Lower Duwamish Waterway Group

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

Appendix J
Recontamination Potential and Regional Site Data

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

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J.1 Introduction

The Lower Duwamish Waterway (LDW) is an estuarine tidal water body located in an urban environment. It has multiple uses, including as a working commercial/industrial waterway. Consequently, multiple external sources of contaminant inputs to the LDW exist. They reflect regional and local sources and are the primary factors influencing the surface sediment contaminant concentrations that will prevail in the long term following any cleanup. In other words, surface sediment within the LDW will have detectable contaminant concentrations following any cleanup actions. The purpose of this appendix is two-fold:

- Evaluate regional data and literature to provide confidence in the long-term model-predicted range of future concentrations (on a site-wide spatially-weighted average concentration [SWAC] basis), which are largely influenced by upstream inflows from the Green/Duwamish River watershed and to a lesser extent by the lateral inflows from the LDW drainage basin. These levels represent a return to urban background and long-term "equilibrium" (i.e., inputs from diffuse sources).
- Assess the potential for recontamination at smaller scales, based on urban inputs. This appendix evaluates LDW post-maintenance dredging data to reveal the nature of sediments being deposited within the site, as lines of evidence for these levels. This appendix also presents published studies and modeling as additional lines of evidence for small-scale recontamination.

For simplicity, this appendix defines "recontamination" as contaminant concentrations in surface sediments that return to unacceptable levels after a cleanup (e.g., concentrations of Washington State Sediment Management Standards [SMS] contaminants above the sediment quality standards [SQS]). While this appendix considers only exceedances of the SQS, other thresholds described in the feasibility study (FS) are also applicable for defining recontamination. Recontamination can be caused by the diffuse, urban sources external to the LDW and by localized resuspension and redeposition of sources internal to the LDW. Source control actions, including those upstream of the site, will affect long-term contaminant concentrations in LDW sediments. The level of surface sediment recontamination will reflect the aggregate inputs of both internal and external sources.

J.1.1 Sources and Pathways of Recontamination

The general external pathways (to both the LDW and to the upstream Green/Duwamish River watershed, which aggregates contaminants from various pathways into the upstream inflow to the LDW) include (see Figure J-1):

- Direct discharge into the LDW (e.g., combined sewer overflows [CSOs] and storm drains)

- Surface water runoff or sheet flow
- Spills and/or leaks to the ground, surface water, or directly into the LDW
- Groundwater migration/discharge
- Bank erosion/leaching
- Atmospheric deposition.

Several national studies have shown that atmospheric fluxes and in-water concentrations of contaminants, polychlorinated biphenyls (PCBs) in particular, correlate strongly with the degree of urbanization surrounding the water body being studied (Gingrich et al. 2001; Jamshidi et al. 2007; Offenberg and Baker 1997; Simcik et al. 1997; Totten et al. 2006; Van Metre and Mahler 2005; Wethington and Hornbuckle 2005).

Internal sources (transport of resuspended contaminated sediments) also influence surface sediment contaminant concentrations, both under existing conditions and in the short term following any cleanup actions. These internal mechanisms include:

- Scour of subsurface sediments
- Bed movement and deposition of surface sediments onto remediated areas
- Deposition of dredging residuals during cleanup actions or maintenance dredging actions.

These internal sources of recontamination are discussed within the body of the FS in terms of model predictions (Section 5) and technology performance (Sections 7 and 8).

In this appendix, multiple lines of evidence are used to provide context for the range of contaminant concentrations that surface sediments in the LDW are predicted to achieve, or equilibrate to, over the long term following remedial actions and source control. The empirical data used in this evaluation reflect the combined effect of the sources listed above, as it is recorded in the sediment bed. LDW sediment data presented in this appendix were collected following focused remedial actions and dredging for maintenance purposes. While it is understood that empirical trends are not necessarily indicative of future source control efforts and long-term trends, they do provide context for shorter-term recontamination potential (on the time span of 0 to 10 years after remedial actions have been completed).

