Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

Appendix E
Methods for Calculating the Volume of Contaminated Sediments Potentially Requiring Remediation

Final Feasibility Study

Lower Duwamish Waterway
Seattle, Washington

FOR SUBMITTAL TO:

The U.S. Environmental Protection Agency
Region 10
Seattle, WA

The Washington State Department of Ecology
Northwest Regional Office
Bellevue, WA

October 31, 2012

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E.1 Introduction

A key component in developing and evaluating remedial alternatives for the Lower Duwamish Waterway (LDW) is the estimation of the volume of contaminated sediment that will potentially require remediation. In particular, the volume of sediment to be removed and disposed of is a major factor in estimating the cost and construction time frame for all remedial alternatives.

Many different methods were explored for calculating contaminated sediment volumes (e.g., subsurface interpolation contours, average thickness, grids, triangulation projection or triangulated irregular network [TIN] terrain models[1], average-end-area[2] estimates). Ultimately, site-wide and area-based volumes were estimated as interpolated isopach thickness layers, developed from regularly spaced cross sections and a TIN terrain surface. Upland and in-water boring information with well-defined stratigraphic markers and good spatial coverage provided a foundation for site-wide geologic interpretations. Data from LDW cores were used to develop contaminant concentration profiles and were correlated with stratigraphy where sufficient subsurface sediment data were available. Together, this information created two geographic information system (GIS)-based mapping layers that were used to estimate contaminated sediment thicknesses.

The purpose of this effort was to create thickness layers for the entire LDW that are independent of the areas of potential concern (AOPCs) and dredge footprints, which may change as additional data become available. These isopach thickness layers are used for generating feasibility study (FS)-level estimates of contaminated sediment volumes.

This appendix discusses:

1) The methods used to develop site-wide isopach layers of contaminated sediment thickness and to estimate sediment volumes (Section E.2)
2) The thickness and distribution trends of contaminated sediments along the LDW and resulting estimates of sediment volumes for each remedial alternative (Sections E.2.5 and E.3)
3) Uncertainty in the data and methods (Section E.4).

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1 A TIN is a series of triangles constructed from spatial coordinates (x, y, and z). This vector-based data structure is used to derive a surface, or terrain.

2 Average-end-area is a volume estimating tool commonly used in highway, road, railroad, and marine construction projects for design and payment purposes. This tool uses cross sections of the project surface area set at regularly spaced intervals. Elevation data are plotted in section view and the dredge area is determined by each cross section. Dredge volume is determined by the average area between two successive cross sections that is then projected along the distance, or spacing, between the cross sections.

The estimated contaminated sediment volumes presented in this FS are considered sufficient for calculating dredged material removal volumes and costs for remedial alternatives. Sufficient uncertainty has been factored into these volume estimates by calculating depth-to-alluvium (or native) volumes well beyond known contaminant depths. Volume estimates used for dredging design will require refinement based on further sampling and analyses during the remedial design phase conducted prior to any remedial action.

E.2 Methods

This section reviews methods used at various remediation sites, describes the method selected for use in the LDW FS based on this review, and describes the steps for estimating sediment volumes based on the selected method.

E.2.1 Review of Common Methods and Selection of Method for the LDW

The methods used to calculate contaminated sediment volumes at various contaminated sediment sites nationwide were reviewed. At the Whatcom Waterway site in Bellingham, Washington, a single contaminated sediment thickness was used because the sediment conditions were fairly uniform across the site (RETEC 2006). At the Lower Fox River and Green Bay Superfund site in Wisconsin, numerous subsurface sediment cores were available with enough spatial resolution to interpolate polychlorinated biphenyl (PCB) concentrations at 2-foot (ft) depth intervals (RETEC 2002). At the Chemical Recovery Systems (Black River) Superfund site in Ohio, contamination extended down to bedrock or dense, native alluvium; this stratigraphic contact was used to estimate the contaminated sediment volumes (IJC 1999). The Lower Passaic River Superfund site in New Jersey used regularly-spaced cross sections to derive average-end-area volume estimates. The two-dimensional (2-D) area of contamination estimated from one cross section was multiplied by the distance to the next cross section along these regularly-spaced intervals (Malcolm Pirnie 2007).

The FS prepared for the Hudson River Superfund site in New York incorporated some simplifications to account for a limited dataset (TAMS 2000). First, the Hudson River FS used only PCB data to delineate the depth of contamination and the volume estimates were keyed spatially to Thiessen polygon-based "target areas." Next, a consistent contaminated sediment depth was applied to each target area. Measured from the deepest mudline elevation located in the area, and following the bathymetric contour of the river, a consistent sediment depth was established.

The method selected for calculating sediment volumes in the LDW is a combination of the basic methods described above. This combined method includes:

1) The lower (native) alluvium stratigraphic contact was identified as the maximum possible depth of contamination, similar to the Black River site in Ohio. Volumes estimated from the mudline to the alluvium are considered

to represent the upper-bound estimate of potential dredge volumes under any remedial alternative.

2) Even though the LDW dataset does not include enough spatial resolution to interpolate concentrations exceeding criteria at specific depth intervals, as was done for the Lower Fox River and Green Bay Superfund site, the available subsurface cores with chemistry and stratigraphy data from the LDW dataset were used to generate half-mile interval cross sections, similar to those generated for the Passaic River. The bottom of any core interval exhibiting a detected contaminant concentration above the sediment quality standards (SQS) or above concentrations of concern for other risk drivers, henceforth referred to collectively as SQS, was interpreted as the lower limit of contamination.[3] A TIN network was developed from cross sections and cores to approximate the thickness of contaminated sediment. The result was a variable thickness site-wide layer.

3) The target areas (or dredge footprints) define the surface requiring remediation, with variable contaminated sediment depths applied to these target areas based on the isopach surface.

This approach is considered the most effective and efficient, based on the available data, for determining contaminated sediment volumes in the LDW.

E.2.2 Method Used to Estimate Sediment Volumes

LDW-wide contaminated sediment volumes were generated using three major steps, which ultimately resulted in a GIS-generated isopach layer of contaminated sediment thickness. The three steps were:

1) **Generalized Cross Sections:** Cross sections were generated in a computer-aided drafting (CAD) program, generally at half-mile intervals along the LDW. In each cross section, three lines of elevation were digitized:

   - ♦ Elevation of mudline (or bathymetry)

[3] All risk drivers were used to develop the contaminated sediment volume. For simplicity, the term "SQS" is used to signify the lower limit of contamination. The lower limit of contamination includes sediment concentrations that exceed concentrations for total PCBs >240 micrograms per kilogram dry weight (µg/kg dw), carcinogenic polycyclic aromatic hydrocarbons (cPAHs) >1,000 µg toxic equivalent (TEQ)/kg dw, dioxins/furans >25 nanograms (ng) TEQ /kg dw, and Sediment Management Standards (SMS) chemicals >SQS. These concentrations define the AOPC 1 footprint (as described in Section 6) and Alternative 5 RALs for subtidal sediments (as described in Section 8). Because cPAH and dioxin/furan exceedances are typically shallower than the SQS exceedances, "SQS" is an appropriate term for discussing thickness of sediment contamination above these concentrations.

- Elevation of the bottom of contamination (lowest depth below the mudline at which detected concentrations of any Sediment Management Standards [SMS] contaminant exceeded the SQS)

- Elevation of the top of the native (lower) alluvium taken from the stratigraphic interface observed in sediment cores and nearby upland explorations (the lower alluvium and its significance are described in Section E.2.3.1).[4]

2) **LDW-wide Isopach Surfaces and Thickness Layers:** The three elevation lines described above were imported into the GIS program. The elevations of the bottom of contamination and the top of the lower alluvium were converted to x, y, z points and subtracted from the bathymetric elevations to represent depths from the mudline. Additional depths obtained from core data (i.e., depths of bottom of contamination and top of lower alluvium at specific x, y locations) were imported into GIS to provide spatial coverage between the half-mile cross sections. A TIN surface was generated using the points described above and in each of the datasets, described in Section E.2.3.2, to create a three-dimensional (3-D) representation of each depth-based surface within the LDW. A TIN applies a network of small triangles between all data points in the digitized data layers to form a 3-D surface.[5] The 3-D surface represents an approximation of the in situ conditions (natural location or position). The TIN application is explained in more detail in Section E.2.4. The TINs were then converted into 10-ft by 10-ft thickness grid cells, which were used to calculate the site-wide sediment volumes.

3) **Site-wide Sediment Volumes:** After the grids were generated, sediment volumes were estimated as the thickness of the grid cell multiplied by the surface area of an area of interest. Volumes were estimated for two layers: a thickness of contamination layer (i.e., mudline to the lower limit of SQS exceedances) and a thickness to lower alluvium layer (i.e., mudline to the

4 The top of the lower alluvium is the assumed maximum possible depth of contamination for any remedial alternative. The lower alluvium is thoroughly defined and its significance is described in Section E.2.3.1.

5 Three TIN surfaces were generated, the first being the bathymetry TIN based on the 2003 bathymetric survey (Windward and DEA 2004) and supplemented with mudline elevations from core data in areas where bathymetric data were not available because the presence of barges or overwater structures and/or low tides inhibited access by the sampling vessel during the bathymetric survey. The bathymetric data used to generate the TIN surface were the results of a high-resolution, multibeam survey with 1-meter (m) resolution capturing bank-to-bank bathymetry, where available. Two additional TINs include a thickness of contamination surface, and a thickness from the mudline to the top of the lower alluvium surface.

lower alluvium surface).[6] Section E.2.5 further discusses the sediment volume calculations and Section E.3 presents the resulting volume estimates. The horizontal extent of the contamination was assumed to be the top of the bank of the in-water study area, which is based on the bathymetric elevation of +11.3 ft mean lower low water (MLLW).

The three-step process used to generate sediment volumes is discussed in detail in the following sections. The sequential tools used to develop the volumes are listed below.

Attribute	Description
Line	An attribute that connects x, y, and z point data referenced to an elevation of interest
Isopach Surface	A two-dimensional surface contoured from lines and point data, expressed as elevation or depth
Layer	A three-dimensional volume of contamination extending below the mudline surface, expressed as thickness

These attribute terms are used throughout this appendix.

E.2.3 Step 1: Generalized Cross Sections

The process of generating sediment volume estimates began by developing a series of cross sections along the LDW, from river mile (RM) 0.0 to RM 4.8 at approximately half-mile increments (Figure E-1). The last cross section was set at RM 4.8, because bathymetric data were not available upstream of this point. Survey point data from sediment samples were used above RM 4.8 to RM 5.0 to estimate volumes in the remainder of the FS study area. Generally, cross sections were oriented perpendicular to the river flow direction, as illustrated in Figure E-1. The specific cross section locations were influenced by the amount, distribution, and type of subsurface data available. Additional cross sections were added to cover geographically unique areas like a bend in the waterway, the presence of Kellogg Island, or a slip. In particular, two cross sections (D-D′ at RM 1.0 W and E-E′ at RM 1.0 E) were added parallel to the navigation channel west of Slip 1 to estimate the thickness of contamination and the depth to the lower alluvium along the navigation channel. Cross section C-C′ at RM 0.5 to RM 0.6, and cross section I-I′ at RM 2.1 were oriented where data were available and adequate to capture the river cut around Kellogg Island and Slip 3. These cross sections were beneficial for estimating the volume of contaminated sediments in the areas of the LDW outside the navigation channel.

6 In Section 8 of the FS, additional volumes were added to these estimated volumes as a contingency to account for design considerations, dredging inaccuracies, and other contingencies typically encountered during construction (e.g., slope cut, debris).

Sixteen cross sections were generated manually. Each cross section used a combination of subsurface sediment chemistry and geology and upland geology where available. Core data collected during various studies, most of which are included in the remedial investigation (RI) project database, were used to populate the cross sections (described in Section E.2.3.2). These data points are illustrated on Figures E-2 through E-17.

When cores were projected onto cross sections such that mudline elevations for cores were different than the elevations of the bathymetric surface, the interpolated contamination and lower alluvium 2-D surfaces were drawn to a similar depth as the contacts in the cores, as opposed to the exact elevations of the contacts. The information from the hand-drawn cross sections was entered into CAD, and used to generate the cross sections shown on Figures E-2 through E-17. Two lines of elevation from each cross section were digitized into x, y, and z coordinates for export to GIS. These two lines, described in Section E.2.3.1, are the elevation of:

1) The bottom of the contaminated sediment layer (the lowest depth below the mudline with detected concentrations of any SMS contaminant greater than the SQS)
2) The top of the lower alluvium layer.

During the collection of the sediment cores, a common occurrence was that less than 100% of the sediment volume was retained. Recovery of sediment in the core is dependent on the nature and uniformity of the sediment, and frictional forces during driving (Windward and RETEC 2007). Some factors that prevent complete recovery of the driven sediment interval include: sediment loss during recovery of the core tube through the water column, compaction of sediment, and blockage during core advancement that prevented material from entering the core tube. As a result of these factors, the amount of sediment in the core tube during field processing (recovered depth) often does not reflect the actual depth below the mudline from which the sediment core was collected (referred to as the *in situ* depth) (Windward and RETEC 2007). The difference between the recovered depth and the drive depth was used to estimate the *in situ* depth over the entire core length. The *in situ* depths for the core data were used to generate the two layers and ensured that neither the depth to contamination nor the depth to the lower alluvium was underestimated.

E.2.3.1 Elevations of Interest

The bottom of contamination is defined as the lowest depth in each core where one or more detected contaminant concentrations exceed the SQS. First, the FS subsurface sediment database was queried to find the lowest depth in each core for which the SQS was exceeded for detected SMS contaminants. The bottom of the sample interval in a core was used for mapping. For example, if a detected SQS exceedance was found in the 4- to 6-ft sampling interval but the next interval (from 6- to 8-ft depth) was non-detect or below the SQS, then the core was assigned a contaminated sediment depth of 6 ft.

Second, other risk drivers were queried to determine if elevated contaminant concentrations (described in footnote 3) were present at lower depths. Collectively, these depths were used as the bottom of contamination in each core, which were then interpolated between cores in each cross section.

The lower alluvium is a native, predominantly dense, sandy stratigraphic unit that was deposited prior to the industrialization of the Duwamish watershed and the straightening of the Duwamish River into the LDW. Because of its depositional time frame, the lower alluvium has not been anthropogenically disturbed or contaminated by industrial activities in the area. It represents the pre-industrial strata, reflects pre-industrial contaminant conditions, and, therefore, should bound the lower extent of any contamination. Thus, the top of the lower alluvium was identified as the maximum possible depth of sediment contamination for any remedial alternative. Contaminant and stratigraphic data from the 2006 RI cores (Windward and RETEC 2007) confirm that SQS exceedances were not detected in the sandy lower alluvium unit.

The bathymetric data used for cross sections and TIN development were collected in 2003 during a LDW-wide survey for the RI (Windward and DEA 2004). In several areas, bathymetric data were not available. These data gaps occurred where barges, overwater structures, and low tides inhibited access by the sampling vessel during the bathymetric survey. Data for these areas (e.g., the Glacier Northwest embayment at RM 1.5 W) were extrapolated from the 2003 bathymetric survey and elevation data from core logs and borings.

Each cross section, except for cross sections C-C′, D-D′, and E-E′, was generated from at least two subsurface sediment cores, such as one deep geotechnical boring from either the east or west bench of the LDW, and at least one upland boring from each side of the adjacent upland area. Because the upland borings generally do not have chemistry data, the depth of contamination was interpolated from at least two in-water subsurface sediment cores in each cross section. This data requirement was set to ensure a higher degree of accuracy and confidence for estimating sediment volumes.

The upland boring logs were reviewed for physical information to confirm and map the depth to the lower alluvium surface. The lower alluvium was identified as a dense, typically medium-grained, non-silty sand to an interbedded silt and sand (with varying amounts of shell fragments located below interbedded silt and sand with abundant natural organic material) or fill units. The elevation of the top of the lower alluvium has been observed in several studies of the Puget Sound region, specifically the Duwamish Valley. From these studies, the elevation for the top of the lower alluvium is generally thought to be encountered at an elevation of about -30 to -50 ft below ground surface in the lower and central valley and between about -20 and 0 ft below ground surface in the upper valley (Booth and Herman 1998). The upland borings were used to confirm that the lower alluvium was reached in the LDW sediment cores (based on elevations).

E.2.3.2 Datasets

Four datasets were used to develop the cross sections along the LDW and to generate the TINs:

- Sediment cores collected for the RI in 2006 and published in a 2007 subsurface sediment data report (Windward and RETEC 2007).
- Other sediment cores collected from the LDW by various entities over the period between 1996 and 2009, now included in the FS subsurface sediment database (Striplin Environmental Associates, Inc. 1996, 1998, 2000; Weston 1999; Windward, DOF, and Onsite Enterprises 2005; USACE 2009a, 2009b; AMEC 2007; Geomatrix 2008; Anchor 2008a, 2008b; AMEC Geomatrix 2009a, 2009b, 2010).
- Upland and in-water boring logs available from the GeoMapNW on-line database (GeoMapNW 2008). These logs were typically generated for geotechnical investigations and are not accompanied by chemistry data.
- Radioisotope cores collected in 2004 for the Sediment Transport Analysis Report (STAR; Windward and QEA 2008).

It was necessary to combine these datasets to interpret both the thickness of contaminated sediments and the depth to the lower alluvium. The following subsections discuss each dataset.

E.2.3.2.1 2006 RI Sediment Cores

The primary data used to generate the cross sections were the cores collected in 2006 for the RI. These cores included both stratigraphic information and contaminant data reported at both recovered and *in situ* depths to about 12 ft below the mudline. These data were generally collected in continuous 1- to 2-ft depth intervals (low resolution) over the length of the core and analyzed for SMS contaminants. *In situ* depths were used where available, because they eliminated uncertainty introduced by core collection techniques and provided a more realistic approximation of actual conditions.

Data from within 400 ft of the transect line for any core were used to generate a cross section. Because stratigraphic and contaminant data can vary with distance, the 400-ft limit was established to ensure that data at greater distances from a given cross section were not applied to it. In general, the RI cores were located close to each transect, with 50% of those cores located within 100 ft of their respective transects, and 92% of those RI cores were located within 400 ft. It is noted that three RI cores (LDW-SC-26, LDW-SC-34, and LDW-SC-41) were located more than 400 ft from their corresponding transect. These cores were still used in this analysis because they provided information on the thickness of contaminated sediments in the navigation channel, where limited core data are available.

E.2.3.2.2 LDW Sediment Cores Collected by Other Entities

The next set of data used to generate the cross sections were the sediment cores collected from the LDW by other entities over the period between 1996 and 2009. These cores were primarily used in the cross sections to identify the thickness of recent sediment deposition, which generally correlated to the contamination layer. The dataset included cores from the following investigations: the Early Action Area (EAA) investigations for Terminal 117 and Boeing Plant 2/Jorgensen Forge (Windward, DOF, and Onsite Enterprises 2005; Geomatrix 2008; AMEC Geomatrix 2009a, 2009b, 2010), EPA's LDW-wide *Site Investigation* (SI; Weston 1999); the U.S. Army Corps of Engineers sampling events for dredged material characterization in the navigation channel (USACE 2009a and 2009b; Striplin Environmental Associates, Inc. 1996, 1998, and 2000); and two maintenance dredging characterizations (AMEC 2007; Anchor 2008a). The historical cores included both stratigraphic information and contaminant data in a mix of recovered and *in situ* depths, depending on the specific dataset. *In situ* depths were used, where available, and in many cases were calculated from the percent recovery and total drive depth information on the core logs.

