## 2.2 Interpolation Methods

The FS uses Thiessen polygons to establish the remediation area. As described in Section 6.1.2.1 of the FS, interpolation using Thiessen polygons was determined to be an appropriate interpolation method to evaluate the extent of contaminant of concern (COC) concentrations throughout the entire Operable Unit (OU) due to the high density of data points with good spatial distribution. Thiessen polygons for risk driver COCs were then compared to the COC-specific RAL and used to determine the areal extent of remediation. A Thiessen polygon refers to the boundary of the area that surrounds a unique data point. Thiessen polygons are a commonly used method for characterizing the distribution of sediment chemical contamination and biological effects by assigning chemical concentrations or other values to areas where no actual data exist (i.e., un-sampled areas). Thiessen polygons have boundaries that define the area that is closest to each point relative to all other points. The polygon size and shape is determined by the proximity of neighboring sample locations. The concentration within the entire polygon is assumed to be equal to the concentration of the sample point located at the centroid. Thus, every un-sampled area is assigned the value of its nearest measurement point. For the FS, Thiessen polygons have been used to identify areas that are above or below RALs.

IDW is an interpolation method that assigns values to unknown points using a weighted average of the values from nearby known sample points. It assigns weights based on the inverse of the distance to each known point. IDW is better suited to interpolate dw sediment concentrations rather than OC-normalized concentrations. In order to develop an IDW interpolation of OC-normalized concentrations, IDW would have to be conducted independently for both PCB dw concentrations and total organic carbon (TOC) concentrations, and then those grid layers would have to be combined to generate an IDW for OC-normalized concentrations. This approach compounds the uncertainties in the IDW interpolation because two different parameters would be interpolated and then combined. Therefore, the level of uncertainty with IDW for OC-normalized concentrations is likely greater than uncertainties associated with OC-normalized interpolation based on Thiessen polygons.

## 2.3 Sensitivity of Remediation Area for PCBs

This section presents the extent of the area for total PCBs above the RAL of 12 mg/kg OC using Thiessen polygons and above the dw equivalent of the RAL using IDW. As noted above, because of uncertainties in generating an OC-normalized IDW interpolation, only dw total PCB concentrations are interpolated with the IDW method. Attachment 1 to this appendix describes the methods to optimize the parameters used for the IDW interpolation that is discussed in this section.[1] In order to compare the remediation area using IDW (using dw concentrations) to the remediation area using Thiessen polygons (using OC-normalized concentrations), the OC-normalized RAL was converted to a dw equivalent using the average OC content for the site (1.6%), which is equal to 192 µg/kg dw. However, applying this approximate equivalent OC content to the waterway as a whole is technically not an accurate measure of exceedances of the proposed RAL. In practice, the measured OC content of each sample should be used to estimate the dw equivalent for that sample.

The remediation area using Thiessen polygons and the RALs in Section 6 of the FS is presented in Figure 1. The black hatched area contains sediments above the PCBs RAL of 12 mg/kg OC, and is thus included in the remediation area. The green portion constitutes the remainder that is included in the remediation area because of sediment concentrations above any of the other RALs besides PCBs. Figure 2 presents the area above 192 µg/kg dw using IDW, shown in orange hatching. The area above any of the other COC RALs besides PCBs is also shown in green, as in Figure 1.

The exact size and shape of the hatched areas on Figures 1 and 2 vary slightly, as shown in Figure 3. Some PCB areas using Thiessen polygons (black hatch) result in a larger area than when using IDW (orange hatch), but other areas result in a larger area when using IDW than Thiessen polygons. These differences are largely because the dw equivalent is based on site-

[1] The IDW parameterization used in this appendix differs from the IDW parameterization used in the EW SRI (Windward and Anchor QEA 2014). The maps in the main portion of the SRI presented the same parameterization used in the LDW, whereas in the present EW FS, the parameterization was optimized for the EW. Attachment 1 shows the optimized parameterization for the EW when using both surface and shallow subsurface sediment (0 to 2 feet), which included the maximum result for sediment core samples in the upper 2 feet below mudline north of the Spokane Street Bridge, are combined. For comparison purposes, the SRI also presents the optimized parameterization for the EW using only surface sediment data in Appendix D of the SRI, which resulted in very similar IDW outcomes to those based on the LDW parameterization.

wide average 1.6% OC rather than the actual OC value measured in each sample. The dw equivalent is not accurate in areas where the OC differs from 1.6% (the average for the site). If actual TOC from a sampling area were to be used that differs from 1.6%, the dw equivalent value would not be 192 µg/kg dw. Other differences are the result the interpolation method, which produces slightly different edges or boundaries.