In Section 9 of the FS, the long-term model-predicted surface sediment contaminant concentrations reflect the "best estimate" of what a combination of remedial actions, source control, and natural recovery can achieve in the LDW on a site-wide basis. The model considers ongoing contributions from nonpoint sources. The bed composition model (BCM) was also used to evaluate localized recontamination potential in the LDW, as presented in this appendix. However, the assessment of ongoing inputs to the

LDW is subject to several limitations. The dataset used for lateral loads is limited and considered only inputs from municipal storm drain solids and CSOs, excluding other potential sources such as groundwater, bank erosion, and most private stormwater discharges. Also, the BCM assigns uniform contaminant concentrations to input points that represent major outfalls and aggregations of smaller outfalls, whereas varying contaminant concentrations are expected, based on empirical data. Similarly, estimates of upstream inputs are based on a limited dataset.

To support this evaluation of an urban signature and long-term model-predicted concentrations, this appendix examines several lines of evidence relative to recontamination potential in the LDW:

- Regional and Puget Sound trends (Section J.2)
- LDW-specific temporal trends and model predictions (Section J.3)
- Atmospheric deposition of contaminants as a pathway to the LDW from external sources (Section J.4).

J.1.2 Land Use and Urban Inputs

The degree of urbanization in the Green/Duwamish River watershed generally decreases with distance upstream. This relative pattern of urban development is not expected to change significantly. Therefore, sources discharging directly to the LDW are expected to have higher contaminant concentrations than those contributing to the upstream Green/Duwamish River watershed into the foreseeable future. This is tied to the observation that atmospheric deposition (either to the surface water itself or to the watershed surrounding the water body) is an important and sometimes dominant pathway for nonpoint source loading to water bodies. These external sources are discussed at length in the remedial investigation (RI; Windward 2010) and summarized in Section 2:

- The Green/Duwamish River watershed is 470 square miles and is divided into four subwatersheds. These are listed upstream to downstream and shown on Figure J-2 (King County 2005):
  - Upper Green River: 142,000 acres from headwaters downstream to the Howard Hanson Dam, contains 45% of the entire watershed's land area and river mileage; primary land use is forest (99%).
  - Middle Green River: 113,000 acres from the Howard Hanson Dam downstream to the confluence with Soos Creek at river mile (RM) 32; major land uses are residential (50%), forest (27%), and agriculture (12%). It contains the cities of Enumclaw, Black Diamond, Covington, and Maple Valley, but most of the area is in unincorporated King County.

- Lower Green River: 41,000 acres from RM 32 downstream to RM 11; historically the White and Cedar/Black rivers joined the Green River in this stretch; major land uses are residential (50%) and commercial/industrial (27%).
- Duwamish estuary: 17,000 acres from RM 11 to 0 (at Harbor Island), including the East and West Waterways; the mouth of the subwatershed is at Elliott Bay. This subwatershed includes the LDW and Duwamish River (King County 2005). This subwatershed contains 36% residential, 18% industrial, and 11% commercial land uses. Eighteen percent of the subwatershed is used for right-of-way areas (including roads and highways); while 17% is open/undeveloped land and parks (Schmoyer, personal communication, 2011).

An assessment of planned development was conducted in a study area comprised of the Upper Green, Middle Green, and a portion of the Lower Green subwatersheds. The assessment showed that the lower portion of the study area is already heavily urbanized, with Soos, Jenkins, and Mill creeks (Auburn) drainage basins having more than 30% impervious cover. A land use change analysis found 18.5 square miles of urban density development planned for forested or bare ground areas, with one half of that development planned in Soos, Jenkins, and Covington creeks (King County 2005).

J.2 Regional and Puget Sound Trends

Urban-influenced nonpoint sources of contaminants to the LDW will influence the extent to which recontamination of any cleanup will occur at either the site-wide or location-specific scale. Following targeted source control efforts to identify and control pathways of elevated levels of contaminants to the LDW, the more diffuse, widespread nonpoint sources will still reach the LDW.