As discussed above, data from cores within 400 ft of the transect line were used to generate a cross section. In general, the historical sediment cores were located close to each transect, with 80% of the cores located within 400 ft of their respective transects. It is noted, though, that two distant (>400 ft) historical cores, C1-PSDDA96 and Avg-8-9-PSDDA98, were included (N-N', Figure E-15) to provide information on the thickness of contaminated sediments in the navigation channel, where limited core data are available.

E.2.3.2.3 Upland and In-water Boring Logs from the GeoMapNW Online Database

The third set of data used to generate the cross sections were the upland and in-water boring logs from the GeoMapNW database (GeoMapNW 2008). This database is a compilation of sediment and soil borings collected throughout the state for various purposes, typically for civil engineering studies including utility corridors, bridge construction, other public works projects, and for private subsurface investigations. The GeoMapNW cores were generally advanced deeper than the cores from the other datasets, and these borings were used only to identify the top of the lower alluvium in each cross section.

The GeoMapNW cores included stratigraphic data but no chemistry data. A higher percentage of GeoMapNW cores was applied to cross sections with distances greater than 400 ft because these cores were used only to identify the elevation of the lower alluvium. Stratigraphic data can be interpolated over wider distances than contaminant data because stratigraphic data represent larger scale regional conditions, while subsurface sediment contaminant data are often more spatially heterogeneous.

One GeoMapNW boring log (ID 41911, A-A′ at RM 0.0) did not include the elevation of the top of the core. In this instance, the mudline elevation from the 2003 bathymetric survey (Windward and DEA 2004) was used as the elevation of the top of the core.

E.2.3.2.4 High Resolution Radioisotope Cores

The final set of data used to generate the cross sections were the high-resolution radioisotope cores that were collected to calculate net sedimentation rates (Windward and QEA 2008). Samples were collected at continuous 2-centimeter (cm) depth intervals over the upper 3 ft of these cores. These cores were used only to estimate the thickness of the recent sediment layer in cross sections at RM 1.45, RM 1.9, RM 3.5, and RM 4.3. It was important to interpolate the recent layer in the cross sections because it helps determine the top (upper limit) of the underlying layers. The radioisotope cores were not used to generate the TINs because they do not include chemistry data or lithology information beyond the recent soft sediment deposition layer.

E.2.3.3 Digitized Lines for Import into GIS

After the generalized cross sections were finalized in CAD, two lines of elevation were digitized from each cross section: the elevation of the bottom of contamination (>SQS), and the elevation of the top of the lower alluvium. This was accomplished by generating a point at every change in slope along each of the surfaces of interest (i.e., bottom of contamination [>SQS] and top of lower alluvium) established in the cross section generation process described in Section E.2.3. These points were then imported into GIS as x, y, and z coordinates.

E.2.4 Step 2: Site-wide Isopach Surfaces and the Creation of Thickness Layers

The digitized data from the 2003 bathymetric survey, the two digitized elevation lines from CAD, and additional x, y, and z coordinates from core data used for spatial coverage were imported into GIS to create three isopach surfaces:

- The mudline elevation (the sediment–water interface) from the RI bank-to-bank bathymetric survey (Windward and DEA 2004) extended shoreward to the top of the bank by the GeoMapNW cores
- The elevation of the bottom of contamination (one or more SMS contaminants at a detected concentration >SQS)
- The elevation of the top of the lower alluvium unit (native contact).

The latter two digitized lines are referred to as the lower limit of contamination and the top of the lower alluvium, respectively.

In GIS, the lower limit of contamination elevation and the top of lower alluvium elevation were subtracted from the mudline elevation to convert these elevation data to layers. In the upland portions of the cross sections, the elevation of the top of the lower alluvium was subtracted from the upland ground surface elevation to generate a depth to the top of the lower alluvium.[7]

Contaminant and stratigraphic data from all cores in the FS subsurface sediment dataset were used to fill in spatial data gaps between cross sections.

Near Kellogg Island, where there were relatively few cores, additional data points were generated to better match significant bathymetric features. The points included estimates of contamination thickness and depth to lower alluvium based on nearby cores, cross sections, and bathymetry (see data points around Kellogg Island; Figures E-1, E-5, E-6, and E-7). This resulted in thickness layers near Kellogg Island that are closer to the expected stratigraphy in this area.

E.2.4.1 Creation of Isopach Surfaces and Layers

Next, a TIN was used to interpolate a two-dimensional representation of the contamination and lower alluvium surfaces using the cross section lines of elevation and core data. A TIN of the mudline elevation was also generated by combining the bathymetric data (Windward and DEA 2004) with the mudline elevations from cores in areas where bathymetric data were not available because the presence of barges and overwater structures and/or low tides inhibited access of the sampling vessel during the bathymetric survey. A network of 10-ft by 10-ft grid cells was generated from the TIN surfaces to provide seamless coverage of the LDW.

Finally, the generation of TIN surfaces was used to produce digitally contoured three-dimensional figures, showing layer thicknesses (Figures E-18 and E-19) below mudline.

Some adjustments were made to these surfaces. For example, when the lower alluvium was not identified in a core log, the total depth of the core plus 1 ft was generally assumed to be the depth of the top of the lower alluvium. However, if nearby, deeper cores identified the top of the lower alluvium, only the cores that identified the top of the lower alluvium were used to generate the TIN (therefore, shallow cores that did not reach alluvium did not alter the TIN if they were contrary to other cores). A project geologist analyzed the core logs, locations, and preliminary TINs.

Analogous adjustments were made to the thickness of contamination layer. In the instances where the deepest sample in a core exceeded the SQS, 1 ft was added to the total depth of the core to represent the lower limit of contamination. However, if sample

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[7] The ground surface elevations from the upland cores were not projected into the in-water portion of the cross sections, and thus did not affect the interpolated bathymetric contour. A sharp slope from the top of bank down to the mudline elevation can be seen on each side of each cross section (Figures E-2 through E-17).

data from nearby, deeper cores identified the lower limit of contamination, then only the cores that identified the lower limit of contamination were used to generate the TIN (therefore, shallow cores that did not reach the lower limit of contamination did not alter the TIN if they were contrary to other cores). In addition, if some sampling intervals were archived and not analyzed for chemistry, then lithology was considered when defining the lower limit of contamination. A project geologist analyzed the core sample intervals, contaminant concentrations, locations, and preliminary TINs.

A minimum contamination depth of 1 ft was assumed within AOPCs 1 and 2. This was necessary to ensure that a minimum contaminated volume was calculated for all dredge areas with detected surface exceedances of the SQS, regardless of whether a core had subsurface sediment contamination. Dredging to at least 1 ft would be required operationally in any area where dredging was the selected remedial action. Therefore, in locations with surface contamination and where the interpolated thickness to the lower limit of contamination was less than 1 ft, a minimum contamination depth of 1 ft was applied for volume estimation within the dredge footprints.

E.2.4.2 Trends in Contamination Thickness in the LDW

A general understanding of the thickness of contamination in various areas of the LDW can help site managers anticipate the volume of sediments to be managed under potential remedial alternatives.

The data compiled to calculate dredging volumes suggest that the depth of contamination (as defined by the SQS) in intertidal areas is generally less than 5 ft, and the average depth of contamination is 1 to 2 ft in intertidal areas. Figure E-20 presents summary statistics of contaminated sediment thickness within the total area of AOPC 1 and also grouped by mudline elevations.

Figure E-20 shows the depth of contamination (i.e. thickness of contaminated sediment) in AOPC 1 by mudline elevation. The figure indicates that higher elevations (e.g., intertidal) generally have thinner contaminated sediment and lower elevations (e.g., subtidal) generally have thicker contaminated sediment. This difference in contamination depths between subtidal and intertidal areas is in part explained by the conceptual site model, which indicates that subtidal areas experience greater net sedimentation rates than intertidal areas, such that contaminated sediments are buried and, therefore, found in deeper and thicker intervals in the subtidal areas.

The maximum depth of contamination observed in any core in the FS dataset was about 27 ft (core SD-DUW433[8]) after datasets from two studies (Terminal 105 and South Park Bridge) were excluded. Among the excluded datasets, the average maximum depth of

[8] Measured depth in core was 0 to 20 ft, but expanded to 27 ft to represent *in situ* conditions (77% core recovery).

contamination was about 21 ft in those cores. Both of these datasets included historical SQS exceedances at depth, but the chemistry data were excluded from consideration because of the sampling methods. The cores were collected with a hollow stem auger, which can vertically draw down and cross-contaminate deeper sediment as the augers are advanced with depth, obscuring contacts. For this reason, these datasets were not used in determining the depth of contamination, although they were retained for determining the depth to the top of the lower alluvium. The thickness to the top of the lower alluvium reached up to 70 ft in some places, which is an unrealistic depth for remedial design; therefore, the maximum depth to the top of the lower alluvium was bound to a reasonable depth below mudline in any given area. The maximum thickness for the lower alluvium was limited to no more than 27 ft from the mudline. The decision to bound the top of the lower alluvium to no more than 27 ft from mudline ensures that all possible contamination above the SQS is accounted for in the estimated sediment volumes. This approach also prevented the maximum extent of the depth of contamination, as represented by the top of the lower alluvium, from being overestimated in the GIS program and resulting TINs.

Regarding the thickness to the top of the lower alluvium, the average thickness in areas with mudline elevations above 0 ft MLLW is 3.5 ft thick. In the shallow subtidal areas and deep intertidal benches (between 0 and -10 ft MLLW), the average thickness to the top of the lower alluvium is about 10 ft, presumably from historical fill material along the banks of the LDW.

E.2.5 Step 3: Calculation of Sediment Neat-line Volumes

The next step was to calculate a neat-line volume[9] for each 10-ft by 10-ft grid cell in the LDW. The neat-line volume associated with each grid cell was calculated by multiplying each layer (thickness) by the area of the grid cell (100 ft^2). Dredge footprint sediment volumes were calculated by summing the volumes in each grid cell within a particular area.

It is noted that each dredge area may have variable depths of contamination. These variable depths are factored into sediment volumes by summing the neat-line volumes associated with each grid cell within the dredge footprint.[10]

For Alternatives 2 through 5, the neat-line volume to the maximum depth of SQS exceedances (SQS isopach) was used as the basis for calculating the volume of contaminated sediment. It was assumed that dredging would occur vertically to the

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[9] The "neat-line volume" is the calculated volume of sediments within a dredge area straight down to the bottom of contamination. Neat-line volumes do not take into account the design of constructible dredge prisms (i.e., side-slopes and box cuts), overdredging, or additional contingencies such as additional sediment characterization.

[10] Engineering constraints used to delineate dredge footprints are discussed in Section 8 of the FS.

maximum depth of SQS exceedances. Dredging for Alternative 6 would be deeper and would occur vertically to the maximum depth of Alternative 6 remedial action level (RAL) exceedances, some of which are below the SQS (deeper than the SQS isopach). Therefore, the neat-line volume would be greater for Alternative 6 than the neat-line volume estimated for the other remedial alternatives. To account for this difference in Alternative 6, the neat-line volume was multiplied by an additional factor of 1.34. The factor of 1.34 was developed by comparing the maximum depth of Alternative 5 RAL exceedances (i.e., "SQS") and the maximum depth of Alternative 6 RAL exceedances for the 62 cores collected for the LDW RI. On average, the maximum depth of the Alternative 6 RAL exceedances was approximately 1.4 ft deeper (or approximately 34% deeper) than the maximum depth of Alternative 5 RAL exceedances (see Tables E-1 and E-2).

The extent of potential contamination was assumed to be limited vertically by the stratigraphic contact at the top of the lower alluvium (native sediment). Therefore, the neat-line volume to the top of the lower alluvium was used for the high sensitivity volume estimate, as discussed in the following section.

During remedial design, sediment volumes described in this appendix will be adjusted to consider common engineering and operational factors in dredging projects. This will be conducted by the collection and analysis of additional sediment cores in all dredge footprints to refine the sediment volume estimates, as described in Section 8.

E.3 Volume Estimates for Remedial Alternatives

Neat-line volumes underrepresent the amount of material that will be removed under actual field conditions. Therefore, these volumes were adjusted by considering the following specific allowance factors:

- An overdredging allowance over the neat-line depth, which is a common contracting approach that accounts for operational characteristics and limitations of dredging equipment.
- An allowance to account for additional sediment characterization (e.g., presence of contaminants below the presently estimated depth of contamination).
- An allowance to account for cleanup passes for residuals management within the dredge-cut prism.
- Additional volumes required for constructability of dredge-cut prisms, such as stable side slopes, box cuts,[11] the spatial resolution of dredge equipment, and the slumping of sediments around the dredge-cut prism.

[11] A box cut is a typical excavation method utilized by the dredge along the side slopes. In this method, the width of the dredge cut is sufficient to allow slope material to slough off to the natural underwater repose of that material.

E.3.1 Best-Estimate Dredge-Cut Prism Volume

To account for the multiple allowances listed above, the neat-line volumes were increased by 50%. This adjustment is consistent with literature evaluations of previous FS volume estimates and actual removal volumes for large sediment remediation sites (Palermo 2009).[12]

Palermo (2009) compared predredging volume estimates with actual dredge-cut prism volumes and computed the average volume allowance (63%) for all the sites reviewed. For Phase 1 of the Hudson River cleanup, when comparing the predredging estimates (neat-line estimate from their FS) with the post-dredging estimates (pay volume that included the box cuts and overdredging, etc.), the volume allowance was determined to be approximately 90% (Arcadis 2010). Table E-3 compares predredging estimates and post-dredging estimates for 19 representative sites as presented in Palermo (2009). The Sitcum Waterway, WA project was excluded because the post-dredging volume was inflated as a result of additional maintenance dredging, and data from Phase 1 of the Hudson River cleanup were included although they were not in the Palermo (2009) report. The table also includes each site's volume allowance and an average volume allowance for all the sites.

Table E-4 presents the best-estimate dredge-cut prism volume estimates for each remedial alternative, along with the low and high sensitivity estimates, which are discussed in the following section.

E.3.2 Dredge-Cut Prism Volumes Used for Sensitivity Analysis

EPA's 1988 RI/FS Guidance states that: "Use of sensitivity analyses should be considered for the factors that can significantly change overall costs of an alternative with only small changes in their values, especially if the factors have a high degree of uncertainty associated with them." For the LDW cleanup, dredge-cut prism volume is a cost-sensitive parameter (see Appendix I). Therefore, low and high volumes were developed to bound the best-estimate dredge-cut prism volume for each remedial alternative.

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[12] "Volume creep" is the term applied to the additional dredge-cut prism volume required as a result of the allowance factors listed above in the introduction of Section E.3 (Palermo 2009). As cited in the paper, "volume creep" also applies to the additional dredge-cut prism volume required as a result of high siltation rates, slumping of the sediments around the dredge-cut prism, and incomplete site characterization. Possible causes of volume creep include changes in remedy approach, cleanup level, or project objectives; expansion of the area of concern or depth of dredging as a result of refinements in site or sediment characterization, sedimentation or erosion occurring between site characterization and active remediation; development of dredge-cut prisms that account for methods of dredge operation, inability to fully remove sediments to the desired depth, overdredging allowances; and redredging required to achieve a cleanup level. (Palermo 2009).

The lower bound dredge-cut prism volume estimate used the same neat-line volume estimates assumed for the best-estimate dredge-cut prism volume. However, instead of a 50% allowance factor, a 25% factor was used to account for overdredging, additional characterization, constructability, and the other allowance factors listed earlier.

The higher bound dredge-cut prism volume estimate used the top of the lower alluvium as the basis for the maximum depth of sediment contamination. No additional allowance was used because the neat-line volume to the top of the lower alluvium was considered to be the reasonable maximum possible dredged volume. For reference, the neat-line volume to the top of the lower alluvium is approximately equal to the neat-line volume to the maximum depth of SQS exceedances plus an additional 100%.

E.4 Sources of Uncertainty

Common sources of uncertainty in volume estimates include: data interpolations, areas with missing bathymetric data, cores without reported mudline elevations, limited core depths, and variability in the quality of data collected caused by different sampling techniques. The areas and depths chosen to represent volumes are also a source of uncertainty. Each of these sources of uncertainty is discussed below.

A level of uncertainty exists when interpolating data and when using data collected over various periods. Over the past 20 years, numerous investigations have been conducted in the LDW to determine the nature and extent of sediment contamination.

A portion of the uncertainty is related to analytical reporting limits that exceed the screening criteria, especially in older data. To account for this uncertainty, the vertical extent of contamination was delineated using only exceedances of the SQS for detected contaminants. As a result, there may be non-detect exceedances of the SQS below the maximum depth of detected SQS exceedances. In approximately 20% of all cores, non-detect exceedances occurred in the deepest sample interval of the core, as depicted in Appendix G. In general, these core samples were either: 1) collected for dredge material characterization (and therefore represent material that has subsequently been dredged), or 2) samples where the primary risk drivers (PCBs, arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), dioxins/furans) were well below the SQS or RALs, but the low organic carbon content of the samples resulted in higher organic carbon-normalized reporting limits that exceeded the SQS. Typically, the non-detected exceedances are due to reporting limit exceedances of the SQS for one or two SMS contaminants, and not exceedances of the SQS or RALs for the primary risk drivers (PCBs, cPAHs, arsenic, and dioxins/furans). This uncertainty is captured in the 50% volume allowance, which accounts for additional characterization during remedial design.

The RI subsurface sampling events in 2006 collected 10- to 12-ft sediment cores, and in most cases, the bottom samples reached “native sediments” (i.e., the lower alluvium) and were below the SQS. On a generalized scale, the vertical extent of contamination (>SQS) has been quantified in most areas, and the lower alluvium contact can be used as a conservative estimate of the maximum depth of contamination for this FS. Uncertainty regarding the spatial coverage of the RI cores was addressed by using multiple datasets and cores collected by different parties. However, many of the historical cores neither determined the maximum vertical extent of contamination nor reached the lower alluvium. This source of uncertainty was managed by interpolation between cores with adequate data. The use of additional upland data from areas adjacent to the LDW further minimized the level of uncertainty in the interpolated data surface for the depth to the lower alluvium by corroborating the thickness of geologic units. These thickness estimates will need to be refined during remedial design for individual areas.

The generation of assumed bathymetric and elevation data discussed in Section E.2.4 is also a source of uncertainty. Not all of the historical sediment core logs reported mudline elevations. For these cores, the 2003 bathymetric data were used to represent the top of the core. Boring elevations reported from the GeoMapNW database and boring logs were used in the analysis of the upland cores when available; however, there was no way to verify the accuracy of those reported data.

The top of bank, or top of shoreline, defined as the bathymetric elevation +11.3 ft MLLW, is the interface between the upland and in-water areas and is well-defined on GIS maps from the RI (Windward 2010). However, there is some uncertainty regarding the slope and elevation of the intertidal and high intertidal areas surrounding the top of bank demarcation. This area was hand-interpolated using the 2003 bathymetric data (Windward and DEA 2004), upland cores, and aerial photographs to better understand these shoreline areas. Historical filling in the shoreline area may contribute to the uncertainty of contaminated sediment volumes and the noticeable differences between the elevations based on the lower limit of SQS exceedances and the top of the lower alluvium.

Another source of uncertainty includes sediment cores with detected SQS exceedances in the lowest sample interval analyzed. Most core samples were collected in 2-ft to 4-ft depth composites (low resolution) and do not have finer resolution of contaminant data. Exceedances of the SQS in a 2-ft or 4-ft composite could be caused by high concentrations in the upper part of the interval even though there are lower concentrations (below the SQS) in the lower part of the interval; however, compositing obscures this distinction. Therefore, the precise depth of the bottom of contamination is unknown.