Nearly all of the area where the PCB interpolation method differs between the two methods is already above one of the other COC RALs (i.e., most hatching is within the yellow area on Figure 3), triggering remediation regardless of PCB concentration. As shown on Figure 3, the discrepancies in the PCB interpolation method are minor compared to the overall remediation footprint.

Table 1 summarizes the footprint associated with each interpolation method for total PCBs. The total area using Thiessen polygons above the OC-normalized RAL of 12 mg/kg OC (108 acres) is greater than the area using IDW above the dw equivalent of 192 µg/kg dw (105 acres). When the areas above the PCB trigger (based on either interpolation method) are combined with the areas exceeding RALs other than PCBs, a larger remedial footprint results when using Thiessen polygons (labeled as Combined Areas in Table 1). Thus, the Thiessen polygon method with the OC-normalized RAL is a more conservative method (i.e., larger remedial footprint) than the IDW method for establishing the EW remediation area (see Table 1).

**Table 1**
**Summary of Area for Thiessen Polygons and IDW for Total PCBs**

| Interpolation Method | PCB Hatched Area | | Portion Outside PCB Hatched Area Above RALs for Other COCs (Non-hatched Green Area in Figures 1 and 2) | | Combined Areas (Hatched and Yellow Area in Figure 3) | |
|---|---|---|---|---|---|---|
| | Acres | Percent of Study Area | Acres | Percent of Study Area | Acres | Percent of Study Area |
| Thiessen Polygons (total PCBs above 12 mg/kg OC[1]) | 108 | 69% | 15 | 9% | 122 | 77% |
| IDW (total PCBs above 192 µg/kg dw[2]) | 105 | 66% | 14 | 9% | 118 | 75% |

Notes:
1. 12 mg/kg OC is the RAL for total PCBs evaluated for this analysis.
2. 192 µg/kg dw is based on conversion of the total PCB RAL (12 mg/kg OC) to dry weight using the average percentage of organic carbon in surface sediments in the East Waterway (1.6 %).

The Study Area is equal to 157 acres.
Green areas (Figures 1 and 2) based on all areas that exceed RALs for all other chemicals except for PCBs.
Yellow area (Figure 3) based on Thiessen polygons for all areas with RAL exceedances, including PCBs.
All estimates of acreage and percent of Study Area are rounded to nearest whole number.

µg – microgram
COC – contaminant of concern
dw – dry weight
IDW – inverse distance weighted
kg – kilogram
mg – milligram
NA – not applicable
OC – organic carbon
PCB – polychlorinated biphenyl
RAL – remedial action level

# 3 EFFECT OF SAMPLE DENSITY AND DETECTION LIMITS ON REMEDIATION AREAS

This section evaluates the effect of existing sample density and detection limits on the remediation areas developed for the EW in the FS alternatives.

## 3.1 Sample Density

Approximately 340 surface sediment and shallow subsurface sediment samples were used to develop the remediation footprint for the 157-acre EW (e.g., see FS Figure 6-1). Most locations were analyzed for the SMS suite of contaminants, which includes all benthic SMS risk drivers (including PCBs) and carcinogenic polycyclic aromatic hydrocarbons (cPAHs). Two COCs were sampled at less spatial coverage compared to the other risk drivers: tributyltin (TBT) and dioxins/furans. As shown in FS Figure 6-1, TBT RAL exceedances were co-located with exceedances of other COCs in all locations except one; in that location, the existing Theissen polygon was added to the remediation footprint. As shown in FS Figure 6-4, dioxin/furan RAL exceedances were co-located with exceedances of other COCs in all locations except three; the polygons associated with these locations were added to the remediation footprint. Since these contaminants are mostly co-located with the other risk drivers, and because the remediation area covers most of the EW, additional TBT and dioxin/furan samples are not expected to appreciably alter the remediation footprint used for the FS alternatives. The delineation of the actual remediation footprint will be refined with additional sampling during remedial design.