Data are available in the region to determine how such general urban sources contribute to recontamination in sediments of urban and near-urban water bodies. The regional data were collected from four sources for evaluation:

- Total PCB, arsenic, and carcinogenic polycyclic aromatic hydrocarbon (cPAH) sediment data collected from five urban water bodies in the Puget Sound region (Table J-1)
- Dioxin/furan sediment data collected immediately offshore of outfalls in the greater Seattle area (Table J-2)
- Dioxin/furan sediment data collected in Elliott Bay as part of the Puget Sound Assessment and Monitoring Program (PSAMP; formerly the Puget

Sound Ambient Monitoring Program) and in and around five open water dredged sediment disposal sites in Puget Sound (Table J-3)[1]

- A literature review of studies and associated data from the Puget Sound region (Table J-4).

J.2.1 Total PCB, Arsenic, and cPAH Sediment Data from Five Puget Sound Region Urban Water Bodies

Surface sediment data from five Puget Sound region urban water bodies (i.e., Elliott Bay, Bellingham Bay, Commencement Bay, Lake Washington, and Lake Sammamish) were queried from the Washington State Department of Ecology's (Ecology) Environmental Information Management (EIM) System in January 2007 (PCBs and arsenic) and in January 2008 (polycyclic aromatic hydrocarbons [PAHs]) by AECOM (known as RETEC/ENSR prior to 2008). The data queried were from samples collected between 1990 and 2004. In these queries, individual PCB Aroclor and PAH data were retrieved and used to calculate total PCBs and cPAH toxic equivalents (TEQs).

J.2.2 Data Treatment

These data were screened to exclude:

- Samples collected as part of a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Model Toxics Control Act (MTCA) cleanup study prior to any sediment remediation (because the goal was to examine how urban sources influence a site after remedial actions have occurred, not before). Data available from post-remediation monitoring events were retained.
- Samples collected as part of routine monitoring of the open water dredged material disposal sites. Data from those sites are representative of regional sediment quality, but were excluded because the sediment characteristics of the disposed material may be biased toward the original locations from where the sediments were dredged.[2] Therefore, the conclusion was that they may not represent the urban water body being investigated.

Elliott Bay data were then reduced and divided in the following manner (Table J-1):

- Data were divided into inner and outer Elliott Bay datasets (Figure J-3).[3] Three locations near the middle and east of the dividing line were included

[1] The five open water disposal sites are not in the same five urban water bodies noted in the first bullet.

[2] Open water disposal site samples were excluded in the analysis of total PCB, arsenic, and cPAH data, but were used for the dioxin/furan evaluation discussed in Section J.2.2.

[3] The demarcation between inner and outer Elliott Bay was delineated by drawing a north-south line from the Duwamish Head in West Seattle to Pier 91/92 north of downtown Seattle.

in the outer Elliott Bay dataset following a 150-meter mean lower low water (MLLW) bathymetric contour.

- Data collected within 250 feet (ft) of the shoreline were excluded (to minimize the possible influence of point sources).
- Data collected from the Denny Way CSO and Pier 51/52 caps (downtown Seattle) were excluded from the inner Elliott Bay dataset. Although they are post-remedy data, the receiving sediments may be influenced by localized outfall discharges.
- Both the inner and outer Elliott Bay datasets exclude data collected before 1991.

For the other urban water bodies, geographical divisions were not used to separate or differentiate among data.

Summary statistics for each urban water body were generated for total PCBs, arsenic, and cPAHs (Table J-1). It is noted that the available data for each water body may not represent the overall conditions in that water body; some of the studies conducted to gather these data were not designed to characterize the entire water body, but rather were designed to focus on particular areas of concern. Aside from the minimal screening discussed above, these data were not thoroughly screened to ensure that all data that might be associated with other potential point sources of contamination (i.e., adjacent to upland contaminated sites) were removed; however, for the purpose of this appendix, which is to evaluate summaries of these data for informational purposes, these datasets are considered adequate.