An overall assumption of this analysis is that the lower alluvium layer is "clean," meaning that this unit represents natural background contaminant concentrations with no SQS exceedances. This assumption is consistent with the LDW conceptual site model of contaminant and geology trends. However, seven historical cores with SQS exceedances were documented in the lower alluvium unit. All seven exceedances have been screened out on a case-by-case basis. Four cores with SQS exceedances at depths presumably within the lower alluvium were advanced by hollow stem auger drilling techniques (Terminal 105 and South Park Bridge cores). This method of sampling commonly produces draw-down of contaminants and contaminated sediment from the contaminated intervals of the boring to lower depths within a boring unless special care is taken during drilling. The samples from these four borings were collected via Shelby tube, split spoon, and Dames & Moore sampling methods. The four exceedances were determined to be false positives at a depth within the lower alluvium from smearing or draw-down of contaminated sediment from shallower intervals. Therefore, these four cores were excluded from the analysis related to depth of contamination; however, the geological interpretations from these cores were used in the depth-to-alluvium calculations. The three remaining cores with SQS exceedances at depths presumably within the lower alluvium were located within the EAAs (Terminal 117 and Duwamish/Diagonal) where possible localized disturbance of the lower alluvium unit may have occurred based on the historical industrial activities in such areas. Cleanup actions in the EAAs either already have been conducted or will be conducted independently of the FS process. The FS does not include volume calculations for the EAAs.

The rest of the samples located completely within the lower alluvium either had detected contaminant concentrations that were below the SQS or they were non-detect. All 35 lower alluvium samples analyzed for total PCBs (outside of EAAs) were non-detect, with reporting limits ranging from 1.9 microgram per kilogram dry weight (µg/kg dw) to 79 µg/kg dw. Of 30 lower alluvium samples analyzed for arsenic, 17 were non-detect and 13 were detect, with a maximum detected concentration of 21 mg/kg dw.

Uncertainty in the volume estimates is also based on variables related to horizontal accuracy, such as horizontal positioning, density of sampling points, terrain uniformity, and the computation method used. This type of spatial uncertainty should be resolved during remedial design.

E.5 Conclusions

The process of estimating contaminated sediment volumes for the LDW remedial alternatives combined approaches from several methods, including subsurface interpolation, a maximum vertical depth constraint, and target areas within the AOPCs to define surfaces requiring remediation with variable contaminated sediment depths. These methods have all been used at other contaminated sediment sites. By using this combined method to calculate the estimated contaminated sediment volumes potentially requiring removal and disposal, results were tailored to site-specific remedial alternatives and design constraints in the LDW. The volume estimates for each remedial alternative are presented in Table E-4 and are considered to be as accurate as can be achieved in the FS without further investigation, which will be conducted as part of remedial design. Sediment volumes potentially requiring removal were estimated by following the process for determining *in situ* sediment volumes as described in this appendix, and accounting for known engineering constraints, volume creep, and residuals management. The specific volume approaches used and their associated cost estimates can be found in Section 8 and Appendix I, respectively. Of the approaches available, one approach was ultimately selected for each remedial alternative.

Combined, all of the data and analyses presented in this appendix can be used to estimate dredge-cut prism volumes for remedial alternatives in the LDW with sufficient confidence for FS-level evaluations and subsequent remedial decision-making.

The estimated volumes, and associated uncertainties in those volumes, affect the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) evaluation of the remedial alternatives and the Model Toxics Control Act (MTCA) disproportionate cost analysis (Sections 9 and 11 of this FS) in the following ways:

- **Short-term effectiveness:** The volumes to be dredged affect the duration of the construction; associated short-term effects on workers, the community, and the environment; and the overall time to achieve the cleanup objectives.
- **Cost:** The volumes to be dredged and disposed of in an upland landfill (or treated) have a roughly linear effect on estimated project cost.
- **Overall protection of human health and the environment:** The short-term effectiveness factors above are a significant consideration in evaluating overall protection.

Finally, it is reiterated that the uncertainties in the volume estimates of the *in situ* contaminated sediments are most important to the dredging portion of each remedial alternative. The scoping and evaluation of other remedial approaches (capping, enhanced natural recovery, and monitored natural recovery) are driven by the area of contamination, which can be estimated with greater confidence than the *in situ* volume.

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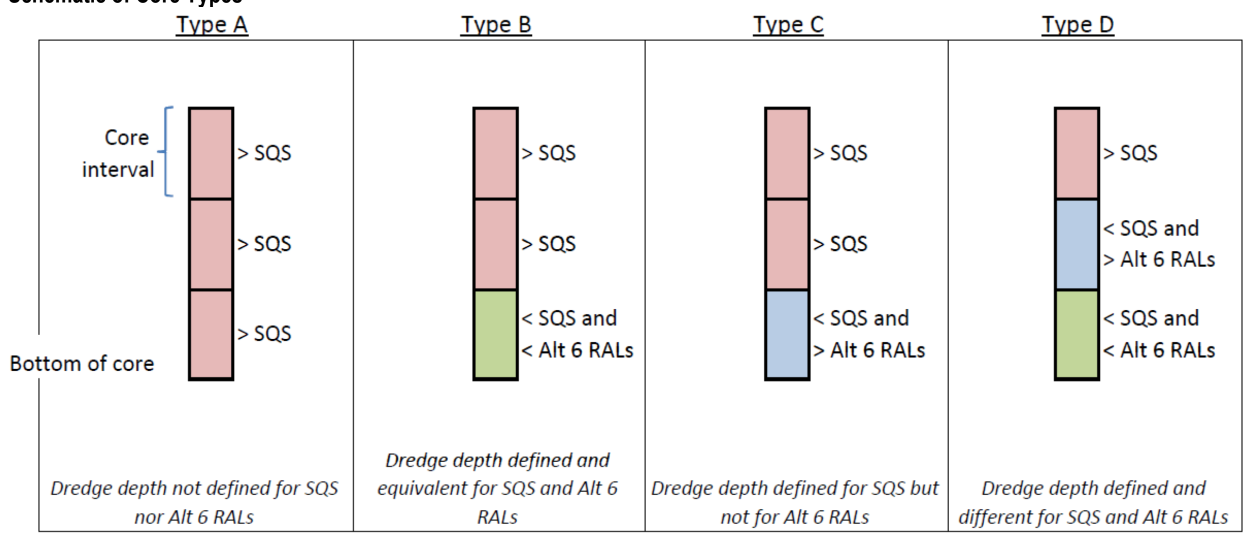
Table E-1 Summary of Dredge Depth Differences between SQS and Alternative 6 RALs for LDW RI Cores

Core Type	Count	Does the Bottom of Core (or Deepest Sample) Reach the Maximum Depth of Contamination?	Average Difference between SQS and Alt 6 RALs (ft *in situ*)	Notes
A	6	Not reached for both SQS and Alt 6 RALs	n/a	Not used in the analysis.
B	36	Reached for both, same depth for SQS and Alt 6 RALs	0.1	Depth difference generally 0 ft, but assume a minimum 1-ft dredge depth for Alt 6 in AOPC 2.
C	14	Reached for SQS, not reached for Alt 6 RALs	4.5	Assume Alt 6 dredge depth is 1 ft below the base of the core or deepest core sample.
D	3	Reached for both, deeper for Alt 6 RALs than SQS	1.9	The maximum depth of contamination is defined for both SQS and Alt 6 based on core data.
Total	59	Average of B, C, and D cores (n = 53):	1.4	Values converted from recovered depths to *in situ* core depths.

Schematic of Core Types



Scaling factor calculation

Average neat volume dredge depth to SQS	4	ft *in situ*
Average increase in dredge depth to achieve Alt 6 RALs	1.4	ft *in situ*
Average neat volume dredge depth to Alt 6 RALs	5.4	ft *in situ*
Average increase in neat volume from SQS to Alt 6 RALs (vertically)	34%	

Notes:

AOPC= area of potential concern; ft = foot; n = number of cores; n/a - not applicable; RAL = remedial action level; RI = remedial investigation; SQS = sediment quality standards

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores

Core Type	Core	AOPC	Sample Depth (ft)[a]		Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a]		Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
			Upper Depth	Lower Depth				Alt 5 Depth[d]	Alt 6 Depth[c]		
A (bottom sample > SQS)	LDW-SC10	1	0	1	260	8	x	> core depth	> core depth	0	n/a
			1	2	290	19	x				
			2	4	1,120	21	x				
			4	5	410		x				
			6	8	350		x				
	LDW-SC17	1	0	1	1,220	110	x	> core depth	> core depth	0	n/a
			1	2	1,040	170	x				
			2	4	9,800	60	x				
			6	8.6	1,900	76	x				
	LDW-SC26	1	0	1	280	40	x	> core depth	> core depth	0	n/a
			1	2	226	36	o				
			2	4	310	67	x				
			6	8	2,300	1,890	x				
			11.1	12.1	140	3	x				
	LDW-SC28	1	0	1	440	114	x	> core depth	> core depth	0	n/a
			1	2	360	18	x				
			2	4	290	30	o				
			5.5	7.5	3,200	760	x				
			12	12.6	540	17	x				
	LDW-SC41	1	0	1	370	20	x	> core depth	> core depth	0	n/a
			1	2	256	16	o				
			2	4	270	16	o				
			4	6	510		x				
			6	7.9	190		x				

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a] Upper Depth	Sample Depth (ft)[a] Lower Depth	Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a] Alt 5 Depth[d]	Dredge Depths (ft)[a] Alt 6 Depth[c]	Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
A (bottom sample > SQS)	LDW-SC8	1	0	1	290	19	x	> core depth	> core depth	0	n/a
			1	2	1,030	20	x				
			2	4	2,900	40	x				
			4	6	5,500	62	x				
			6	8	3,800		x				
			8	10	540	21	x				
B (bottom sample < SQS and < Alt 6 RALs)	LDW-SC1	1	0	0.5	85		o	4	4	0	n/a
			0.5	1	350		x				
			1	1.5	6,700		x				
			0	2	3,400	22	x				
			1.5	2	4,300		x				
			2	4	440	10	x				
			4	6	1.9		o				
	LDW-SC11	1	0	0.8	3,000	28	x	0.8	0.8	0	n/a
			0.8	2	1.95	9	o				
			2	3.4	1.95	7	o				
			3.4	4.1	2	9	o				
			4.1	5							
	LDW-SC12	1	0	0.5	64		o	6.6	6.6	0	n/a
			0.5	1	106		o				
			1	1.5	134		o				
			0	2	350	20	x				
			1.5	2	320		x				
			2	2.5	2,000		x				
			2.5	3	630		x				

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a] Upper Depth	Sample Depth (ft)[a] Lower Depth	Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a] Alt 5 Depth[d]	Dredge Depths (ft)[a] Alt 6 Depth[c]	Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
B (bottom sample < SQS and < Alt 6 RALs) (continued)	LDW-SC12 *(continued)*	1	3	3.5	138		o				
			2	4	2,500	19	x				
			3.5	4	790		x				
			4	6.6	420		x				
			6.6	8.7	1.95		o				
	LDW-SC14	1	0	1.4	4,500	24	x	10	10	0	n/a
			1.4	2	2,060	22	x				
			2	4.1	1,550	22	x				
			4.1	6	420		x				
			6	8.7	70		x				
			10	11	1.95		o				
	LDW-SC15	1	0	1	360	30	x	8	8	0	n/a
			1	2	340	20	x				
			2	4	510	25	x				
			4	6	1,950		x				
			8	10	2		o				
	LDW-SC16	1	0	2	330	21	x	8	8	0	n/a
			2	4	5,400	20	x				
			4	6	3,400	20	x				
			8	10	18	14	o				
			10	10.8							

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a] Upper Depth	Sample Depth (ft)[a] Lower Depth	Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a] Alt 5 Depth[d]	Dredge Depths (ft)[a] Alt 6 Depth[c]	Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
B (bottom sample < SQS and < Alt 6 RALs)	LDW-SC18	1	0	1	182	11	o	1	1	0	n/a
			1	2	19.6	3	o				
			2	4	1.95	3	o				
			8	10.7							
	LDW-SC19	1	0	1	280[b]	20	o	9	9	0	n/a
			1	2	233	20	x				
			2	4	250	24	x				
			4	6	440		x				
			6	7	2,400		x				
			9	11.9	1.95		o				
	LDW-SC2	1	0	2	1,380	190	x	10.7	10.7	0	n/a
			2	4	2,900	210	x				
			4	6	209	270	x				
			8	10	237		x				
			10.7	12	1.9	3	o				
			12	13							
	LDW-SC20	1	0	2	3,200	20	x	8	8	0	n/a
			2	4	600	17	x				
			4	6	400		x				
			8	10	95		o				
	LDW-SC201	1	0	1.5	1,450	19	x	8	8	0	n/a
			1.5	4	530	13	x				
			4	6	340		x				
			8	10	1.95		o				
			10	11.8							

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a]		Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a]		Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
			Upper Depth	Lower Depth				Alt 5 Depth[d]	Alt 6 Depth[c]		
B (bottom sample < SQS and < Alt 6 RALs)	LDW-SC202	2	0	1	30	13	o	0	1	1	n/a
			1	2	1.9	12	o				
			2	4	1.95	9	o				
	LDW-SC21	1	0	1	250	20	x	6.2	6.2	0	n/a
			1	2	145	19	o				
			2	4	380	34	x				
			4	6.2	1,680		x				
			6.2	8	2		o				
			10	11.3	1.95		o				
	LDW-SC22	1	0	1.1	56	12	o	1	1	0	n/a
			1.1	2	26	8	o				
			2	4	7.8	7	o				
			6	7.7							
	LDW-SC23	2	0	2	177	18	o	8	8	0	n/a
			2	4	219	20	x				
			4	6	880		x				
			6	8	400		x				
			8	10.2	41		o				
	LDW-SC24	1	0	1	280	30	x	1	1	0	n/a
			1	2	36	11	o				
			2	4	1.95	3.5	o				
			8	10							

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a]		Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a]		Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
			Upper Depth	Lower Depth				Alt 5 Depth[d]	Alt 6 Depth[c]		
B (bottom sample < SQS and < Alt 6 RALs)	LDW-SC25	1	0	1	310	50	x	8	8	0	n/a
			1	2	360	91	x				
			2	4	430	170	x				
			4	6	800	250	x				
			8	9.1	1.95	8	o				
	LDW-SC29	1	0	1	33	14	o	1	1	0	n/a
			1	2	1.95	11	o				
			2	3.6	1.95	3	o				
	LDW-SC3	outside AOPC	0	2	2	3	o	0	0	0	n/a
			2	4	1.95	3.5	o				
			6	8							
	LDW-SC30	1	0	2.5	12.9	3	o	1	1	0	n/a
			2.5	4	1.95	3.5	o				
			4	5.9							
	LDW-SC31	1	0	1	370	20	x	2.8	2.8	0	n/a
			1	2.8	330	17	x				
			2.8	4	2.7	3	o				
			4	5.9							
	LDW-SC32	1	0	1	1,010	20	x	5.2	5.2	0	n/a
			1	2	1,720	40	x				
			2	4	2,450	30	x				
			5.2	8	1.9		o				
			10	11							

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a]		Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a]		Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
			Upper Depth	Lower Depth				Alt 5 Depth[d]	Alt 6 Depth[c]		
B (bottom sample < SQS and < Alt 6 RALs)	LDW-SC33	1	0	0.5	490		x	8	8	0	n/a
			0.5	1	790		x				
			1	1.5	4,700		x				
			0	2	3,100	56	x				
			1.5	2	2,500		x				
			2	2.5	210		x				
			2.5	3	940		x				
			2	4	420	13	x				
			4	6	280	14	x				
			8	10	1.95		o				
			9.5	10							
	LDW-SC36	2	0	1	75	12	o	0	1	1	n/a
			1	2	2	11	o				
			2	4	1.9	10	o				
			8	10							
	LDW-SC38a/b	1	0	1	450	11	x	3	3	0	n/a
			1	2	710	10	x				
			2	3	3,400	13	x				
			3	3.3	14	3.5	o				
	LDW-SC4	1	0	1	143	18	x	4	4	0	n/a
			1	2	490	63	x				
			2	4	600	14	x				
			4	6	1.95		o				
			6	6.7							

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a] Upper Depth	Lower Depth	Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a] Alt 5 Depth[d]	Alt 6 Depth[c]	Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
B (bottom sample < SQS and < Alt 6 RALs)	LDW-SC40	1	0	1.3	160	7	x	1.3	1.3	0	n/a
			1.3	2	2	3	o				
			2	4	1.95	3	o				
			4	6							
	LDW-SC43	1	0	2	2	3.5	o	1	1	0	n/a
			2	4	1.95	3	o				
			9	9.8							
	LDW-SC44	1	0	0.5	260		x	3.2	3.2	0	n/a
			0.5	1	880		x				
			1	1.5	200		o				
			0	2	510	16	x				
			1.5	2	140		o				
			2	2.5	270		x				
			2.5	3	150		o				
			2	3.2	450	19	x				
			3	3.5	2		o				
			3.2	4	1.95	9	o				
			4	5.8							
	LDW-SC47	1	0	1	72	3	o	3	3	0	n/a
			1	2	2,000	12	x				
			2	3	490	8	x				
			3	4	2	3	o				
			8	10							

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a] Upper Depth	Sample Depth (ft)[a] Lower Depth	Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a] Alt 5 Depth[d]	Dredge Depths (ft)[a] Alt 6 Depth[c]	Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
B (bottom sample < SQS and < Alt 6 RALs)	LDW-SC48	2	0	1	77	3	o	0	1	1	n/a
			1	2	1.9	3	o				
			2	4	1.95	3.5	o				
			4	5.8							
	LDW-SC5	1	0	1	510	17	x	2.2	2.2	0	n/a
			1	2.2	66	14	x				
			2.2	4	1.95	3	o				
			4	6							
	LDW-SC51	1	0	2	1,290	25	x	3.8	3.8	0	n/a
			2	3.8	700	55	x				
			3.8	5.8	1.95		o				
	LDW-SC55	1	0	1	13.5	10	o	1	1	0	n/a
			1	2	1.95	3	o				
			2	3	2	3	o				
			4	6							
	LDW-SC56	1	0	2	330	7	x	2	2	0	n/a
			2	4	1.95	6	o				
			4	5.6							
	LDW-SC7	1	0	1	1,300	17	x	1.7	1.7	0	n/a
			1	1.7	1,270	11	x				
			1.7	4	2.75	3	o				
			8	8.7							

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a] Upper Depth	Lower Depth	Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a] Alt 5 Depth[d]	Alt 6 Depth[c]	Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
C (bottom sample < SQS and > Alt 6 RALs)	LDW-SC203 (replicate of LDW-SC34)	1	0	1	250	20	x	4	> sample depth	3	PCB
			1	2	110	20	x				
			2	4	174	15	x				
			4	6	181		o				
			8	8.8							
	LDW-SC27	1	0	0.5	250		x	3	> sample depth	2.5	As
			0.5	1	2,000		x				
			1	1.5	3,200		x				
			0	2	3,300	19	x				
			1.5	2	1,510		x				
			2	2.5	840		x				
			2.5	3	290		x				
			2	4.5	250	17	x				
			3	3.5	60		o				
			3.5	4	1.95		o				
			4	4.5	1.95		o				
			7.8	9.5							
	LDW-SC34 (gravel/glass at 8.7 ft; suspect non-native to bottom)	1	0	1	210	20	x	2	> sample depth	7	PCB/As
			1	2	280	20	x				
			2	4	250[b]	15	o				
			8	9.4							
	LDW-SC35 (pieces of concrete at 5.9 ft)	1	0	2	370	18	x	2	> sample depth	4	PCB/As
			2	4	150	16	o				
			6	8							