## 3.2 Reporting Limits Above the SQS at Stations Outside the Remediation Area

Three locations have non-detected results with reporting limits that are greater than the SQS for at least one COC[2] and are outside of the total remedial footprint (based on the RAL set including 12 mg/kg OC for PCBs). As shown in Table 2, two locations had reporting limit (RL) exceedances for 2,4-dimethylphenol, and the RLs for butyl benzyl phthalate and 1,4-dichlorobenzene each exceeded the SQS at one location. All three of these chemicals were rarely detected at concentrations above the SQS in the EW, with only one detected exceedance for 2,4-dimethylphenol and nine detected exceedances for butyl benzyl

[2] The benthic COCs identified in the EPA-approved ERA (Windward 2012) did not include chemicals that were never detected above the SQS (e.g., 1,2,4-trichlorobenzene and hexachlorobenzene).

phthalate and 1,4-dichlorobenzene, which represents less than 5% of the total surface sediment samples.

While there is some uncertainty associated with RL exceedances, the risk to benthic organisms is not considered significant because: 1) matrix interferences (that result in higher RLs in the laboratory) only occur in a few samples; 2) the SQS only identifies areas with the potential to have adverse effects to benthic organisms; 3) the only chemical with reporting limits above the cleanup screening level (CSL) is 2,4-dimethylphenol, which is a case where the SQS and CSL are the same value; and 4) all detected COCs are below RALs in these locations.

The EW will be sampled during remedial design to refine the remediation footprint.

## Table 2
## Stations Outside the Remediation Area with Reporting Limits above SQS

| Location Name | Depth | Chemical | Dry Weight Reporting Limit (µg/kg dw) | Carbon Normalized Reporting Limit (mg/kg OC) | SQS | CSL | CSL/SQS Unit | Above SQS | Above CSL |
|---|---|---|---|---|---|---|---|---|---|
| EW-108 | 0-10 cm | 2,4-Dimethylphenol | 53 U | NC | 29 | 29 | µg/kg dw | Yes | Yes |
| EW-108 | 0-10 cm | Butyl benzyl phthalate | 53 U | 9.5 U | 4.9 | 64 | mg/kg OC | Yes | No |
| EW-RM-18 | 0-10 cm | 1,4-Dichlorobenzene | 20 U | 3.5 U | 3.1 | 9 | mg/kg OC | Yes | No |
| S-64/40 | 0-10 cm | 2,4-Dimethylphenol | 49 U | NC | 29 | 29 | µg/kg dw | Yes | Yes |

Notes:
1. OC normalization was not performed for samples outside of the carbon normalization range from 0.5% to 4% TOC.

µg – microgram
cm – centimeter
dw – dry weight
CSL – cleanup screening level
kg – kilogram
mg – milligram
NC – not calculated
OC – organic carbon
SQS – sediment quality standards
TOC – total organic carbon
U – result not detected at the reporting limit shown

# 4 SUMMARY

The methods used to develop the remediation footprints are reasonable for the FS development and comparison of alternatives. The FS establishes the remediation area using Thiessen polygons based on an OC-normalized RAL, which is preferred to an IDW interpolation using dw concentrations for the following reasons:

- The organic content in sediment affects the bioavailability, and thus toxicity, of PCBs. Use of a dw threshold of 192 µg/kg dw does not consider the influence of area- or sample-specific organic content and its effect on toxicity and bioavailability.
- The use of a dw PCB concentration for mapping the remedial footprint is not consistent with the associated RAL for PCBs of 12 mg/kg OC. Using the PCB dw equivalent based on average site-wide TOC content would not accurately map the OC-normalized RAL because sample-specific TOC content is accurate for each sample.
- Although remediation areas in the LDW were interpolated using a dw equivalent of the OC-normalized RAL (12 mg/kg OC) as a surrogate for the OC-normalized RAL, this was done in part because the LDW has lower data density in areas that was less evenly distributed than what is available for the EW. However, the remedial design footprint for the LDW is currently based on a RAL of 12 mg/kg OC.
- The remedial footprint that is established for FS purposes is intended to provide a reasonable basis for determining the area and volume associated with each remedial alternative. Therefore, it is important to apply a consistent set of rules (and assumptions) to develop the remedial footprint for FS purposes to avoid biasing a remedial alternative. The FS compares each remedial alternative relative to other alternatives, but does not attempt to finalize the remedial footprint, which is completed during remedial design.