J.2.2.1 Summary of Data

A reasonable degree of consistency in contaminant concentrations is expected for sediments from the same region (i.e., from the Puget Sound region). This is because the chemical composition of stormwater runoff and atmospherically deposited material may be similar within broad urbanized geographic regions, including the LDW watershed. It is difficult to completely resolve point sources from other source contributions measured in surface sediments. Thus, it is appropriate to compare concentrations observed in the urban water bodies (Table J-1) to the long-term model-predicted concentrations for the LDW (equilibrium) and to areas with localized recontamination potential. Both are influenced by urban sources. The results of these comparisons are discussed for three of the four human health risk drivers:

- The mean total PCB concentrations from these water bodies, excluding inner Elliott Bay, are in the range of 40 to 90 micrograms per kilogram dry weight (µg/kg dw). This is consistent with the best-estimate long-term model-predicted concentrations of 40 to 50 µg/kg dw and the full sensitivity range

of long-term model-predicted concentrations of 10 to 100 µg/kg dw[4] (Figure J-4a). These data also suggest surface sediment concentrations in small areas (90th percentile of data) of up to about 200 µg/kg dw (Table J-1, excluding inner Elliott Bay).

- For arsenic, the mean concentrations from these water bodies, excluding Lake Sammamish, are in the range of 5 to 10 milligrams (mg)/kg dw. The Lake Sammamish mean concentration is 15 mg/kg dw. This data range is fairly tight. The urban water bodies yield statistics very similar to the full sensitivity range of long-term model-predicted concentrations of 7 to 10 mg/kg dw (Figure J-4b). These data also suggest concentrations in small areas (90th percentile) of up to about 17 mg/kg dw (Table J-1).
- The cPAH data from Commencement Bay, Lake Sammamish, and Lake Washington have the highest mean values (more than 200 µg TEQ/kg dw). Data from outer Elliott Bay and Bellingham Bay have cPAH means around 100 µg TEQ/kg dw. This is consistent with the best-estimate long-term model-predicted concentrations of 100 to 120 µg TEQ/kg dw (full sensitivity range from 50 to 320 µg TEQ/kg dw) (Figure J-4c). The mean cPAH concentration for inner Elliott Bay exceeds 580 µg/kg dw (Table J-1), which suggests concentrations in small areas around 300 to 500 µg TEQ/kg dw. This range also includes the 90th percentile of the outer Elliott Bay dataset.

J.2.3 Greater Seattle Dioxin/Furan Sediment Sampling Immediately Offshore of Outfalls

Surface sediment sampling for dioxins/furans in the greater Seattle metropolitan area was conducted as part of the RI sampling event in 2005. This Seattle-area study was designed to collect sediment samples near storm drains and other areas receiving runoff associated with typical urban sources. The total number of samples was relatively small (n= 11; Windward 2010), but these data were combined with other lines of evidence for assessing recontamination potential in this appendix.

The criteria used to select sampling areas representative of urban influences were as follows: 1) the area must receive drainage from basins with land uses similar to the LDW; 2) the area must not be located near known industrial point sources of dioxins/ furans; 3) the area must represent a range of receiving water environments; and 4) the area must represent a range of stormwater discharge frequencies, volumes, and types similar to those in the LDW.

The mean of these data, excluding samples from the Ship Canal and Union Bay, which exceeded 50 nanograms (ng) TEQ/kg dw, was 14.9 ng TEQ/kg dw. The 90th percentile

[4] The full range of BCM predictions are presented in Sections 9 and 10 of the FS, and are the result of low to high sensitivity runs of the BCM input parameter values 30 years after remediation of Alternative 6.

was 16.3 ng TEQ/kg dw (Table J-2; Windward 2010). These data are higher than the full range of long-term model-predicted concentrations (2 to 8 µg/TEQ/kg dw), but they are indicative of sediment concentrations immediately offshore of outfalls in the Greater Seattle area.

J.2.4 Dioxin/Furan Data from Regional Open Water Disposal Sites

Because the dioxin/furan data are limited compared to data for the other human health risk drivers, urban water body data for this risk driver were obtained from studies of Puget Sound open water disposal sites (Table J-3) and included in the analysis.

Dioxins/furans were analyzed from Dredged Material Management Program (DMMP) samples collected near and within five nondispersive open water dredged material disposal sites from 2005 to 2008. These data were compiled in an effort to revise guidelines related to open water disposal of dioxin/furan-containing dredged material. Data were provided as a part of a series of public meetings led by the DMMP related to these guidelines in 2009 (DMMP 2009).