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a] Upper Depth	Sample Depth (ft)[a] Lower Depth	Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a] Alt 5 Depth[d]	Dredge Depths (ft)[a] Alt 6 Depth[c]	Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
C (bottom sample < SQS and > Alt 6 RALs)	**LDW-SC37**	1	0	1	450	150	x	5.3	> core depth	2.6	As
			1	2	950	121	x				
			2	4	550	2,000	x				
			5.3	6.9	1.95	21	o				
	LDW-SC39 (alluvium at 8.5 ft)	1	0	1	208	9	x	4	> sample depth	4.5	PCB
			1	2	440	7	x				
			2	4	220	14	x				
			4	6	150		o				
			8.5	9.2							
	LDW-SC45	1	0	1	230	15	x	5	> core depth	2	PCB
			1	2	270	13	x				
			2	4	570	25	x				
			5	6	122		o				
	LDW-SC46	1	0	1	214	16	x	4	> sample depth	3.8	PCB
			1	2	185	13	x				
			2	4	270	18	x				
			4	6.8	195		o				
			10	11.2							
	LDW-SC49a (core did not reach alluvium)	1	0	1	75	10	x	8	> core depth	4	PCB
			1	2	150	10	o				
			2	4	420	11	x				
			4	6	780		x				
			6	8	810		x				
			8	10	130		o				

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a]		Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a]		Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
			Upper Depth	Lower Depth				Alt 5 Depth[d]	Alt 6 Depth[c]		
C (bottom sample < SQS and > Alt 6 RALs)	LDW-SC50a (non-silt sand below 2.8 ft)	1	0	1	510	707	x	2.8	> sample depth	2.2	As
			1	2	780	281	x				
			2	2.8	75	161	x				
			2.8	4	1.9	21	o				
			8	9.8							
	LDW-SC53 (head of Slip 6)	1	0	2	68	20	o	1	> sample depth	4	As
			2	4	77	20	o				
			8	10							
	LDW-SC54 (alluvium at 5.5')	2	0	2	109	12	o	0	> sample depth	5.5	PCB
			2	4	111	11	o				
			8	10							
	LDW-SC6	1	0	0.5	167		o	6	> sample depth	3	As
			0.5	1	97		o				
			1	1.5	101		o				
			0	2	172	21	o				
			1.5	2	94		o				
			2	2.5	176		o				
			2.5	3	350		x				
			3	3.5	490		x				
			3.5	4	1,590		x				
			2	4.5	1,640	41	x				
			4	4.5	2,600		x				
			6	8	4.5	20	o				
			8	8.5							

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Core Type	Core	AOPC	Sample Depth (ft)[a] Upper Depth	Sample Depth (ft)[a] Lower Depth	Total PCBs (µg/kg dw)[b,c]	Arsenic (mg/kg dw)[b,c]	SMS (x = > SQS) (o = < SQS)[c,d]	Dredge Depths (ft)[a] Alt 5 Depth[d]	Dredge Depths (ft)[a] Alt 6 Depth[c]	Assumed Difference in Depth between SQS and Alt 6 RALs (ft)	Contaminant Driving the Increased Alt 6 Dredge Depth
C (bottom sample < SQS and > Alt 6 RALs)	LDW-SC9	1	0	1	3,600	17	x	2.6	> sample depth	2.4	As
			1	2.6	2,700	30	x				
			2.6	4	67	16	o				
			6.4	8.5							
D (bottom sample < Alt 6 RALs; plus at least one intermediate sample between SQS and Alt 6 RALs)	TLDW-SC13	1	0	0.5	460		x	1	2.5	1.5	PCB
			0.5	1	470		x				
			1	1.5	280		o				
			0	2	480	16	x				
			1.5	2	360[b]		o				
			2	2.5	120		o				
			2.5	3	1.95		o				
			3	3.5	1.9		o				
			2	4	53	13	o				
			8	9.5							
	LDW-SC42	2	0	1	107	10	o	0	2	2	PCB
			1	2	163	13	o				
			2	4	88	13	o				
			10	12							
	LDW-SC52	1	0	1	3,000	17	x	1	2	1	As
			1	2	65	28	o				
			2	4	2	3	o				
			4	5							

Average thickness from base of SQS to the base of Alternative 6 RALs for cores types B, C, and D (n=53) = 1.1 ft

Average *in situ* thickness assuming 80% recovery = 1.4 ft

Table E-2 Dredge Depth Differences between SQS and Alternative 6 RALs for the LDW RI Cores (continued)

Notes:

a. Depths are expressed as recovered depths, not *in situ* depths

b. PCBs were shaded pink based on dry-weight concentration (>240 µg/kg dw). However, the SMS exceedance status and Alternative 5 dredge depth were based on carbon-normalized concentrations for total PCBs (12 mg/kg oc). This results in some apparent discrepancies for samples >240 µg/kg dw and <12 mg/kg oc.

c. Alternative 6 RALs are 100 µg/kg dw for PCBs and 15 mg/kg for arsenic, and SQS for other SMS contaminants.

d. Based on all SMS contaminants

1. Blank cell indicates sample was not analyzed.

2. This analysis used the RI cores because they constitute a consistent dataset, they have sample intervals with relatively fine resolution, and they often have samples below the maximum depth of contamination. This analysis assumes that the average trends in the RI cores are representative of the average trends across the LDW.

3. Table E-1 provides the key for the color coding used in this table.

4. The Alt. 6 RAL for dioxins/furans was lower than the Alt. 5 RAL, however, there were no instances where consideration of dioxins/furans in cores would have resulted in a lower dredge depth, so a column for dioxins/furans is not included.

5. The Alt. 6 RAL for cPAHs and SMS was the same as the Alt. 5 RAL, so there was no need for considering cPAHs.

> core depth: indicates the dredge depth could not be defined by the core data because the deepest sample exceeded the RAL

Alt = remedial alternative; AOPC = area of potential concern; cPAH = carcinogenic polycyclic aromatic hydrocarbons; dw = dry weight; ft = feet; kg = kilogram; LDW = Lower Duwamish Waterway; µg = microgram; mg = milligram; n = number of cores; n/a = not applicable; oc = organic carbon; PCB = polychlorinated biphenyl; RAL = remedial action level; RI = remedial investigation; SMS = Sediment Management Standards; SQS = sediment quality standard

Table E-3 Comparison of Predredging and Post-dredging Volume Estimate at Representative Sites

Site	Predredging Estimated Volume (cy)	Post-dredging Estimated Volume (cy)	Volume Allowance Factor
Ashtabula River, OH	500,000	497,000	0.99
Bayou Bonfouca, LA	150,000	170,000	1.13
Black Lagoon, MI	90,000	115,000	1.28
Cumberland Bay, NY	93,000	195,000	2.10
Duwamish Diagonal, WA	70,000	68,000	0.97
Fox River OU1, WI	406,000	370,000	0.91
Fox River Phase 1, WI	138,000	132,000	0.96
Grand Calumet River, IN	750,000	786,000	1.05
Harbor Island Lockheed Shipyard, WA	55,000	70,000	1.27
Harbor Island Todd Shipyard, WA	116,000	220,000	1.90
Head of Hylebos, WA	217,000	404,000	1.86
Hudson River – Phase 1, NY*	133,000	256,000	1.92
Manistique Harbor, MI	104,000	188,000	1.81
Marathon Battery, NY	56,000	82,000	1.46
Northwest Oil Drain, UT	40,000	51,000	1.28
Puget Sound Naval Shipyard, WA	200,000	226,000	1.13
Reynolds Metals, NY	52,000	86,000	1.65
United Heckathorn, CA	65,000	107,000	1.65
Waukegan Harbor, IL	47,000	50,000	1.06
		Average Volume Allowance Factor (19 sites)	**1.38**

References:

Palermo 2009. *In Situ Volume Creep for Environmental Dredging Remedies*. Fifth International Conference on Remediation of Contaminated Sediments, D3. Jacksonville, Florida. February 4, 2009.

*Arcadis 2010. *Phase 1 Evaluation Report, Hudson River PCBs Superfund Site*. Prepared for General Electric Company, Albany, NY. March 2010.

Note:

The Sitcum Waterway, WA project was excluded because the post-dredging volume was inflated as a result of additional maintenance dredging.

cy = cubic yards

Table E-4 Comparison of Dredge-cut Prism Volumes for Each Remedial Alternative

		Dredge-cut Prism Volume		
		Best-estimate	Low sensitivity	High sensitivity
	Neat-line Volume to Lower Limit of Contamination[a]	Neat-line Volume to Lower Limit of Contamination+ 50%[b]	Neat-line Volume to Lower Limit of Contamination+ 25%[b]	Neat-line Volume to Lower Alluvium[c]
Remedial Alternative	*In situ* Volume (cy), Rounded			
2 Removal	250,000	370,000	310,000	430,000
2 Removal with CAD	250,000	370,000	310,000	430,000
3 Removal	390,000	590,000	490,000	770,000
3 Combined Technology	200,000	300,000	250,000	430,000
4 Removal	700,000	1,000,000	870,000	1,400,000
4 Combined Technology	370,000	560,000	470,000	730,000
5 Removal	1,100,000	1,600,000	1,300,000	2,200,000
5 Removal with treatment	1,100,000	1,600,000	1,300,000	2,200,000
5 Combined Technology	430,000	640,000	540,000	850,000
6 Removal	2,600,000	3,900,000	3,300 ,000	4,300,000
6 Combined Technology	1,000,000	1,500,000	1,200,000	1,700,000

Notes:

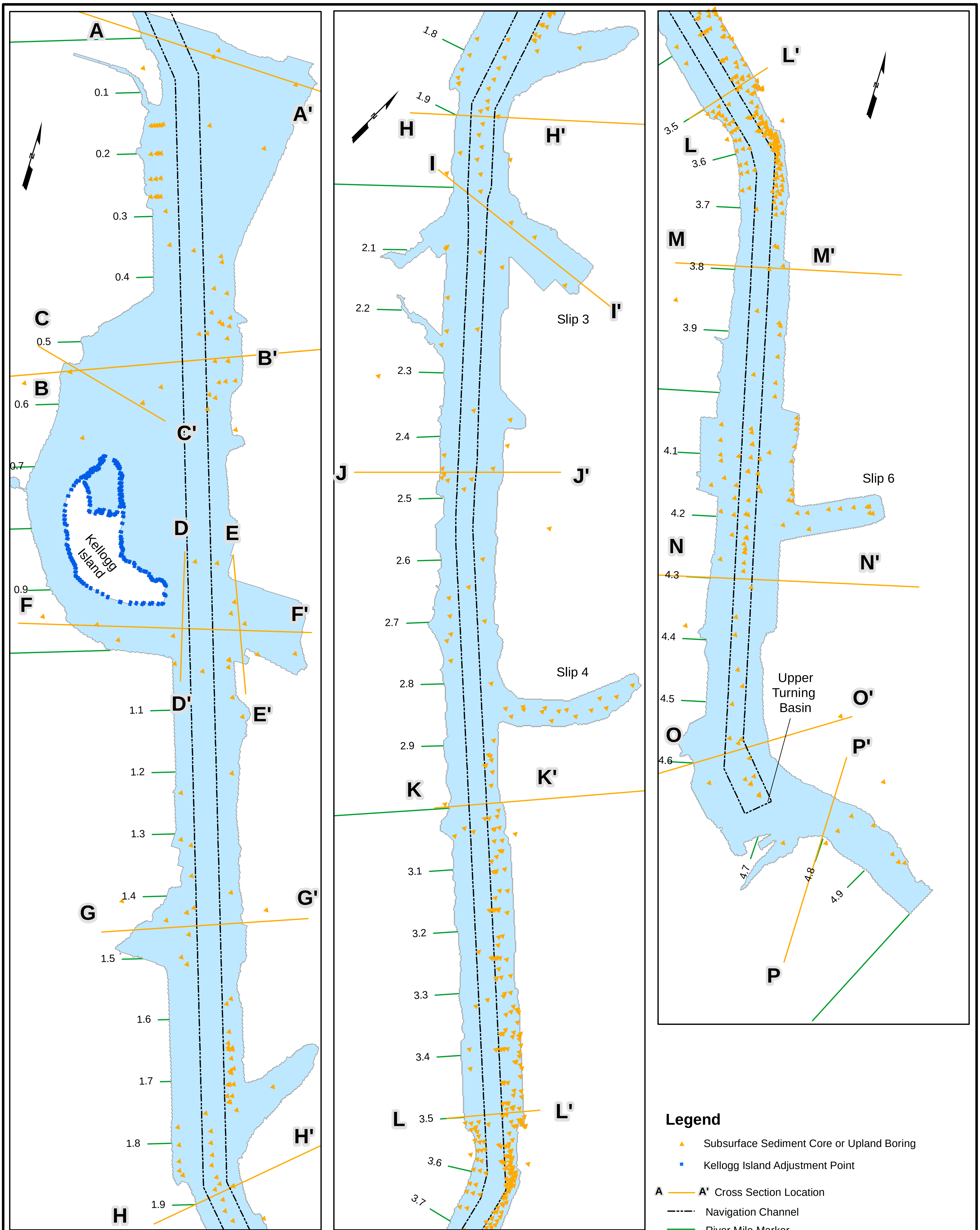
1. Volumes are shown rounded to two significant figures. Volumes are calculated prior to rounding; therefore, hand-calculated values may appear slightly different than those shown.

a. Neat-line volume to the lower limit of contamination (>SQS) is the *in situ* removal volume without incorporating side-slopes, box-cuts, overdredging, or contingencies. The neat-line volumes for Alternatives 2 through 5 are assumed to be to the maximum depth of SQS exceedances, and the neat-line volume for Alternative 6 is assumed to be to the maximum depth of Alternative 6 RALs, which is approximately the neat-line volume to the maximum depth of SQS exceedances +34%.

b. The additional allowance accounts for the method of dredge operation, allowable dredging overdepth, box cuts for slopes, and layback slopes for deeper excavations (Palermo 2009).

c. Neat-line volume to lower alluvium is assumed to be the maximum removal volume, including side-slopes, box-cuts, overdredging, and contingencies.

CAD = contained aquatic disposal; cy = cubic yards; RALs = remedial action level; SQS = sediment quality standard



Notes:
1. See Figures E-2 through E-17 for cross sections.
2. Kellogg Island adjustment points were used to constrain the contamination thickness and provide a more realistic interpolation near Kellogg Island.

Feet
0 200 400 800

AECOM

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway
Final Feasibility Study
60150279-14.49

Locations of Cross Sections and Cores Used to Estimate Sediment Volumes

DATE: 10/31/12	DWRN:MVI/sea	Revision: 0	FIGURE E-1

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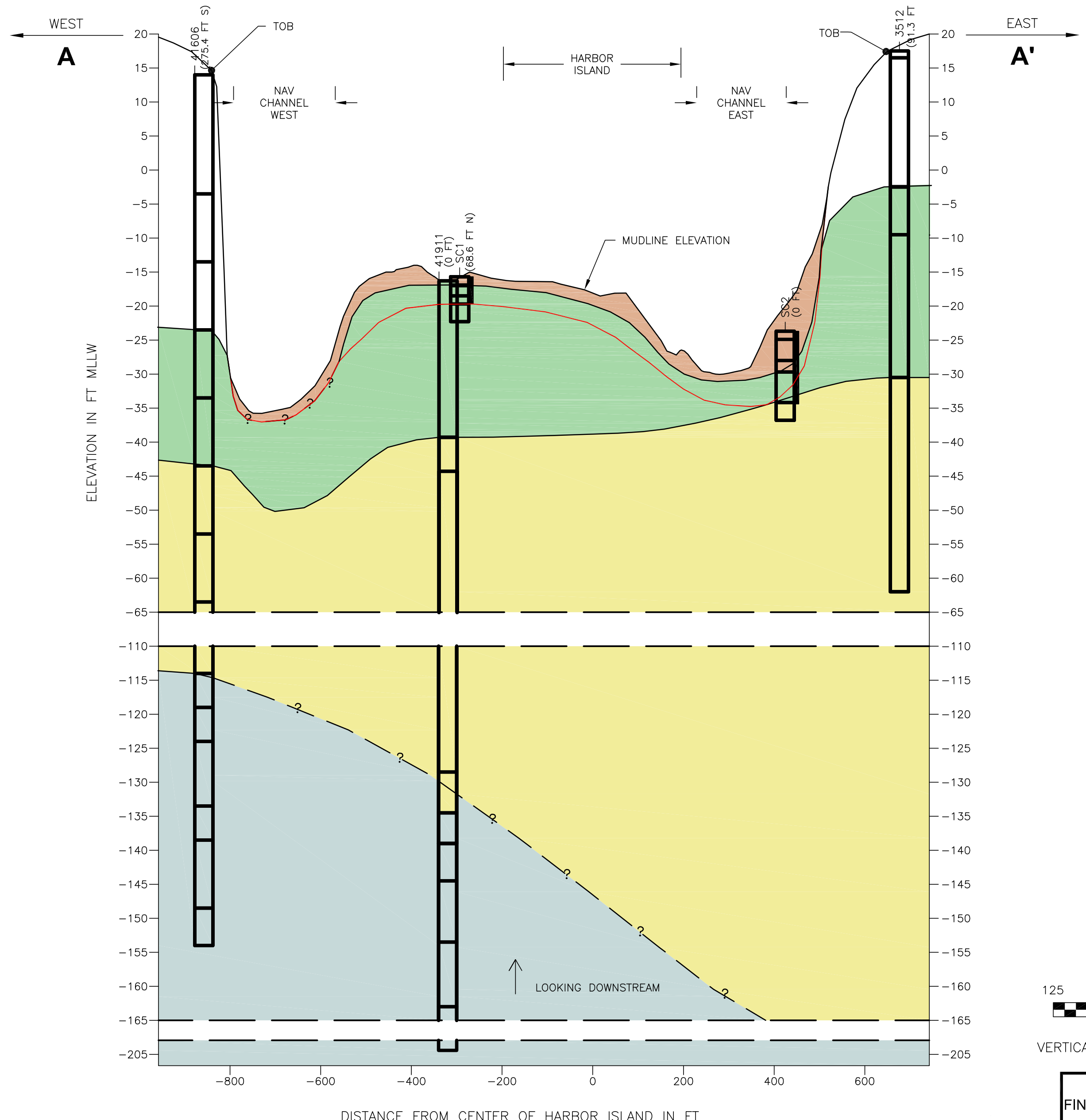
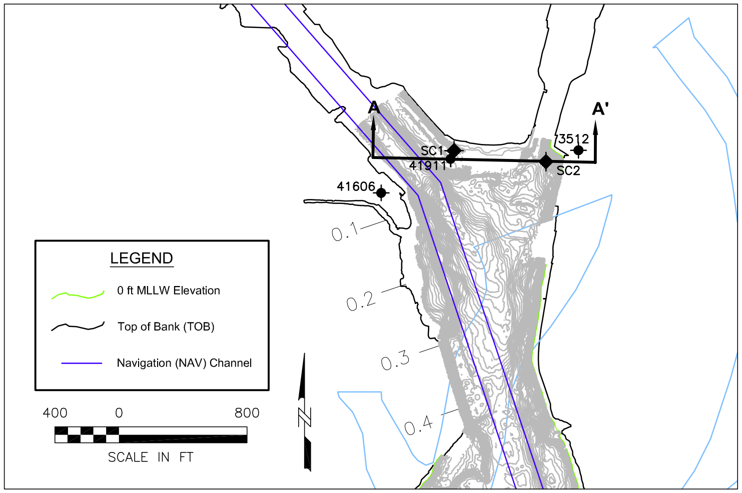


125 0 250

SCALE IN FT

VERTICAL EXAGGERATION = 15:1



LEGEND

- 0 ft MLLW Elevation
- Top of Bank (TOB)
- Navigation (NAV) Channel

400 0 800

SCALE IN FT

STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) — Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- TOB — Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances. Where intervals immediately below intervals with SQS exceedances were not analyzed, the intervals not analyzed were assumed to also have SQS exceedances.
5. GeoMapNW core 41911 was assumed to start at mudline due to lack of elevation data.
6. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).
7. The core SC2 sample at 8-10 ft was analyzed after the RI dataset was finalized. Although the data for this sample are not in the RI dataset, they are used in this cross section.