This appendix explored the uncertainty associated with interpolation of areas using either Thiessen polygons or IDW, the sampling density of COCs, and detection limits above RALs. In all cases, these uncertainties are relatively minor primarily because the sampling density is relatively high, the contaminants tend to be co-located in the EW, and the remediation footprint covers most of the EW. Consistent with other sediment cleanups, these uncertainties are addressed in two ways:

- As described in Appendix F of the FS, an additive design factor has been applied to better estimate the volume of contaminated sediment assumed to require removal. Any additional volume derived from the IDW interpolation area outside of the Thiessen polygon area will be accounted for in this factor, so adding that area becomes unnecessary. This approach has been acceptable to EPA in the past and accounts for additional volume removed following dredge prism design as a result of the following components (Palermo 2009):
  - Refining horizontal limits that require removal (from additional sediment characterization during design)
  - Additional volume for constructability of dredge prisms, such as stable side slopes
  - Allowable overdredge thickness
- Additional surface sediment characterization is likely to be conducted during remedial design in order to more accurately delineate the boundaries of areas with contaminants above RALs that will require remediation. Further boundary delineation may result in expanding or contracting the limits of required remediation. However, for purposes of FS evaluation, refinement of the remedial boundaries is not considered necessary in order to assess remedial alternatives.

# 5 REFERENCES

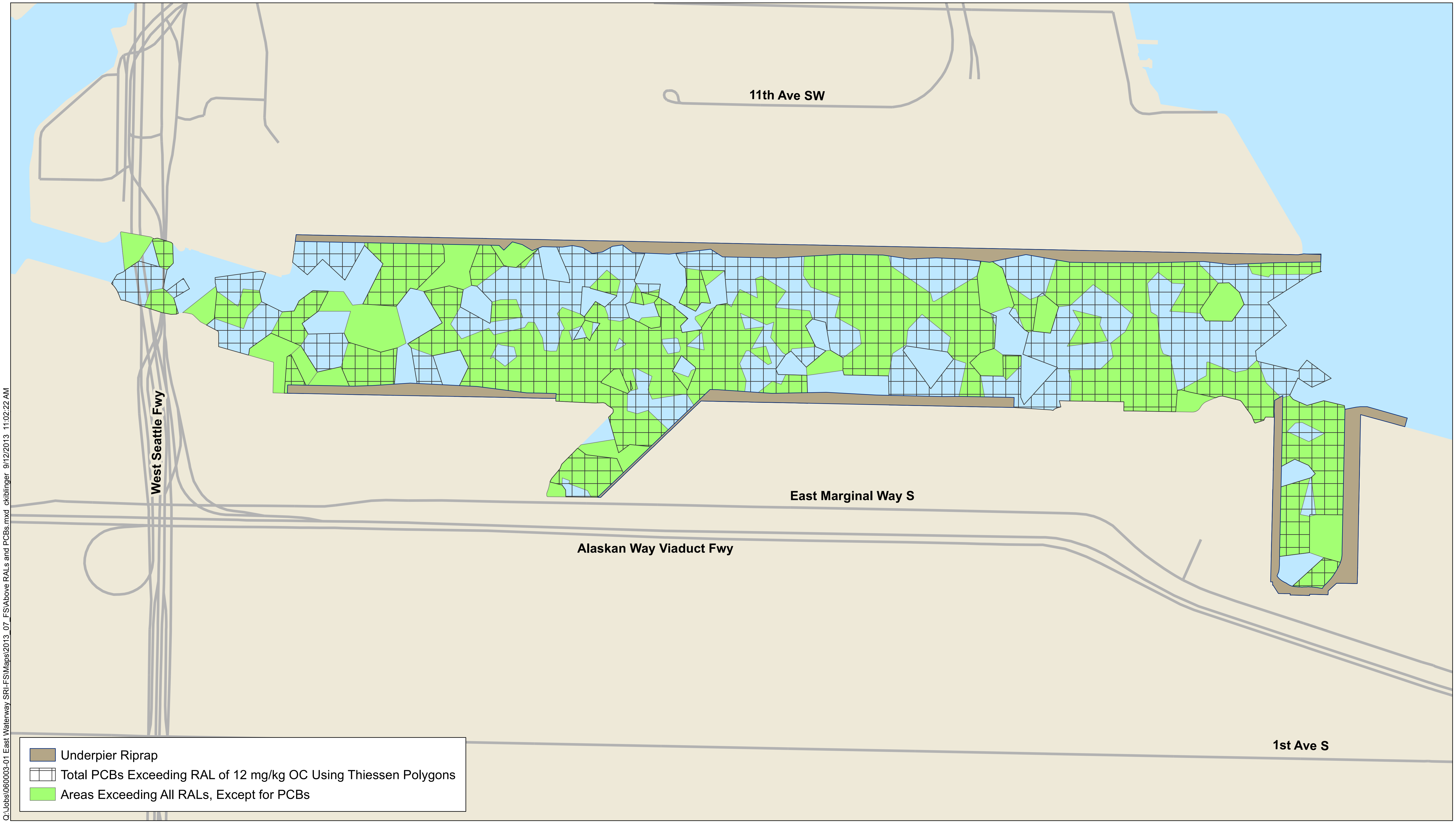
EPA (U.S. Environmental Protection Agency), 2014. Record of Decision, Lower Duwamish Waterway Superfund Site. USEPA Region 10. November.

