despite their applicability to DDx. Ex-situ soil mixing treatment technologies will be specifically evaluated in the EE/CA per a directed change from the USEPA (USEPA 2010).

7.1.1 Effectiveness and Implementability

Available literature and academic research have been used to evaluate which technologies have been proven at the bench or field scale, and especially which technologies have been applied at USEPA-regulated Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sediment sites where pesticides, in particular DDx, are the focus. Often, only a few of these criteria are met in the literature review.

Based on this review and the properties of the COIs, the effectiveness of the evaluated technologies toward the suite of organic compounds is summarized below, from most to least effective:

- Effective toward organic targets: ex-situ LTTD. However, the presence of harbor-wide COIs such as dioxin and PCBs render the LTTD approach infeasible.
- Moderately effective toward organic targets: soil mixing with chemical oxidants; soil mixing with ZVI (and clays, i.e., chemical reduction); bioremediation with sequenced anaerobic-aerobic technology. These technologies can be applied ex-situ or in-situ (within the CDF). Generally, ex-situ treatment will be more effective because it allows for better mixing/contact and engineering.

- Low or partial effectiveness toward organics: stand-alone aerobic or anaerobic bioremediation (ex-situ or in-situ).

Solidification/stabilization could be effective at reducing the mobility and leachability of the target organics, but would not provide contaminant reduction unless other reagents are added to the S/S mixture.

Some of the technologies evaluated would not provide effective treatment of metals. LTTD typically destroys the organic carbon content of the soil, thereby limiting the metal sorption capacity of the treated soil or otherwise creating a metals precipitation problem where none previously existed. Some forms of anaerobic bioremediation could precipitate some of the heavy metals as sulfide or iron sulfide complexes, but these minerals can also be solubilized, pending the local geochemical environment. And in some biological treatments that use iron, metals can be removed from the dissolved phase.

While several technologies do appear to have potential to be technically effective toward DDx, they may not be implementable given the Site conditions; the anticipated materials, size, layout, or volume of the conceptual CDF construction; or other logistical factors. Implementability of the technologies is summarized below:

- Medium/moderate implementability:
  - In-situ soil mixing and in-situ sequenced anaerobic-aerobic bioremediation – Both techniques would require mobilizing large equipment to achieve sufficient soil mixing within the CDF to ensure homogenization and contact with reagents.
  - Ex-situ soil mixing technology – Any technology that relies on contact to achieve treatment or stabilization would be easier to implement and engineer in an ex-situ application.
  - Ex-situ sequenced anaerobic-aerobic bioremediation and ex-situ aerobic bioremediation – Both techniques would require multiple acres at the Site to landfarm soils and provide aeration, but are feasible. They could also require dust suppression.
- Low/no implementability:
  - LTTD – While the factors of cost and sustainability and the potential to create more toxic compounds (dioxins and furans) could ultimately screen this technique from consideration, it is implementable given the availability of space on Site, appropriate power, and the ability to obtain multiple permits.

- Chemical oxidation (persulfates/ozone) – Persulfate in-situ chemical oxidation (ISCO) shows the most promise toward treating the organic compounds. However, persulfate chemical oxidation has the potential to corrode and degrade metal sheeting used in construction of the CDF wall. Fenton's reagent and ozone technology also show promise, but are too short-lived to achieve contact.

7.1.2 Sustainability

Green remediation is the practice of considering all environmental effects of remedy implementation and incorporating options to maximize the net environmental benefit of cleanup actions. USEPA's technology primer, Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites (USEPA 2008a), outlines the principles of green remediation and best management practices for reducing the footprint of environmental cleanups throughout a project's lifetime. USEPA addresses green remediation by focusing on the following six core elements:

- Energy requirements (e.g., mobile and stationary forms)
- Air emissions (e.g., from mobile and stationary sources of energy, off-gassing from the remedial technology)
- Water requirements and impacts on water resources (e.g., potable water use, water reuse, water generated on site from treatment, discharge of process water to surface waters, stormwater management, groundwater supply and quality)
- Land and ecosystem impacts (e.g., impacts on flora and fauna habitat, change in impervious coverage affecting stormwater generation)
- Material consumption and waste generation (all material throughput of the system during every stage of the project, including temporary and permanent materials and how they are handled)
- Long-term stewardship actions (a broad topic that includes aspects indirectly affected by the remedial system, such as community vitality, health and safety concerns, contribution to climate change)

In evaluating a remedial system on the basis of these six core elements, activities performed during investigation, pilot study, installation/construction, and operation and maintenance are all considered.