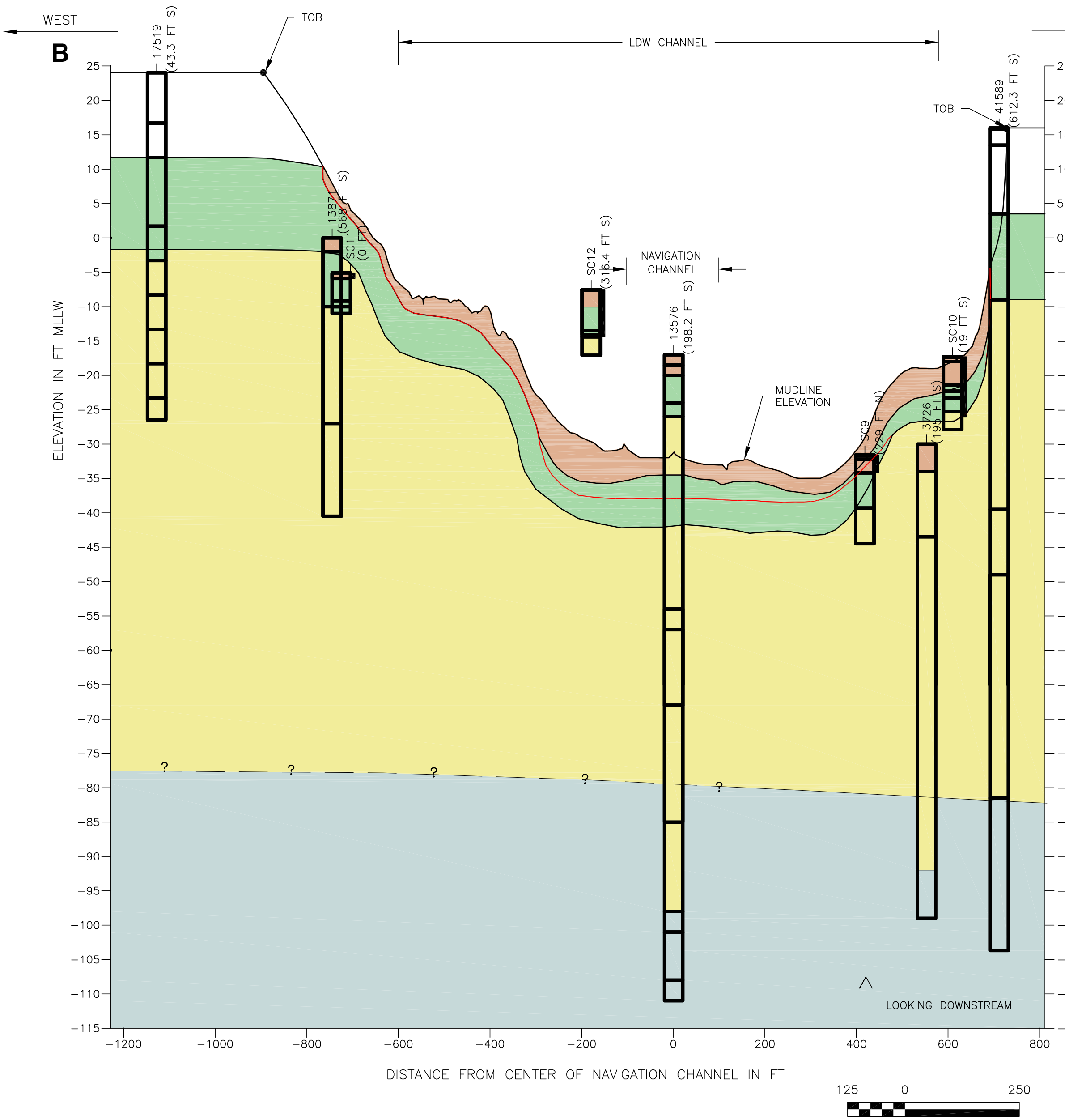
* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

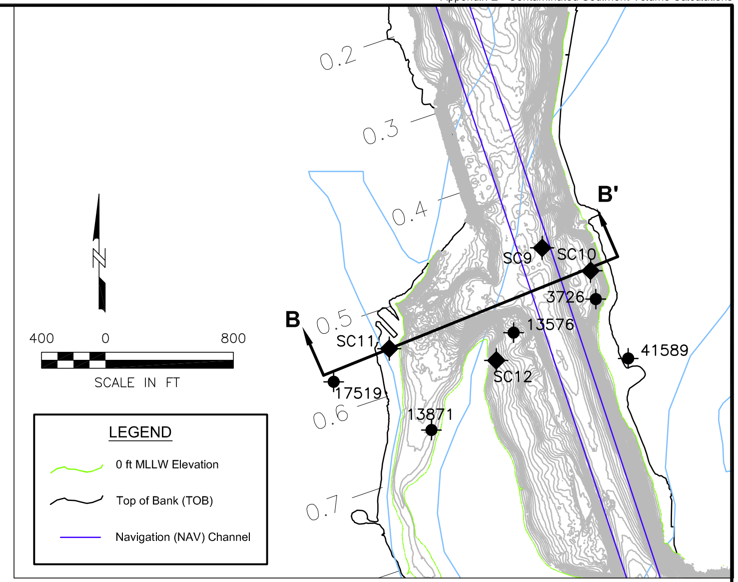
AECOM

Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18	CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 0.0
DATE: 10/31/12 DRWN: E.M./SEA REV: 0	FIGURE E-2





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) – Core Name – (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- TOB – Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances.
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

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Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

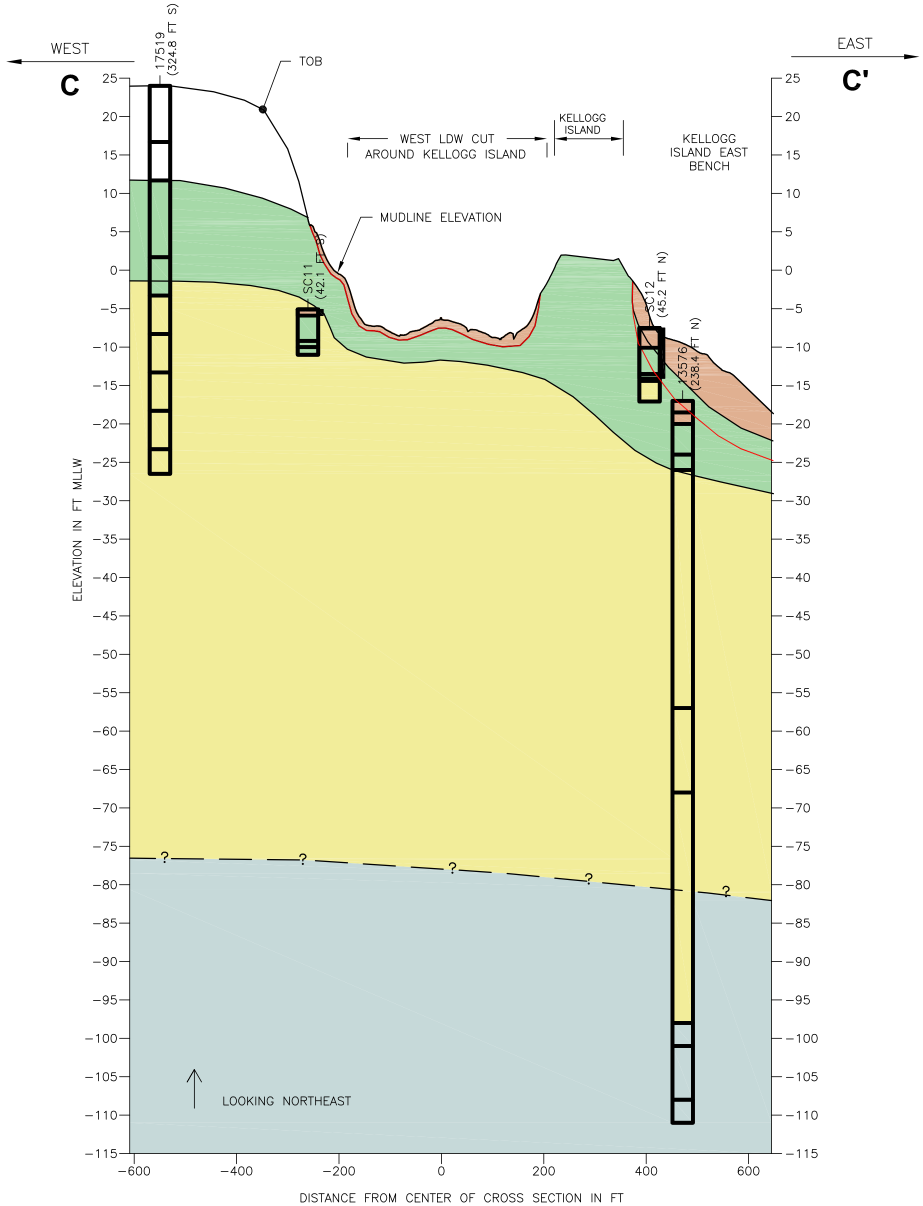
LOWER DUWAMISH WATERWAY
FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS
60150279-14.18

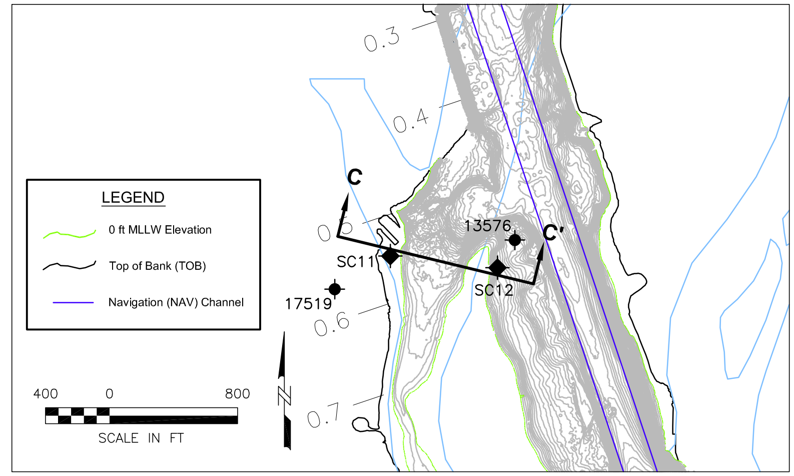
CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 0.5

DATE: 10/31/12 | DRWN: E.M./SEA | REV: 0

FIGURE E-3

File: G:\PROJECTS\CADD\Lower Duwamish\2009 FS Cross Sections\rm0.5.dwg Layout: FIGURE E-3 User: oliveriam Plotted: Nov 06, 2012 - 11:57am Xrefs:





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) – Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMap core
- RI/historical core
- TOB – Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances.
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1

AECOM

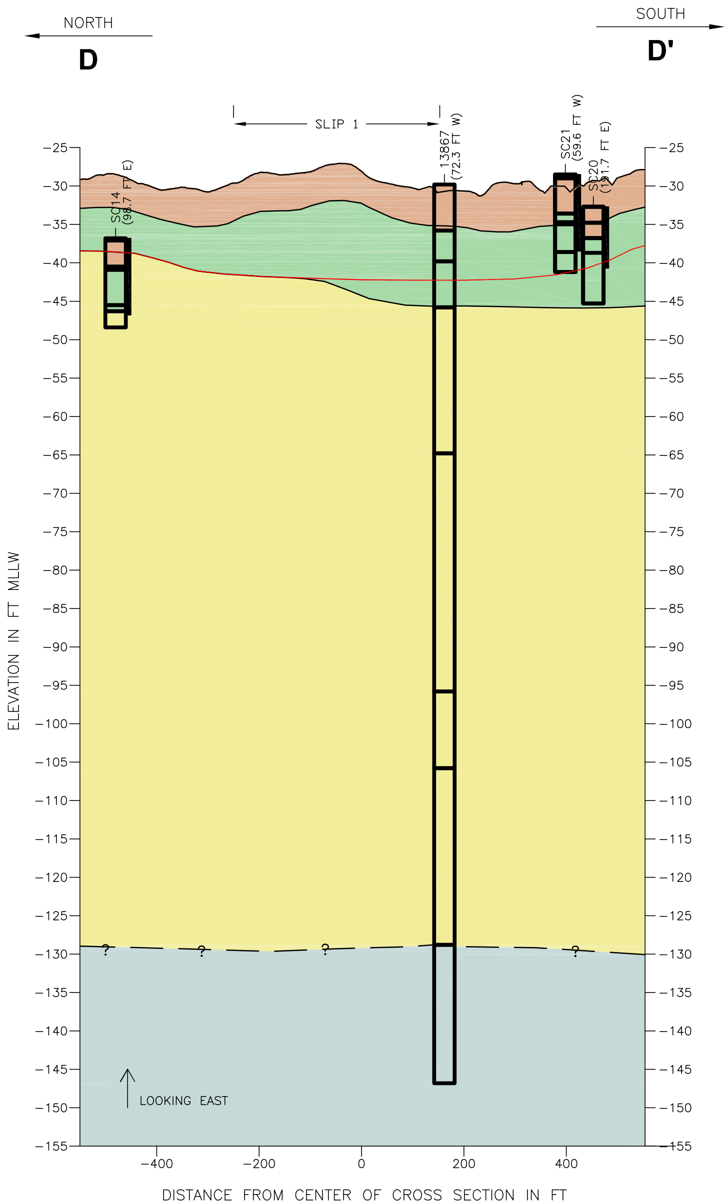
Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

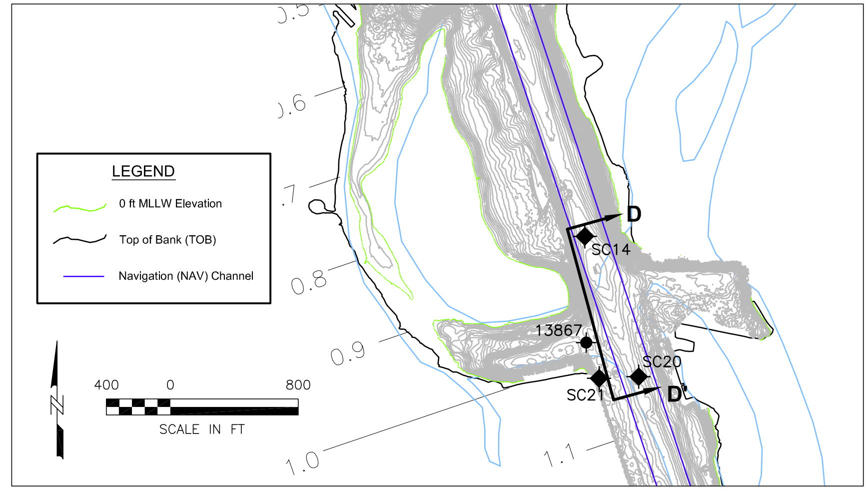
LOWER DUWAMISH WATERWAY
FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS
60150279-14.18

CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 0.5 TO 0.6

DATE: 10/31/12	DRWN: E.M./SEA	REV: 0	FIGURE E-4

File: G:\PROJECTS\CADD\Lower Duwamish\2009 FS Cross Sections\rm0.5A.dwg Layout: FIGURE E-4 User: oliveriam Plotted: Nov 06, 2012 – 12:30pm Xref's:





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) — Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- TOB — Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances. Where intervals immediately below intervals with SQS exceedances were not analyzed, the intervals not analyzed were assumed to also have SQS exceedances.
5. The core SC21 sample at 6.2-8 ft was analyzed after the RI dataset was finalized. Although the data for this sample are not in the RI dataset, they are used in this cross section.
6. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

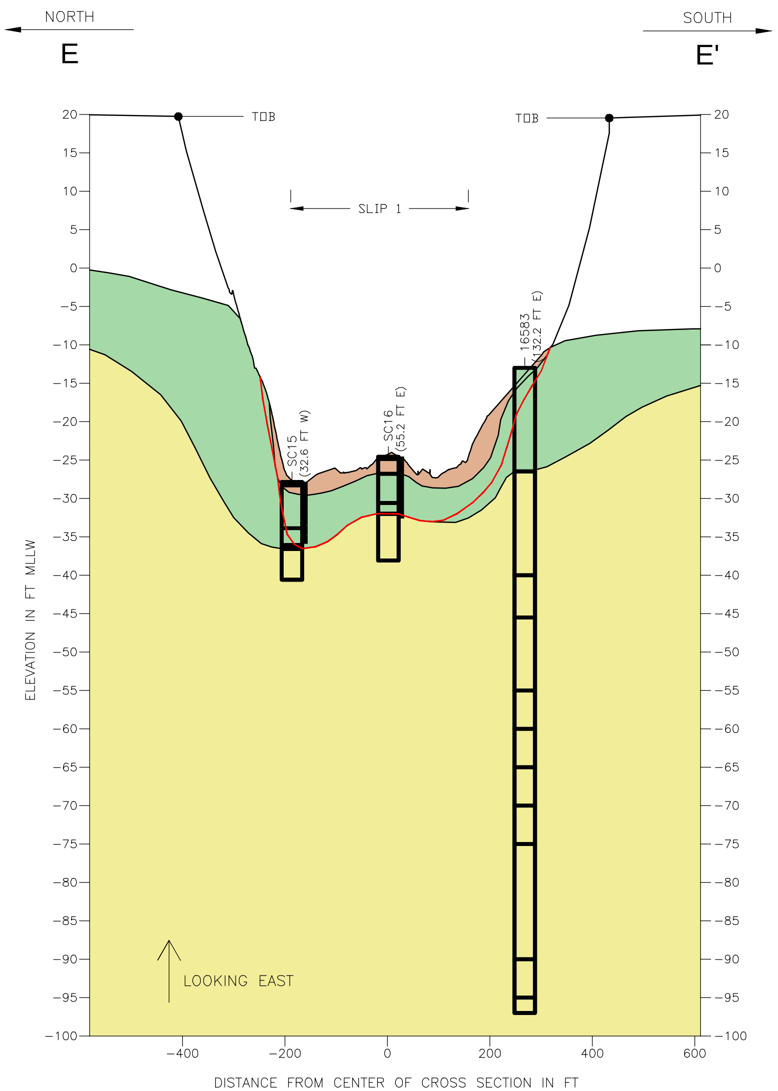
125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1

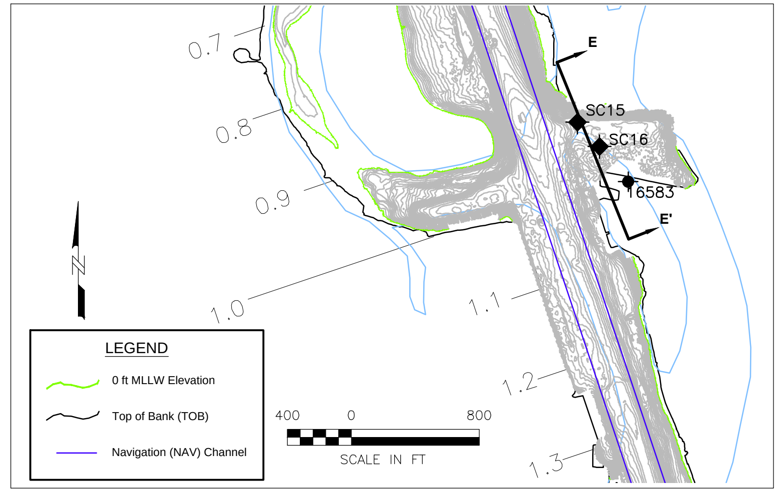
AECOM

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18	**CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 1.0 WEST**
DATE: 10/31/12 DRWN: E.M./SEA REV: 0	**FIGURE E-5**