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

Windward, 2012. Baseline Ecological Risk Assessment (ERA). Appendix A, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. August 2012.

Windward and Anchor QEA, 2014. Supplemental Remedial Investigation, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. January 2014.

# FIGURES




0 250 500 750 1,000

Scale in Feet

**Figure 1**

Total PCB Remediation Area Using Thiessen Polygons

Feasibility Study - Appendix C

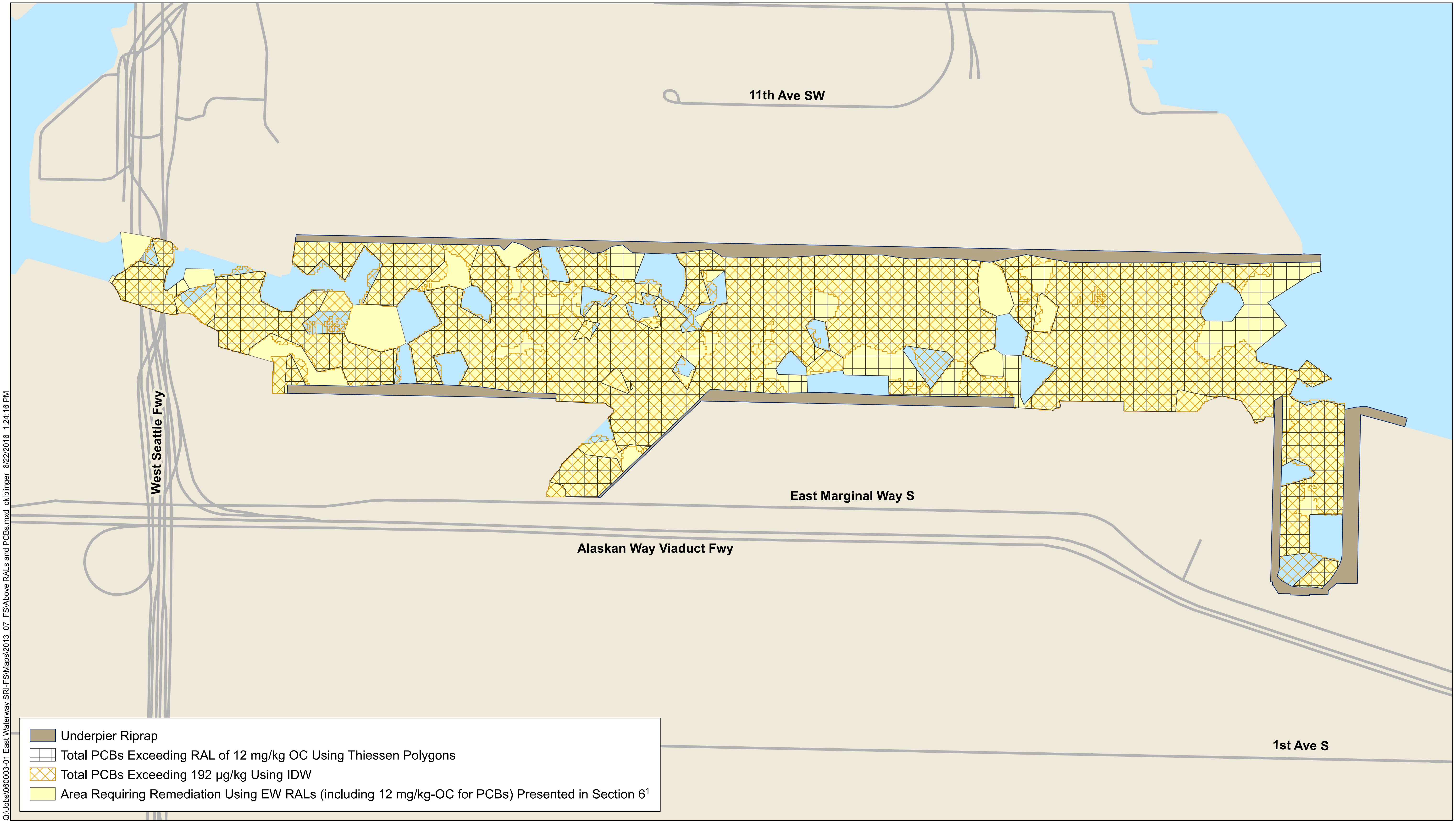
East Waterway Study Area


Q:\Jobs\060003-01 East Waterway SRI-FS\Maps\2013_07_FS\Above RALs and PCBs.mxd ckiblinger 9/12/2013 11:02:46 AM

**NOTE:**
1. 192 µg/kg is dw equivalent of PCB RAL of 12 mg/kg OC assuming site-wide TOC of 1.6%.

0 250 500 750 1,000
Scale in Feet

**Figure 2**
Total PCB Remediation Area Using IDW
Feasibility Study - Appendix C
East Waterway Study Area




**NOTE:**
1. Includes total PCBs; total PCB RAL is 12 mg/kg OC.

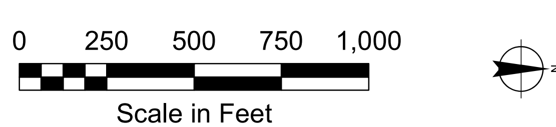



**Figure 3**
Potential Remediation Areas Based on Different PCB Interpolation Methods
Feasibility Study - Appendix C
East Waterway Study Area

# ATTACHMENT 1
# IDW MEMORANDUM

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# MEMORANDUM

| | | | |
|---|---|---|---|
| **To:** | Ravi Sanga, EPA | **Date:** | January 31, 2014 |
| **From:** | Dan Berlin and Erik Pipkin, Anchor QEA on behalf of Port of Seattle | **Project:** | 060003-01.101 |
| **cc:** | Doug Hotchkiss, Port of Seattle<br>Jeff Stern and Debra Williston, King County<br>Pete Rude, City of Seattle | | |
| **Re:** | Selection of East Waterway Inverse Distance Weighted Interpolation Parameters | | |

This memorandum describes the analysis conducted to select optimized interpolation parameters for calculating an inverse distance weighted (IDW) interpolated surface for total polychlorinated biphenyls (PCBs) within the East Waterway Study Area (EW). The methodology for optimizing IDW interpolation parameters for the