Sample locations were divided into on-site and off-site samples (the latter at least one-eighth of a mile from the sites; Table J-3). The mean concentrations at the Elliott Bay disposal site (2005 and 2007) were 6 and 8 ng TEQ/kg dw for on-site and off-site samples, respectively. Dioxin/furan data were also collected in Elliott Bay in 2008 for the PSAMP to assess ambient conditions. These samples were not collected in close proximity to the Elliott Bay disposal site. The PSAMP surface (0 to 10 centimeter [cm]) samples had a slightly lower mean of 5 ng TEQ/kg dw (range 1 to 14 ng TEQ/kg dw)[5] compared to the 2005/2007 DMMP samples. For the other urban bays, the mean values of the DMMP on-site samples ranged from 2 to 6 ng TEQ/kg dw. The mean values of the off-site samples ranged from 2 to 8 ng TEQ/kg dw; more samples were collected off-site, which could account for the larger range (DMMP 2009, Wakeman and Hoffman 2006).

Some regional differences may exist, but these dioxin/furan data generally support the full range of long-term model-predicted concentrations of 2 to 8 ng TEQ/kg dw (Figure J-4d).

J.2.5 Published Studies on Regional Trends

Coring studies and temporal surface sediment sampling of water bodies within the Puget Sound region provide valuable information regarding regional sources, trends, and current concentrations on a large scale. The PSAMP (Partridge et al. 2005) shows that in urban watersheds, and in Puget Sound in particular, concentrations of industrial contaminants are decreasing in sediments, while concentrations of contaminants related

[5] Samples within 250 ft of the shoreline were excluded to eliminate samples that could be significantly influenced by potential nearshore sources. Two outliers at 87 and 97 ng TEQ/kg dw were also excluded.

to urbanization (e.g., bis(2-ethylhexyl)phthalate [BEHP] and PAHs) are increasing. The temporal trends from 10 long-term PSAMP monitoring stations sampled from 1989 to 2000 documented decreases in metal concentrations and increases in PAH concentrations over time. The decreases in industrial-sourced contaminants, such as metals, are linked to the use of best management practices (BMPs) and controls on industrial activities and waste disposal. The increases in PAH concentrations can be linked to general urbanization. Using population growth as a surrogate for urbanization, the City of Seattle has grown by about 47,000 people, or by 9%, from 1990 to 2000. This rate is twice as fast as the city's growth from 1980 to 1990 and close to the national increase of 10% growth in a 10-year period (City of Seattle 2008).

Empirical data from previous sediment cleanups in the Puget Sound region suggest that some recontamination may occur in localized areas near large outfalls. Recent trends in Puget Sound have shown increasing concentrations of persistent, non-point source contaminants typically found in urbanized areas and often associated with street dirt, car exhaust, and asphalt paving.

Table J-4 summarizes the regional and national studies evaluated to describe regional trends. Figures J-4a through J-4d graphically present the range of regional concentrations relative to long-term model-predicted concentrations. Empirical data trends observed from regional and national studies help provide context for the long-term model-predicted concentrations and for recontamination potential in the LDW. These findings are described below.

J.2.5.1 Total PCBs

The National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends (NST) Program (McCain et al. 2000) reports much lower total PCB surface sediment concentrations in less-urbanized water bodies. In the Nisqually Reach (Puget Sound), an area with no urban or industrial development, total PCB sediment concentrations were around 10 µg/kg dw while samples collected in Elliott Bay were significantly higher, up to 1,000 µg/kg dw (McCain et al. 2000). This program also evaluated six sediment cores collected in the main basin of Puget Sound, which had maximum concentrations of 35 µg/kg dw in subsurface sediment and an average concentration of 8 µg/kg dw in the surface-interval samples (Lefkovitz et al. 1997).