A qualitative review of the sediment treatment alternatives in light of the six core elements of green remediation provides a valuable perspective from which to evaluate

the treatment technologies. The in-situ applications would likely have fewer energy requirements and associated air emissions than would ex-situ applications that involve double handling of the sediment with trucks and heavy equipment. However, thermal techniques (i.e., LTTD) have significantly greater energy requirements and air emissions than do the other techniques. Thermal treatments also pose greater health and safety risks because of the potential formation of dioxins and furans. In-situ applications pose less exposure risk from dust, odor, and vapor controls during placement/mixing activities than do ex-situ applications.

Dewatering operations for all technologies (excepting in-situ aerobic and anaerobic bioremediation, ISCO, and in-situ chemical reduction) would produce another treatment need to manage the water, which would require additional energy use and create a potential surface water discharge.

The treatment alternatives have varying degrees of material consumption. In general, injection treatments could be more material-intensive than other technologies depending on the spacing of the injection wells. The chemical oxidation treatment technologies that require ozone generation on Site would increase risks to health and safety. Any treatment requiring multiple injection or mixing events could consume more energy and materials than comparable technologies that do not require multiple events.

Based on this cursory evaluation, the treatment technologies are listed below in order from more to less sustainable:

- In-situ anaerobic bioremediation
- In-situ soil mixing—S/S
- In-situ aerobic bioremediation
- In-situ chemical reduction
- In-situ chemical oxidation
- In-situ soil mixing—ZVI and clays
- In-situ soil mixing—chemical oxidants
- In-situ sequenced anaerobic-aerobic bioremediation

- Ex-situ biological treatment—anaerobic
- Ex-situ biological treatment—aerobic
- Ex-situ soil mixing—S/S
- Ex-situ soil mixing—ZVI and clays
- Ex-situ soil mixing—chemical oxidants
- Ex-situ biological treatment—sequenced anaerobic-aerobic
- Ex-situ LTTD

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Table D-1
Summary of COIs and Potential Treatment Technology Applicability

Preliminary CDF Screening Evaluation
Arkema Early Action
Portland, OR

Chemical Class	Analyte	Ex Situ Treatment Options							In-Situ Treatment Options						
		Low Temperature Thermal Desorption	Soil Mixing Solidification Stabilization	Soil Mixing Zero Valent Iron and Clays	Ex Situ Chemical Oxidation	Biological Treatment Anaerobic Treatment	Biological Treatment Aerobic Treatment	Biological Treatment Sequenced Anaerobic-Aerobic Technology	Soil Mixing Solidification Stabilization	Soil Mixing Zero Valent Iron and Clays	In Situ Anaerobic Bioremediation	In-Situ Aerobic Bioremediation	In-Situ Sequenced Anaerobic-Aerobic Bioremediation	In Situ Chemical Oxidation	In-Situ Chemical Reduction
Primary COIs															
Pesticides	Total of 2,4' and 4,4'-DDD	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pesticides	Total of 2,4' and 4,4'-DDE	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pesticides	Total of 2,4' and 4,4'-DDT	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other Harborwide COIs															
Aroclors	Aroclor 1242		X	X	X			?	X	X			?	X	X
Aroclors	Aroclor 1248		X	X	X			?	X	X			?	X	X
Aroclors	Aroclor 1254		X	X	X			?	X	X			?	X	X
Aroclors	Aroclor 1260		X	X	X			?	X	X			?	X	X
Aroclors	Aroclors		X	X	X			?	X	X			?	X	X
Butyltins	Tributyltin ion	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Dioxin Furans	Dioxin/furan TCDD toxicity equivalent		X	X	X			?	X	X			?	X	X
Dioxin Furans	Dioxin-like PCB congener TCDD toxicity equivalent		X	X	X			?	X	X			?	X	X
Dioxin Furans	Total TCDD toxicity equivalent		X	X	X			?	X	X			?	X	X
Metals	Arsenic (total)		X	X	X			X	X	X			X	X	X
Metals	Cadmium (total)		X	X					X	X					X
Metals	Chromium (total)		X	X				X	X	X			X		X
Metals	Copper (total)		X	X					X	X					X
Metals	Iron (total)		X	X					X	X					X
Metals	Lead (total)		X	X					X	X					X
Metals	Mercury (total)	X	X	X					X	X					X
Metals	Nickel (total)		X	X					X	X					X
Metals	Perchlorate		X	X		X		X	X	X	X		X		X
Metals	Selenium (total)		X	X					X	X					X
Metals	Thallium (total)		X	X					X	X					X
Metals	Vanadium (total)		X	X					X	X					X
Metals	Zinc (total)		X	X					X	X					X
PAH	2-Methylnaphthalene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Acenaphthene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Acenaphthylene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Anthracene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Benz(a)anthracene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Benzo(a)pyrene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Benzo(b)fluoranthene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Benzo(g,h,i)perylene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Benzo(k)fluoranthene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Chrysene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Dibenzo(a,h)anthracene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Fluoranthene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Fluorene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Indeno(1,2,3-cd)pyrene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Naphthalene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Phenanthrene	X	X		X	X	X	X	X		X	X	X	X	
PAH	Pyrene	X	X	X	X	X	X	X	X	X	X	X	X	X	
PCB Congeners	Polychlorinated biphenyls		X	X	X			?	X	X			?	X	X
Pesticides	Aldrin	X	X	?	X	X	?	X	X	?	X	?	X	X	
Pesticides	Dieldrin	X	X	?	X	X	?	X	X	?	X	?	X	X	
Pesticides	Endrin	X	X	?	X	X	?	X	X	?	X	?	X	X	
Pesticides	gamma-Hexachlorocyclohexane	X	X	?	X	X	X	X	X	?	X	X	X	X	
Pesticides	Heptachlor epoxide	X	X	?	X	X	?	X	X	?	X	?	X	X	
Pesticides	Total chlordanes	X	X	?	X	X	?	X	X	?	X	?	X	X	
Phenols	Pentachlorophenol	X	X	X	X	X	?	X	X	X	X	?	X	X	X
Phenols	Phenol	X	X		X	X	X	X	X		X	X	X	X	
Phthalates	Bis(2-ethylhexyl) phthalate	X	X		X	X	X	X	X		X	X	X	X	
Phthalates	Dibutyl phthalate	X	X		X	X	X	X	X		X	X	X	X	
SVOC	Hexachlorobenzene	X	X	X	X			?	X	X			?	X	X
SVOC	Hexachlorobutadiene	X	X	X	X			?	X	X			?	X	X
SVOC	Hexachlorocyclopentadiene	X	X	X	X			?	X	X			?	X	X