EW is based on the process described in a memorandum prepared for the Lower Duwamish Waterway Feasibility Study (LDW Memo; LDWG 2007). The process presented in that memorandum varied the circular search radius and power for multiple IDW interpolated surfaces. Using this process, 18 IDW surfaces for total PCBs were created for the EW using the same range of input values for circular search radius and power as specified in the LDW Memo. Errors for each surface were then calculated in the same manner as in the LDW Memo using tools within ESRI's ArcGIS software.

The process for selection of optimized IDW interpolation parameters for the EW was conducted using components of the Feasibility Study (FS) dataset that will be used to select areas that require active remediation. Specifically, point data used to create IDW surfaces included samples from the entire study area with PCB results in surface sediment (0 to 10 centimeters [cm]) and shallow subsurface sediment (0 to 2 feet), which included the maximum result for sediment core samples in the upper 2 feet below mudline north of the Spokane Street Bridge. Also included in the query were 0- to 10-cm samples collected following dredging in 2005 in the Phase 1 removal area prior to placement of clean cover material.

ESRI's ArcGIS Geostatistical Analyst (GA) was used to create the IDW surfaces using the input parameters for circular search radius and power fixed to the values shown in Table 1. Consistent with the method used in the LDW Memo, the maximum/minimum number of closest samples used for grid-cell interpolation was varied between 1/1 and 10/1. Cell size was set at 10 feet, and mean higher high water (MHHW) was used as an input barrier to prevent interpolation between areas separated by dry land.

In order to evaluate the errors of each parameter set, both a GA layer and an ESRI grid were created. The cross-validation tool available within GA was used to calculate the mean error and the root mean square error (RMSE).