File: G:\PROJECTS\CADD\Lower Duwamish\2009 FS Cross Sections\rm1.0_west.dwg Layout: FIGURE E-5 User: oliveriam Plotted: Nov 06, 2012 - 12:34pm Xref's:





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

SC19 (214 FT)
- Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- TOB Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances. Where intervals immediately below intervals with SQS exceedances were not analyzed, the intervals not analyzed were assumed to also have SQS exceedances.
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

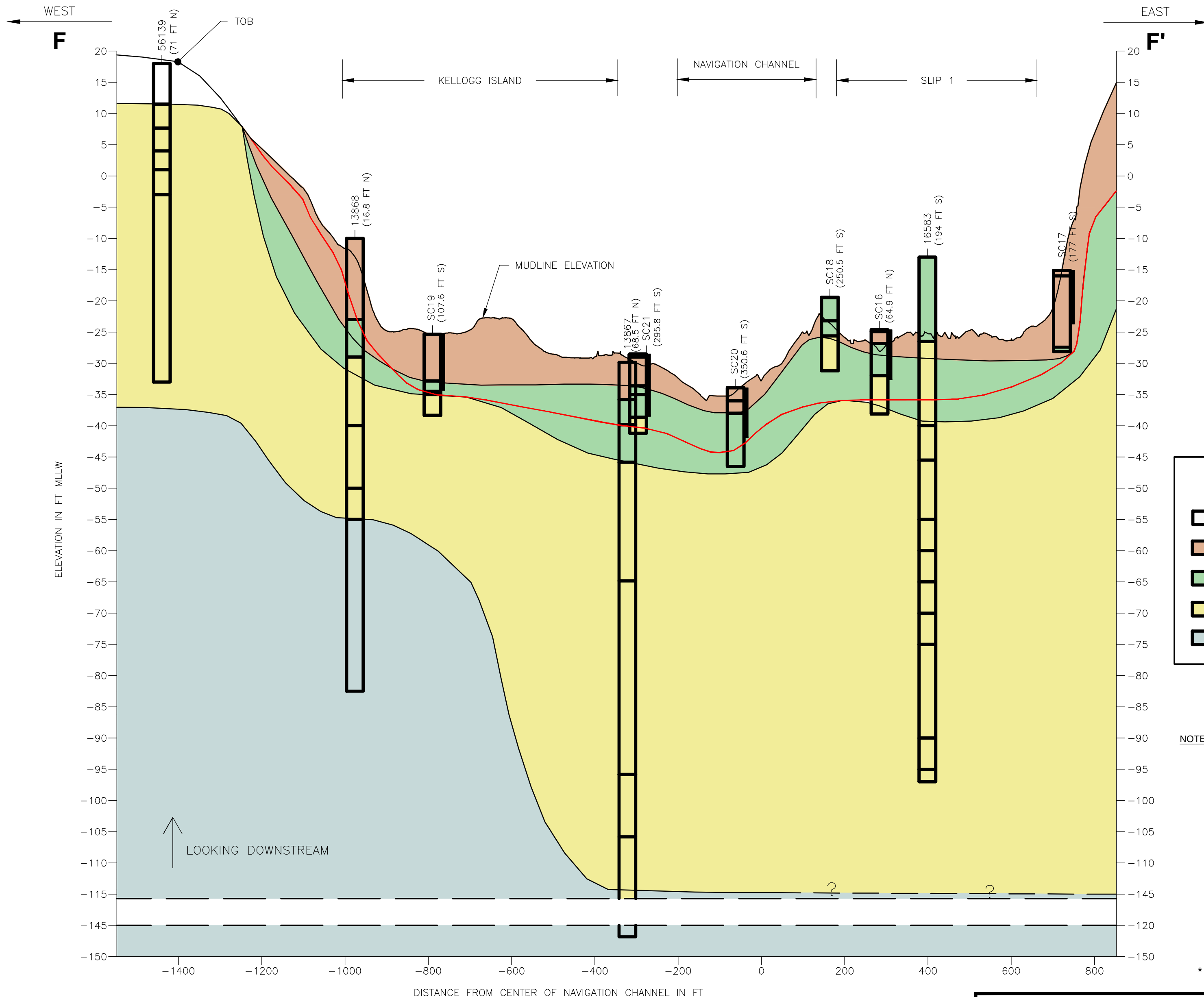
125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1

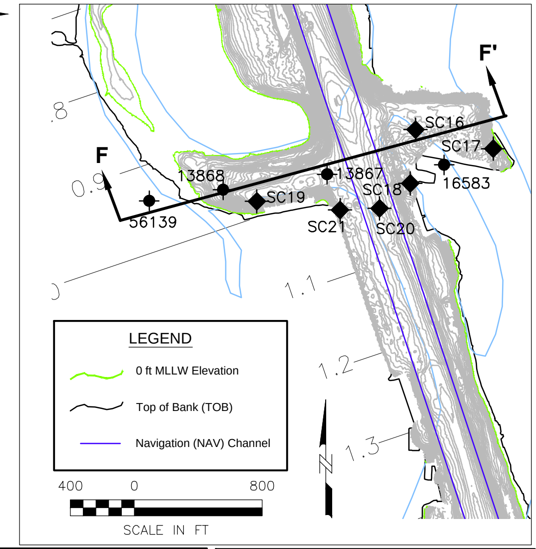
AECOM

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18			CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 1.0 EAST
DATE: 10/31/12	DRWN: E.M./SEA	REV: 0	FIGURE E-6

File: G:\PROJECTS\CADD\Lower Duwamish\2009 FS Cross Sections\rm1.0_east.dwg Layout: FIGURE E-6 User: oliveriam Plotted: Nov 06, 2012 - 12:38pm Xref's:





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) – Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- Radioisotope core
- TOB Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances. Where intervals immediately below intervals with SQS exceedances were not analyzed, the intervals not analyzed were assumed to also have SQS exceedances.
5. The core SC21 sample at 6.2-8 ft was analyzed after the RI dataset was finalized. Although the data for this sample are not in the RI dataset, they are used in this cross section.
6. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

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Lower Duwamish Waterway Group
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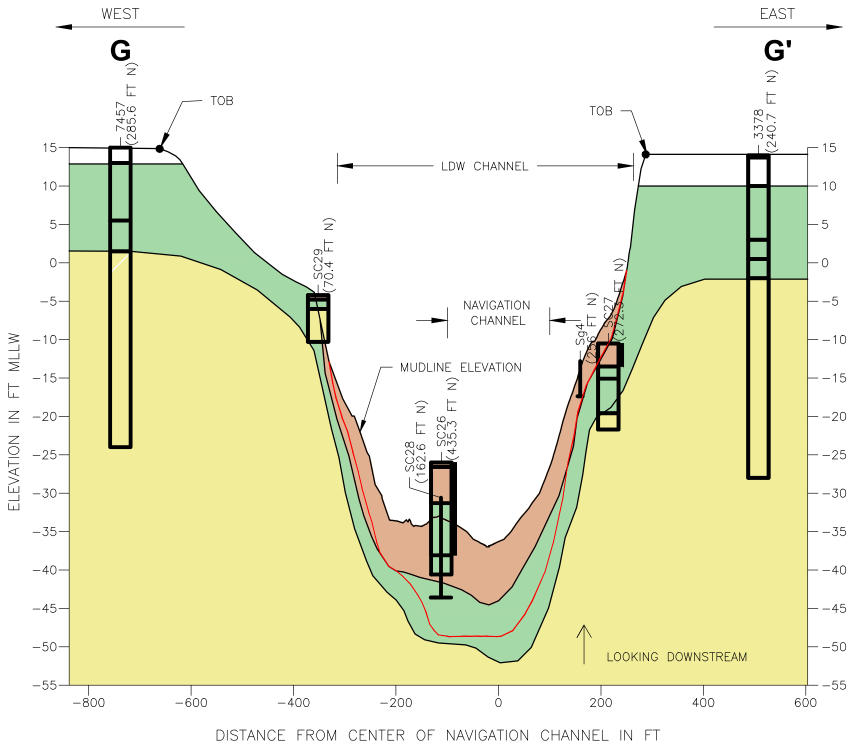
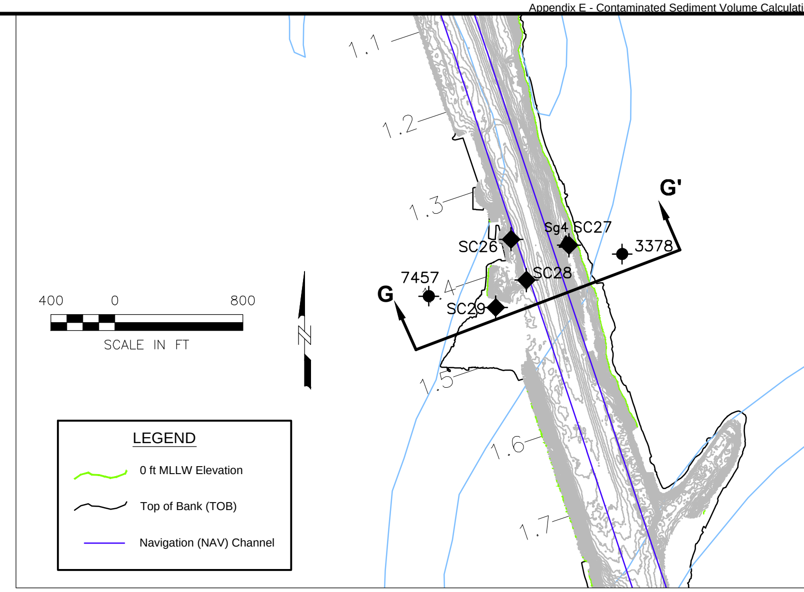
LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18	CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 1.0
DATE: 10/31/12 DRWN: E.M./SEA REV: 0	FIGURE E-7

File: G:\PROJECTS\CADD\Lower Duwamish\2009 FS Cross Sections\rm1.0.dwg Layout: FIGURE E-7 User: oliveriam Plotted: Nov 06, 2012 - 12:40pm Xref's:





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) — Core Name (Dist. from cross section to core in ft)
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- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- Radioisotope core
- TOB — Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances.
5. SC26 was chosen to be illustrated over SC28 because the core log for SC26 shows (at depth) the transition interface from recent sediment to the lower alluvium. SC28, at depth, does not indicate the interface between recent sediment and lower alluvium.
6. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

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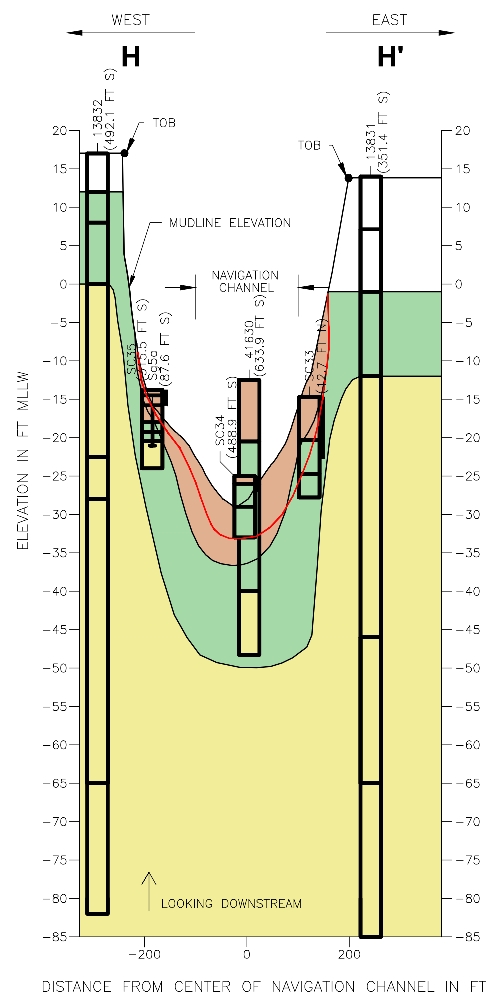
125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1

AECOM

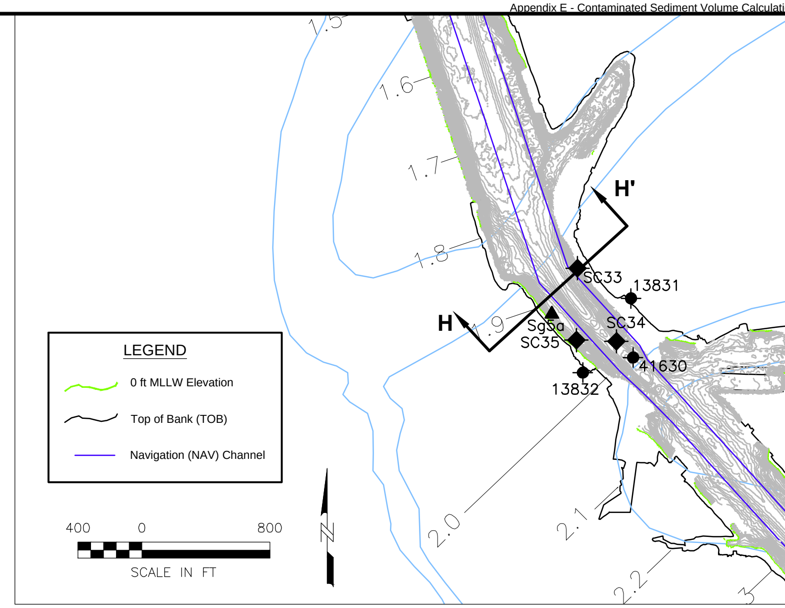
Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18	**CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 1.45**
DATE: 10/31/12 DRWN: E.M./SEA REV: 0	**FIGURE E-8**

File: G:\PROJECTS\CADD\Lower Duwamish\2009 FS Cross Sections\rm1.45.dwg Layout: FIGURE E-8 User: oliveriom Plotted: Nov 06, 2012 - 12:47pm Xref's:

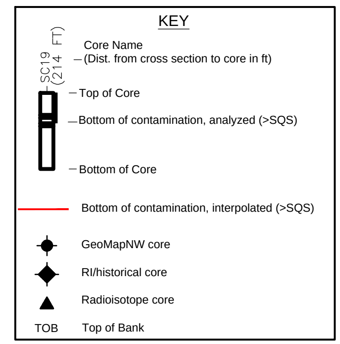


125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1



STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit



NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances. Where intervals immediately below intervals with SQS exceedances were not analyzed, the intervals not analyzed were assumed to also have SQS exceedances.
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

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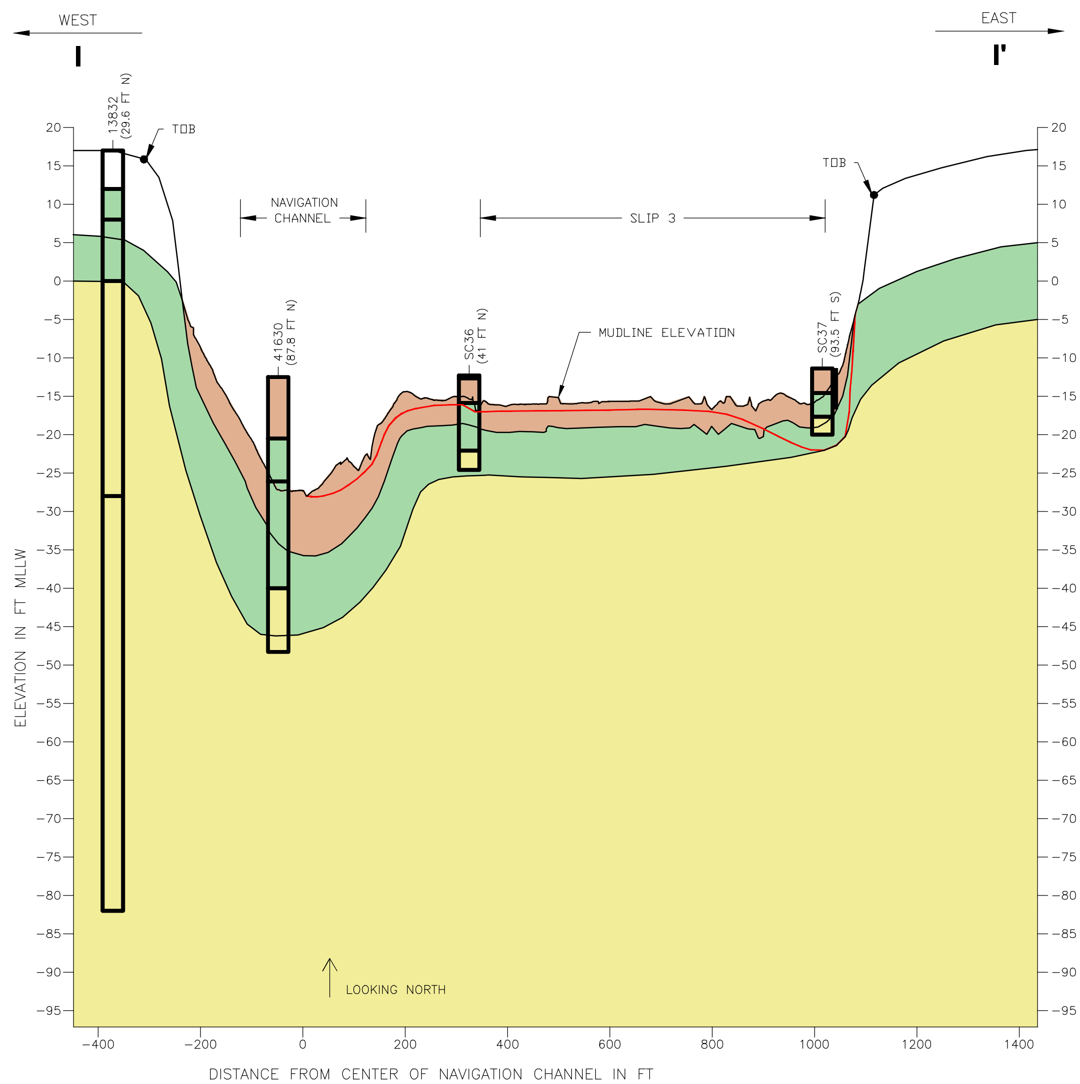
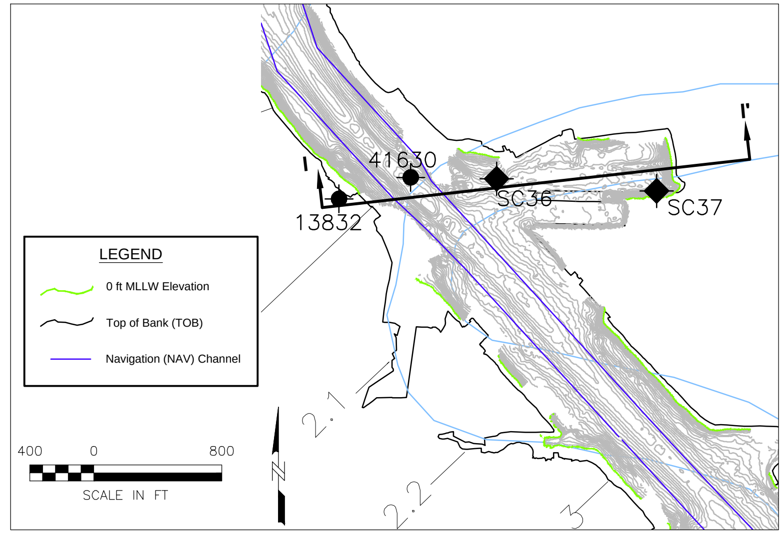
LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18			CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 1.90
DATE: 10/31/12	DRWN: E.M./SEA	REV: 0	FIGURE E-9





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) — Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- TOB — Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances. Where intervals immediately below intervals with SQS exceedances were not analyzed, the intervals not analyzed were assumed to also have SQS exceedances.
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1