Notes:
X = Applicable
? = Information not available
COI = Constituent of interest
CDF = Confined disposal facility
DDD = Dichlorodiphenyldichloroethane
DDE = Dichlorodiphenyldichloroethylene
DDT = Dichlorodiphenyltrichloroethane
PAH = Polycyclic aromatic hydrocarbon
PCB = Polychlorinated biphenyl
SVOC = Semivolatile organic compound
TCDD = 2,3,7,8-tetrachlorodibenzo-p-dioxin

Table D-2

Oxidant Strengths

Preliminary CDF Screening Evaluation

Arkema Early Action

Portland, OR

Chemical Species	Standard Oxidation Potential (volts)
Hydroxyl Radical ($\cdot OH^-$)	2.8
Sulfate Radical ($\cdot SO_4^-$)	2.5
Ozone	2.1
Sodium Persulfate	2.0
Hydrogen Peroxide	1.8
Permanganate (Na/K)	1.7
Chlorine	1.4
Oxygen	1.2
Superoxide ion ($\cdot O^-$)	-2.4

Source: Adapted from ITRC 2005a

Table D-3

Oxidant Reactivities

Preliminary CDF Screening Evaluation

Arkema Early Action

Portland, OR

Oxidant	High Reactivity	Moderate Reactivity	Low Reactivity
Ozone	PAHs, Pesticides	--	--
Hydrogen Peroxide	--	PAHs	Pesticides
Fenton's Reagent	--	PAHs	Pesticides
K/Na Permanganate	PAHs	Pesticides	--
Sodium Persulfate (iron-activated)	--	PAHs, Pesticides	--
Sodium Persulfate (heat-activated)	PAHs, Pesticides	--	--

Source: Adapted from USEPA 2006a

Table D-4

Chemical Reduction Applications

Preliminary CDF Screening Evaluation

Arkema Early Action

Portland, OR

Treatment Categories	Example Materials	Constituents Treated
Metal-enhanced reductive dechlorination of organic compounds	Zero-valent metals (Fe)	Chlorinated ethenes, ethanes, methanes, and propanes; chlorinated pesticides, freons, nitrobenzene
Metal-enhanced reduction for metals contaminants	Zero-valent metals (Fe), basic oxygen furnace slag, ferric oxides	Chromium, uranium, arsenic, technetium, lead, cadmium, molybdenum, mercury, phosphorus, selenium, nickel
In-situ redox manipulation	Sodium dithionite, calcium polysulfide	Chromium, chlorinated ethenes

Source: Adapted from ITRC 2005b