The mean error can be defined as the averaged difference between the measured and predicted values and calculated by the equation below.

$$\frac{\sum_{i=1}^{n}\left(\hat{Z}(s_i) - z(s_i)\right)}{n}$$

where:

| | | |
|---|---|---|
| n | = | number of points |
| $\hat{Z}$ | = | measured value |
| z | = | predicted value |
| s | = | value |
| i | = | point number |

The RMSE is the square root of the averaged squared difference between the measured and predicted values and determined by the equation below.

$$\frac{\sqrt{\sum_{i=1}^{n}\left(\hat{Z}(s_i) - z(s_i)\right)^2}}{n}$$

where:

| | | |
|---|---|---|
| n | = | number of points |
| $\hat{Z}$ | = | measured value |
| z | = | predicted value |
| s | = | value |
| i | = | point number |

Cross-validation calculates error by omitting a point from the input, calculating the interpolated value using the remaining points, and then comparing the interpolated value to the measured value. This is conducted for each point in the dataset to determine the mean error and RMSE. In addition, a point table was exported for each IDW from GA, which included the measured and interpolated value for each point, and was subsequently used to calculate the mean absolute error.

In addition to the cross-validation errors, an observed RMSE was also calculated. The observed RMSE was calculated in the same manner as in the LDW Memo and was used along with the RMSE to identify the optimized set of interpolation parameters. Observed RMSE is calculated using the same RMSE equation; however, points are not iteratively removed. Rather, the difference between the measured and predicted values at each point location is used. Results may differ from the CV RMSE if individual data points are not spatially coincident with the IDW raster cells, which is a function of the point distribution and raster cell size and extent. To facilitate the calculation of observed RMSE, a simple process was built within ArcGIS Model Builder to automate the geoprocessing.

Consistent with the process described in the LDW Memo, the lowest RMSE and observed RMSE were the key statistical metrics used to identify the optimized set of parameters for IDW interpolation in the EW. The parameter combination with the lowest RMSE has the lowest dataset variability. RMSE decreases as the search radius increases and as the power decreases (within each search radius group). The IDW interpolation with the lowest observed RMSE results in the lowest error based on a comparison of measured versus predicted values. Based on these metrics, parameters for IDW interpolation using the EW FS dataset are optimized with a power of 1 and circular search radius of 75 feet, as indicated in Table 1.

**Table 1**
**Interpolation Parameters Tested for Total PCBs – East Waterway**

| Power | Circular Search Radius (feet) | Cross Validation | | | Observed RMSE |
|---|---|---|---|---|---|
| | | Mean Error | Mean Absolute Error | RMSE | |
| 1 | 250 | 57.3 | 714.4 | 1260 | 675 |
| 2 | 250 | 76.3 | 750.7 | 1351 | 666 |
| 3 | 250 | 80.2 | 766.6 | 1406 | 728 |
| 4 | 250 | 80.8 | 776.2 | 1438 | 793 |
| 5 | 250 | 81.2 | 784.5 | 1456 | 851 |
| 10 | 250 | 86.6 | 809.8 | 1506 | 1000 |
| 1 | 150 | 99.0 | 811.9 | 1432 | 670 |
| 2 | 150 | 106.6 | 826.9 | 1487 | 666 |
| 3 | 150 | 105.8 | 829.3 | 1519 | 728 |
| 4 | 150 | 103.6 | 830.0 | 1536 | 793 |
| 5 | 150 | 101.8 | 832.0 | 1547 | 851 |
| 10 | 150 | 101.7 | 841.5 | 1578 | 1000 |
| 1 | 75 | 94.9 | 878.0 | 1625 | 648 |
| 2 | 75 | 95.7 | 878.3 | 1636 | 666 |
| 3 | 75 | 95.3 | 878.8 | 1638 | 728 |
| 4 | 75 | 95.2 | 872.8 | 1640 | 793 |
| 5 | 75 | 95.6 | 873.0 | 1642 | 851 |
| 10 | 75 | 100.5 | 876.6 | 1656 | 1000 |

Notes:
1. A maximum of 10 and a minimum of 1 "nearest neighbor" data points were used in all interpolations.
2. Cell size for all interpolations is 10 feet.
3. Lowest Observed RMSE occurs with power of 1 and circular search radius of 75 feet (shaded).
PCB – polychlorinated biphenyl
RMSE – root mean square error

## REFERENCES

LDWG (Lower Duwamish Waterway Group), 2007. Draft Memorandum: Updated Methodology for Interpolating Surface Sediment Chemistry in the Lower Duwamish Waterway Feasibility Study. Prepared by RETEC. December 11.