AECOM

Lower Duwamish Waterway Group
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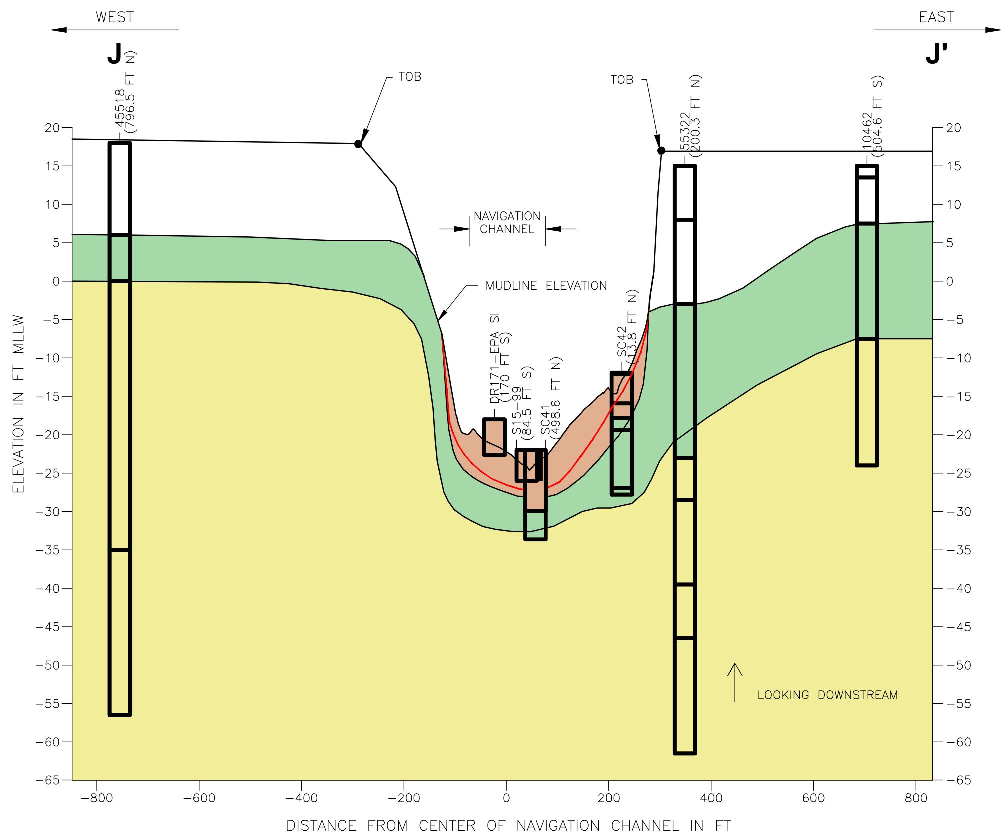
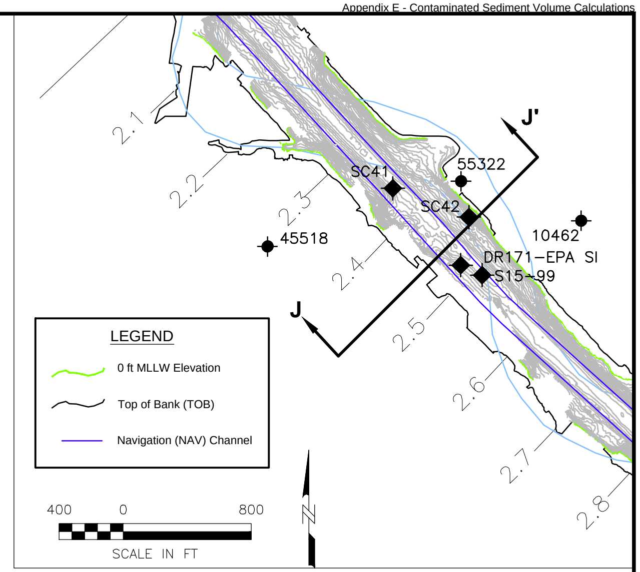
LOWER DUWAMISH WATERWAY
FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS
60150279-14.18

DATE: 10/31/12 | DRWN: E.M./SEA | REV: 0

CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 2.10

FIGURE E-10





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) — Core Name (Dist. from cross section to core in ft)
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- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- TOB Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances.
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

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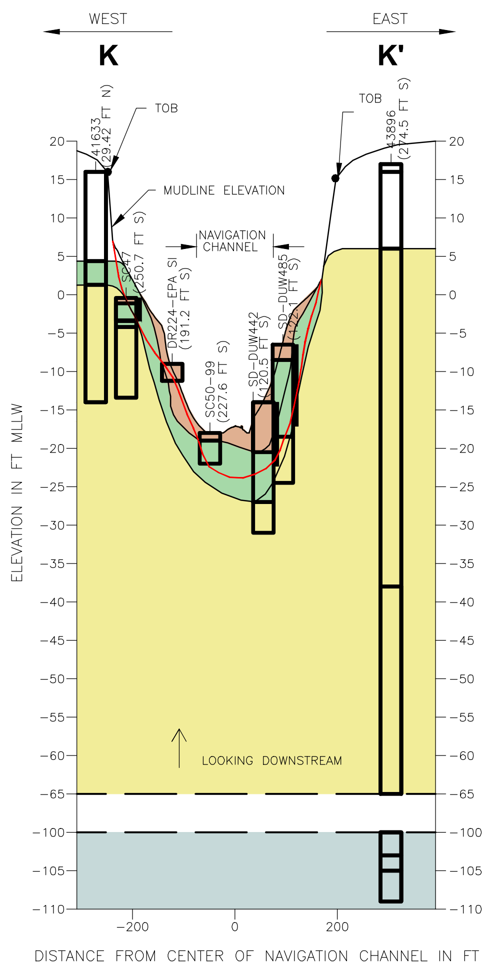
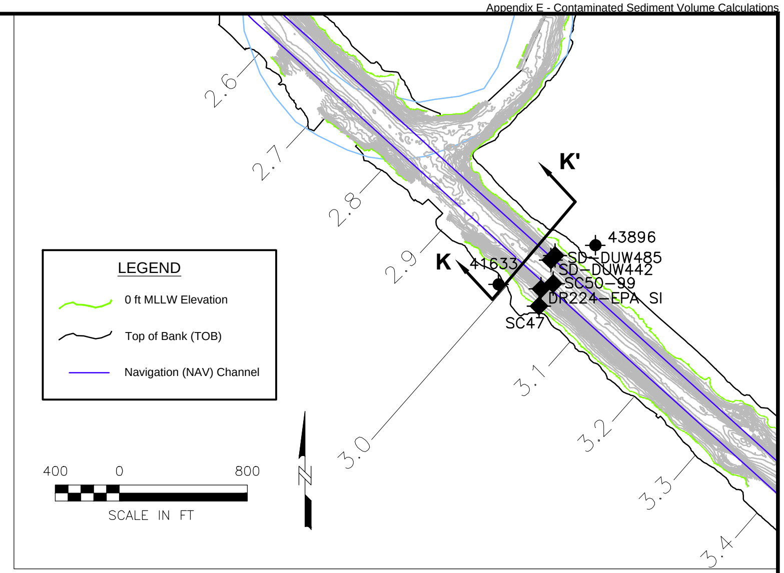
Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18			CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 2.45
DATE: 10/31/12	DRWN: E.M./SEA	REV: 0	FIGURE E-11





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) – Core Name (Dist. from cross section to core in ft)
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- GeoMapNW core
- RI/historical core
- TOB – Top of Bank

NOTES

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3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances.
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

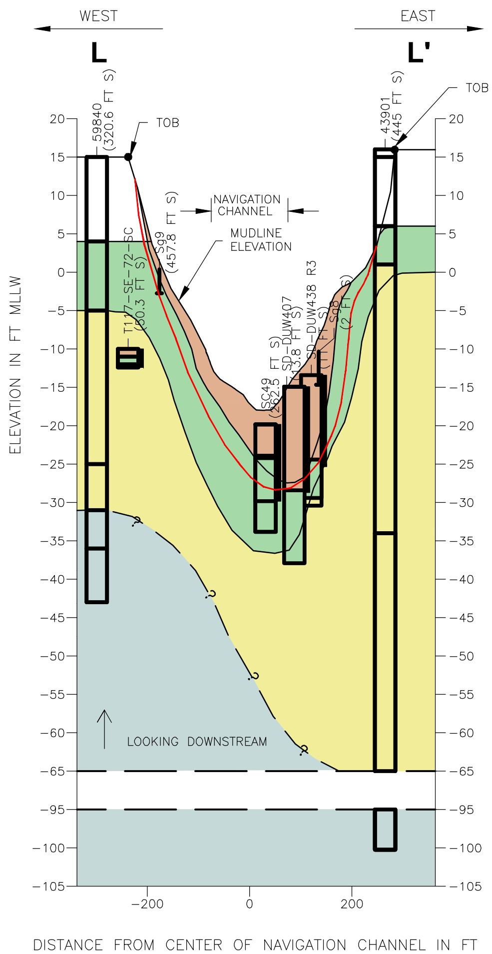
* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1

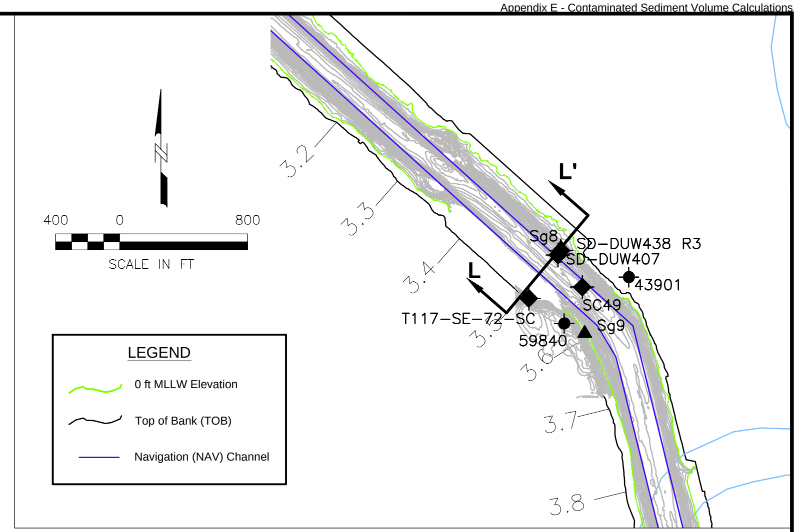
AECOM

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18			CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 3.0
DATE: 10/31/12	DRWN: E.M./SEA	REV: 0	FIGURE E-12



125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1



STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) — Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- Radioisotope core
- TOB — Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances.
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

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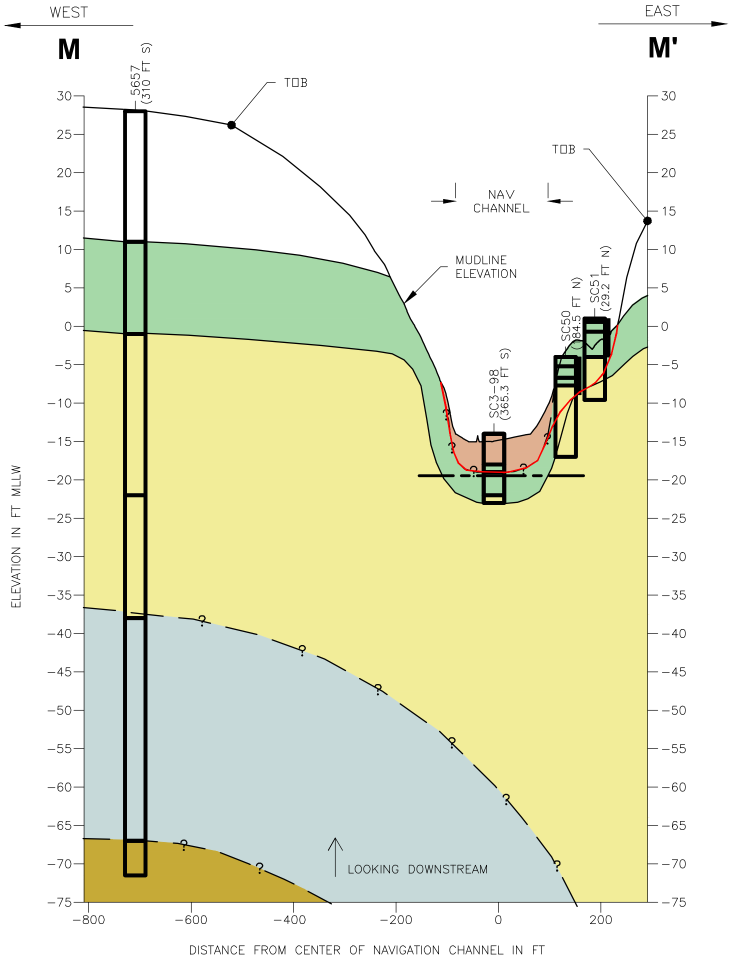
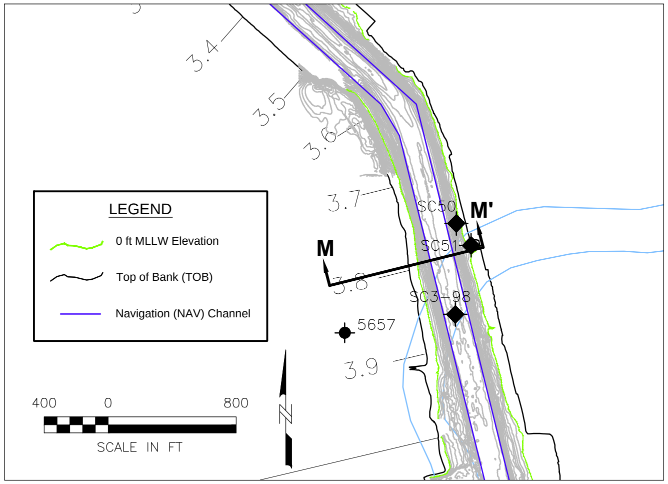
Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18	CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 3.5
DATE: 10/31/12 DRWN: E.M./SEA REV: 0	FIGURE E-13





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit
- Bedrock

KEY

- SC19 (214 FT) — Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Depth of 1999 dredge event to -15/-16 ft + 2 ft overdredge
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- TOB — Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. Contamination layer = mudline to maximum depth of detected SQS exceedances.
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1

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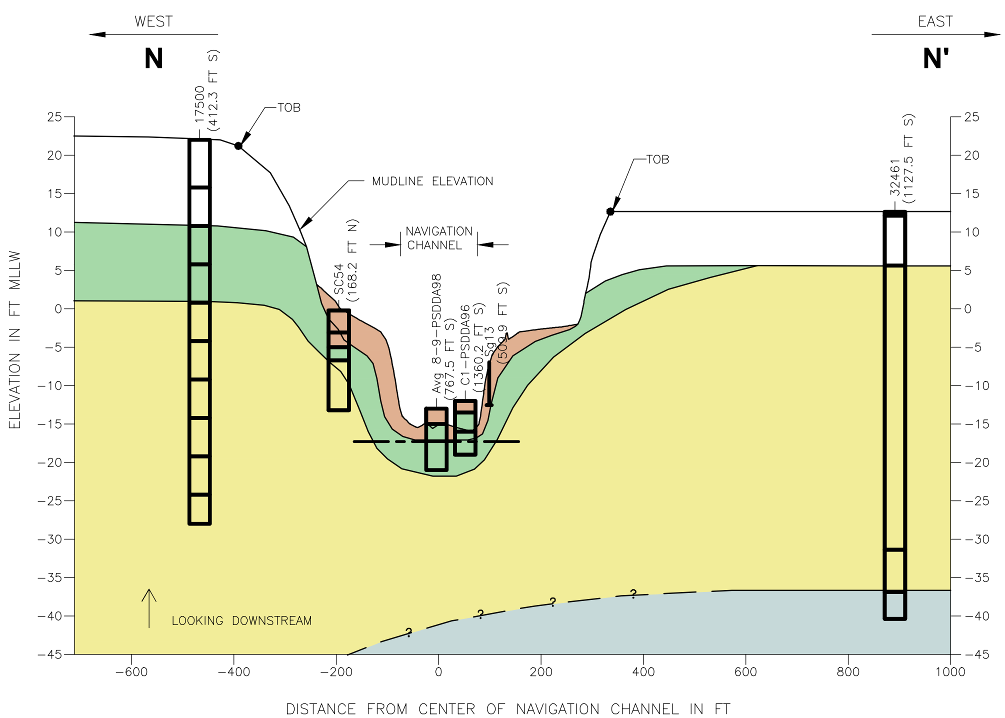
Port of Seattle / City of Seattle / King County / The Boeing Company

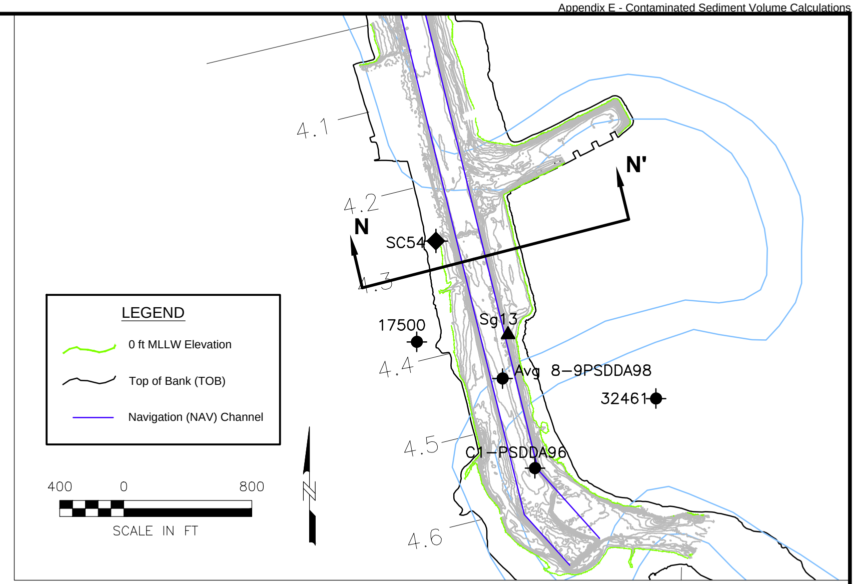
LOWER DUWAMISH WATERWAY
FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS
60150279-14.18

DATE: 10/31/12 | DRWN: E.M./SEA | REV: 0

CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 3.8

FIGURE E-14





LEGEND

- 0 ft MLLW Elevation
- Top of Bank (TOB)
- Navigation (NAV) Channel

400 0 800
SCALE IN FT

STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) — Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Depth of 12/07-1/08 dredge event to -15/-16 ft + 2 ft overdredge
- GeoMapNW core
- RI/historical core
- Radioisotope core
- TOB — Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. No contamination > SQS for the in-water cores.
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1