Sediment cores collected from two remote lakes on the Olympic Peninsula (Lake Ozette and Beaver Lake, WA) revealed maximum total PCB concentrations at depth (i.e., they were buried by less contaminated sediment) at 60 and 175 µg/kg dw in intervals dated in the mid-1960s. By the mid-1970s, concentrations had fallen to 40 and 100 µg/kg dw, respectively (Cleverly et al. 1996 as cited in Yake 2001). These core trends demonstrate the historical trends in total PCB contamination away from urban influences. Figure J-4a displays only the more recent data, which are relevant to the long-term model-predicted concentrations.

Lake Ballinger (Snohomish County, light urban) and Lake Washington (urban) sediment cores contained total PCB concentration peaks of 220 and 265 µg/kg dw at depth, respectively, in sediment dated in the 1960s. Concentrations in these cores fell to 40 and 75 µg/kg dw, respectively, in intervals dated in the 1980s (shallower intervals; USGS 2000 as cited in Yake 2001). This demonstrates the land use gradients (i.e., higher concentrations in more urbanized areas) and historical trends of buried peaks and decreasing total PCB concentrations with decreasing depth.

In another study, Van Metre and Mahler (2005) analyzed sediment core data from 38 urban and reference (non-urban, undeveloped) lakes distributed across the United States. Higher total PCB concentrations were found in dense urban lakes with a historical (1965 to 1975) median of 275 µg/kg dw, dropping to 108 µg/kg dw in shallower core intervals (post-1990). Light urban lakes had total PCB concentrations ranging from 51 (1970s) to 15 µg/kg dw (post-1990).[6]

The total PCB concentrations reported in these studies (Table J-4) were coincident with the degree of urban land use surrounding the water bodies. This suggests, in the case of the LDW, the need to consider inputs to the LDW from its immediate drainage basin as opposed to focusing exclusively on solids entering the site from the Green/Duwamish River (i.e., from upstream inflows where nonpoint sources originate from a less-urbanized watershed than the LDW drainage basin).

These studies (concentrations reported in Table J-4) support the best-estimate of long-term model-predicted total PCB concentrations range of 40 to 50 µg/kg dw, and the full sensitivity range of long-term model-predicted concentrations of 10 to 100 µg/kg dw. Localized areas can potentially recontaminate above 100 µg/kg dw (Figure J-4a; based on the dense-urban data median in Cleverly et al. 1996 as cited in Yake 2001, and Van Metre and Mahler 2005).

J.2.5.2 Arsenic

Sediment data collected during three regional studies have shown (Table J-4; Figure J-4b):

- Arsenic concentrations from 10 to 25 mg/kg dw in Lake Washington and Lake Ballinger (Snohomish County) subsurface sediment dated between 1960 and 2000 (USGS 2000 as cited in Yake 2001).
- Arsenic concentrations in the range of 10 to 20 mg/kg dw in Puget Sound subsurface sediment dated after 1970 from three cores far removed from river discharges or outfalls, with buried peak concentrations of 28 mg/kg dw and pre-industrial concentrations in the range of 5 to 10 mg/kg dw (Lefkovitz et al. 1997).

[6] For this study, land use in the watersheds was categorized as "dense urban" (>52% urban land use; 14 lakes), "light urban" (5-42% urban; 17 lakes), or "reference" (<1.5% urban; 7 lakes), as determined from the 1992 USGS National Land Cover Data.

- Temporal trends in surface sediments from Puget Sound nonurban and urban areas reported by PSAMP (Partridge et al. 2005). This study revealed minimal changes in arsenic concentrations over recent time. The study showed a median arsenic concentration of 10 mg/kg dw within a 1989 to 1996 dataset, with a decrease in all concentrations to below 10 mg/kg dw for a sampling event conducted in 2000.

The EIM database, maintained by Ecology, was also queried for post-2000 arsenic data from surface soil samples in the vicinity of the LDW and within the LDW watershed. The majority of the 765 samples were collected in conjunction with the *Tacoma Smelter Plume King County Child Use Study* and the *Tacoma Smelter Plume Phase II Mainland Footprint Study*. The mean arsenic soil concentration of this dataset was 10 mg/kg dw, and the 90th percentile was 20 mg/kg dw.

NOAA's NST Program cited mean arsenic concentrations of up to 13 mg/kg dw along the Pacific Coast, with the reference station (Dana Point, California) at 9.3 mg/kg dw (Meador et al. 1994).