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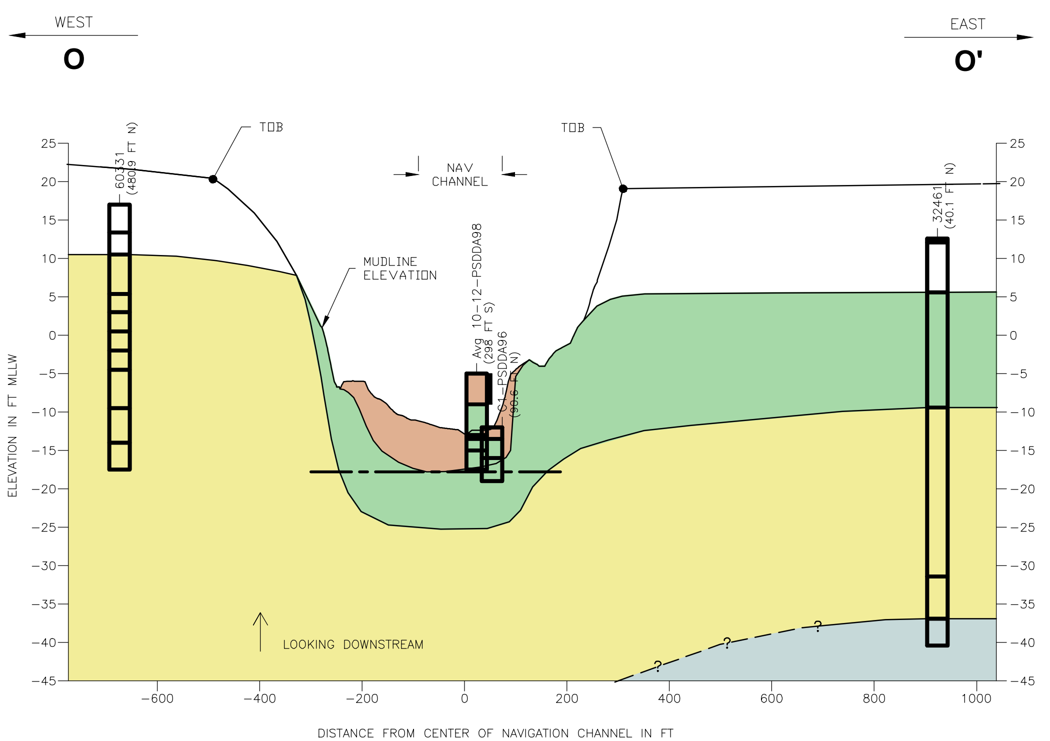
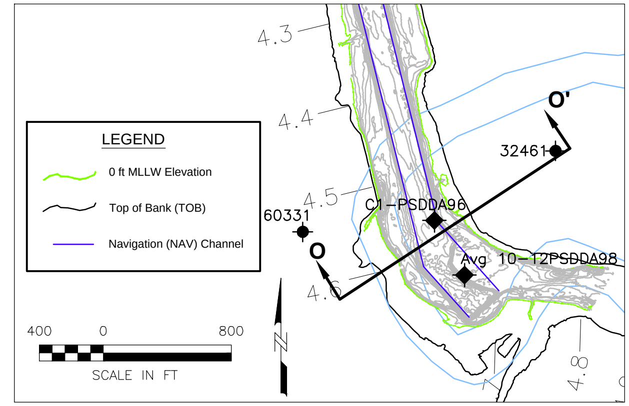
LOWER DUWAMISH WATERWAY
FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS
60150279-14.18

DATE: 10/31/12 | DRWN: E.M./SEA | REV: 0

CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 4.3

FIGURE E-15





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT): Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Depth of 12/07-1/08 dredge event to -15/-16 ft + 2 ft overdredge
- GeoMapNW core
- RI/historical core

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. No interpolated contamination on cross section because of recent dredge event (12/07 - 1/08)
5. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1

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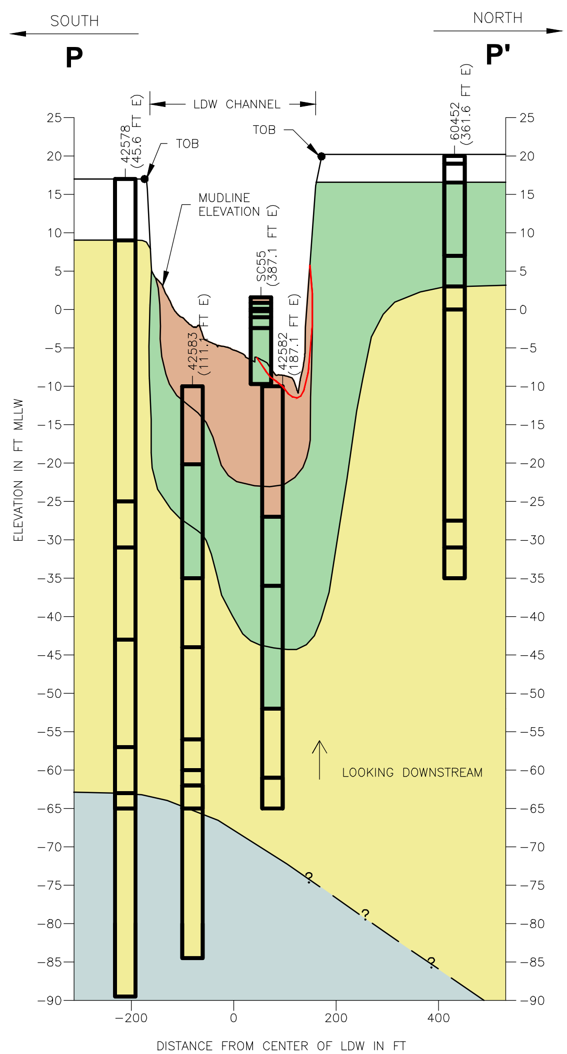
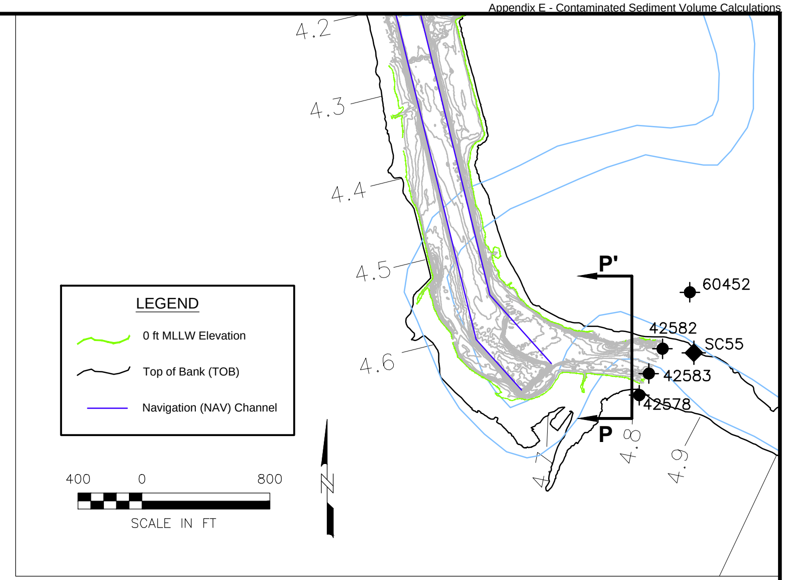
LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18	CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 4.6
DATE: 10/31/12 DRWN: E.M./SEA REV: 0	FIGURE E-16





STRATIGRAPHY*

- Upland Fill
- Recent Sediment
- Upper Alluvium/Transition
- Lower Alluvium
- Dense Post-Glacial and Glacial Unit

KEY

- SC19 (214 FT) – Core Name (Dist. from cross section to core in ft)
- Top of Core
- Bottom of contamination, analyzed (>SQS)
- Bottom of Core
- Bottom of contamination, interpolated (>SQS)
- GeoMapNW core
- RI/historical core
- TOB – Top of Bank

NOTES

1. GeoMapNW core stratigraphy presented in recovered depths. RI chemical data and stratigraphy presented in *in situ* depths. Historical core chemical data and stratigraphy presented in *in situ* depths where percent recovery available; otherwise presented in recovered depths. Actual contacts may vary.
2. GeoMapNW cores from Pacific Northwest Center for Geologic Mapping Studies. http://geomapnw.ess.Washington.edu/index.php
3. Top of bank is estimated based on elevation of upland cores.
4. No contamination > SQS for the in-water cores.
5. Surficial contamination confirmed to 1 ft below mudline on east bench.
6. Mudline elevation source based on bathymetric survey by David Evans & Associates, Inc. (Windward & DEA 2004).

* Stratigraphy terminology is used in subsurface data report (Windward Environmental, LLC and RETEC 2007) and sediment transport analysis report (Windward Environmental, LLC and QEA 2008).

125 0 250
SCALE IN FT
VERTICAL EXAGGERATION = 15:1

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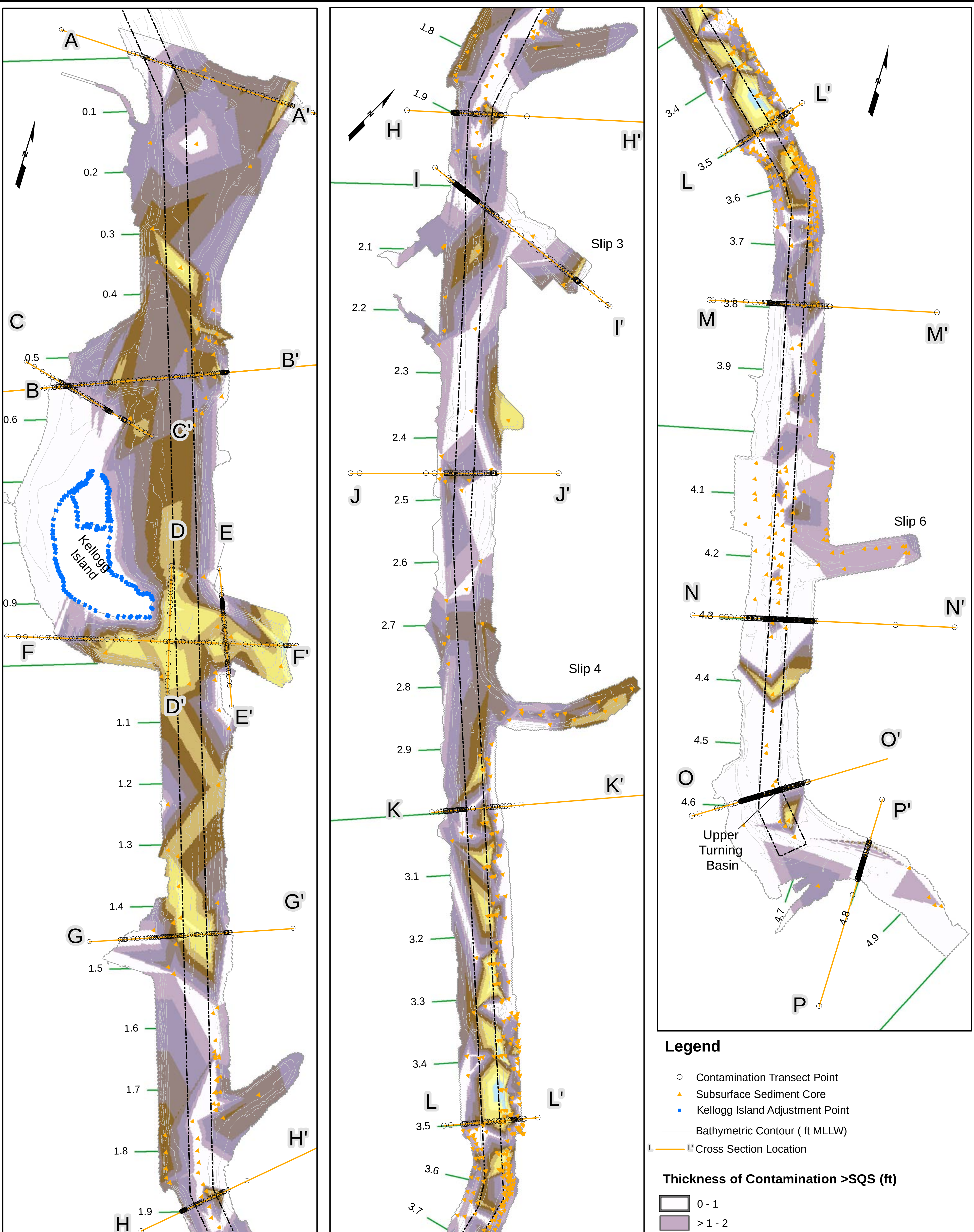
LOWER DUWAMISH WATERWAY FINAL FEASIBILITY STUDY - VOLUME CALCULATIONS 60150279-14.18			**CROSS SECTION OF DEPTH OF CONTAMINATION AND LOWER ALLUVIUM RIVER MILE 4.8**
DATE: 10/31/12	DRWN: E.M./SEA	REV: 0	**FIGURE E-17**

File: G:\PROJECTS\CADD\Lower Duwamish\2009 FS Cross Sections\rm4.8.dwg Layout: FIGURE E-17 User: oliveriom Plotted: Nov 06, 2012 - 12:58pm Xref's:



Legend

- ○ Contamination Transect Point
- ▲ Subsurface Sediment Core
- ■ Kellogg Island Adjustment Point
- Bathymetric Contour (ft MLLW)
- L — L' Cross Section Location

Thickness of Contamination >SQS (ft)

- 0 - 1
- > 1 - 2
- > 2 - 4
- > 4 - 6
- > 6 - 8
- > 8 - 10
- > 10 - 14
- > 14 - 18
- > 18 - 23

- Navigation Channel
- River Mile Marker

Notes:
1. The elevations from the transect points and the elevations from the cores and borings were subtracted from the mudline elevations from the cross sections or cores, respectively. These thickness data were interpolated to generate a thickness TIN.
2. The resulting TIN was converted to a grid to provide seamless coverage for the study area.
3. For grid cells within the RAL exceedance area, a minimum 1-ft thickness was assigned.
4. To display interpolated elevation data, the thickness grid was subtracted from the bathymetry grid. The bathymetry grid is a combination of the 2003 David Evans bathymetry (Windward and DEA 2004) and the mudline elevations of the cores.
5. There are no upland borings on this figure because the upland borings did not include chemistry data.
6. Transect points on this figure represent vertices along the interpolated contamination lines from the CAD generated cross sections. They are not the same points as those on Figure E-19.
7. CAD = computer-aided design, RAL = remedial action level, TIN = triangulated irregular network.

Feet
0 200 400 800

L:\Lower Duwamish FS\FS_Final_GIS\FS_GIS_MXDs_Oct12\Appendix E\FigureE-18ContamThick.mxd

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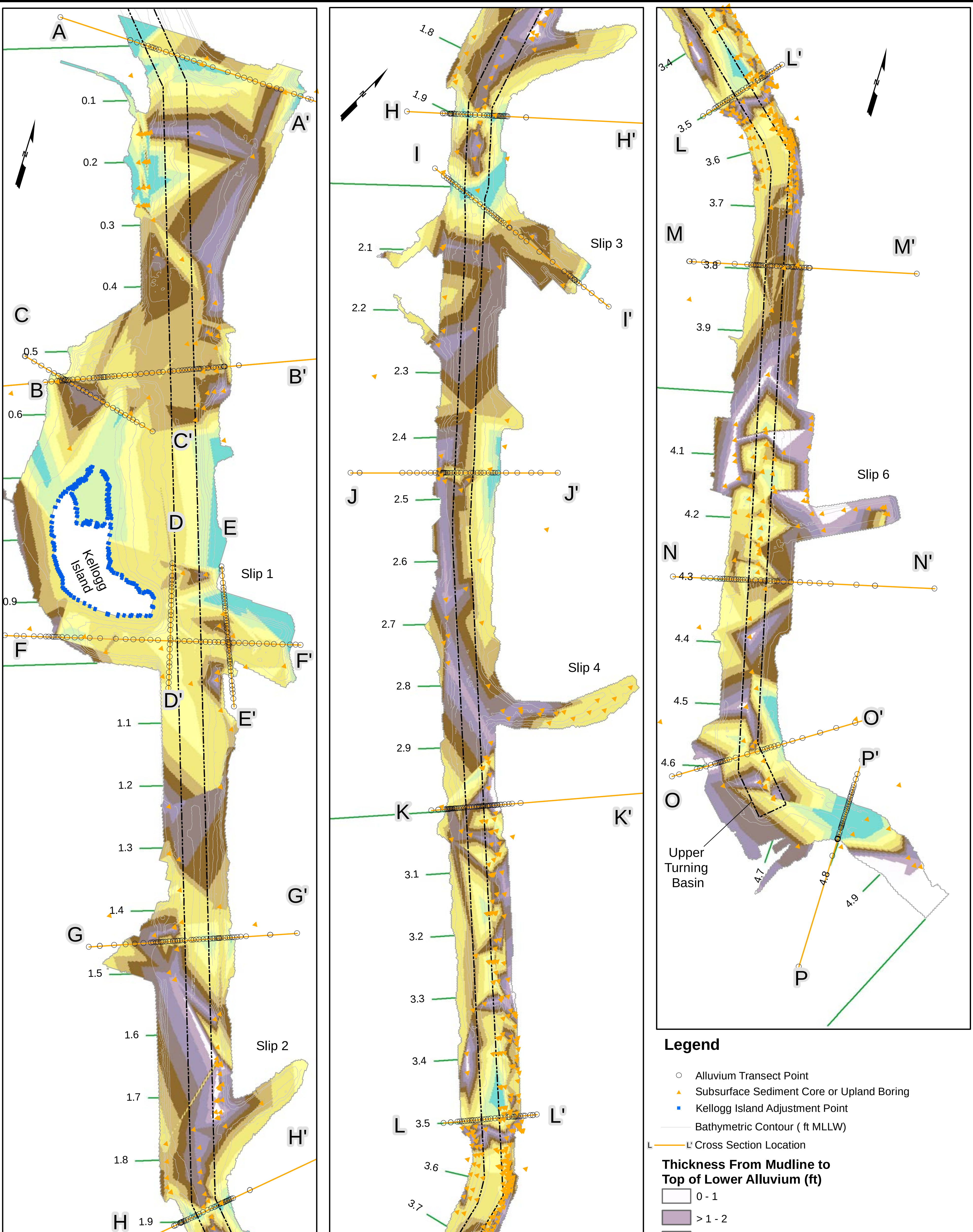
Lower Duwamish Waterway
Final Feasibility Study
60150279-14.49

DATE: 10/31/12 | DWRN:MVI/sea | Revision: 0

Interpolated Thickness of Contaminated Sediment Layer from Mudline to Maximum Depth of SQS Exceedances

FIGURE E-18



Legend

- ○ Alluvium Transect Point
- ▲ Subsurface Sediment Core or Upland Boring
- ■ Kellogg Island Adjustment Point
- Bathymetric Contour (ft MLLW)
- L——L' Cross Section Location

Thickness From Mudline to Top of Lower Alluvium (ft)

- 0 - 1
- > 1 - 2
- > 2 - 4
- > 4 - 6
- > 6 - 8
- > 8 - 10
- > 10 - 14
- > 14 - 18
- > 18 - 22
- > 22 - 23

- Navigation Channel
- River Mile Marker

Notes:
1. The elevations from the transect points and the elevations from the cores and borings were subtracted from the mudline elevations from the cross sections or cores, respectively. These thickness data were interpolated to generate a thickness TIN.
2. The resulting TIN was converted to a grid to provide seamless coverage for the study area.
3. For grid cells with thickness from mudline to top of lower alluvium greater than 27 ft, the maximum thickness was set to 27 ft.
4. To display interpolated elevation data, the thickness from mudline to top of lower alluvium grid was subtracted from the bathymetry grid. The bathymetry grid is a combination of the 2003 David Evans bathymetry (Windward and DEA 2004) and the mudline elevations of the cores.
5. Transect points on this figure represent verticies along the interpolated lower alluvium lines from the CAD generated cross sections. They are not the same points as those on Figure E-18.
6. CAD = computer-aided design, TIN = triangulated irregular network.

Feet: 0 200 400 800

L:\Lower Duwamish FS\FS_Final_GIS\Oct2012\FS_GIS_MXDs_Oct12\Appendix E\FigureE-19AlluvThick.mxd

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Final Feasibility Study
60150279-14.49

Interpolated Thickness of Sediment Layer From Mudline to Lower Alluvium

DATE: 10/31/12 | DWRN:MVI/sea | Revision: 0

FIGURE E-19

Figure E-20 Estimated Thickness of Contaminated Sediment in AOPC 1 vs. Mudline Elevation