Rice (1999) summarized concentrations of trace elements, including arsenic which is an element naturally present in soil, in streambed surface sediments throughout the United States, and reported a median arsenic concentration of 6.3 mg/kg dw. This study also documented median arsenic concentrations in nonurban indicator site soils ranging from 4.8 to 21 mg/kg dw.

Arsenic data from these studies provide evidence of the regional concentrations (Table J-4; Figure J-4b) and support the full sensitivity range of long-term model-predicted concentrations of 7 to 10 mg/kg dw, with localized areas containing sediment concentrations in the range of 10 to 20 mg/kg dw from general urban inputs.

J.2.5.3 cPAHs

Lefkovitz et al. (1997) evaluated sediment cores from three locations in Puget Sound that were geographically remote from river discharges and outfalls. The data show increasing benzo(a)pyrene, or B(a)P, concentrations beginning around 1900, peaking in the 1950s, and leveling off in the 1980s to a concentration of approximately 100 µg/kg dw. B(a)P is used as a surrogate for cPAHs because this individual PAH was commonly analyzed and reported in these studies, although other individual PAHs required for the calculation were not.[7]

In the 2000 PSAMP monitoring event, the B(a)P mean (of all samples) ranged from 143 µg TEQ/kg dw (in the 1989 to 1996 dataset) to 100 µg/kg dw (in the 2000 dataset). However, some individual PAHs, total PAHs, and high molecular weight PAHs

[7] cPAHs are also called B(a)P equivalents because the calculation of the TEQ adjusts the concentrations of seven PAH compounds based on their toxicity to mammals relative to that for B(a)P.

increased over time (1989 to 1996 dataset compared to 2000 dataset) in most areas of Puget Sound from which samples were collected (Partridge et al. 2005).

Van Metre et al. (2000 as cited in Yake 2001) observed that B(a)P from Lake Washington sediment cores showed little temporal (depth) variation in concentrations that remain at or below approximately 100 µg/kg dw. Conversely to PCB trends, Lake Ballinger sediment data exhibited a steep increase in B(a)P to concentrations in the 1,000 to 3,000 µg/kg dw range by the 1990s. This increase was likely associated with increased urbanization and population growth. These PAH temporal trends differ from those discussed earlier in this appendix for PCBs for at least three reasons:

- PCBs are recalcitrant and are very slow to degrade, relative to PAHs. Therefore, a lack of buried peak concentrations of PAHs in the core profiles could, in part, be due to degradation.
- PCBs are man-made chemicals, such that they are only produced by industrial processes, whereas PAHs are derived from both natural and urban sources.
- PCBs were intentionally produced. They were specifically manufactured prior to 1979 by particular industrial processes. In contrast, certain PAHs are unintentionally produced and are released to the atmosphere by combustion.

The body of literature on urban sediments suggests that PAH concentrations vary in proportion to the level of urbanization within a watershed. Van Metre and Mahler (2005) observed upward trends in PAH concentrations over time and strong correlations with urban land use. Increases occurred almost exclusively in lakes surrounded by urban watersheds. The Van Metre and Mahler (2005) data show median B(a)P concentrations in cores collected from dense urban lakes rising from 580 µg/kg dw during the period 1965 to 1975 up to 1,500 µg/kg dw in the post-1990 period (a 2.6-fold increase). The data for light urban lakes show median B(a)P concentrations during the same time periods rising from 50 to 120 µg/kg dw.

Similarly, Mauro et al. (2006) found that soils sampled in urban areas had average B(a)P concentrations of 495 µg/kg dw, with a median concentration of 130 µg/kg dw.

In summary, the Puget Sound (Lefkovitz et al. 1997) and light urban lakes data (Van Metre and Mahler 2005) support the best estimate of long-term model-predicted cPAH concentrations of about 100 to 120 µg TEQ/kg dw (full sensitivity range from 50 to 320 µg TEQ/kg dw). These regional studies, supported by national trends, document that localized inputs can result in contaminant concentrations above the upstream BCM input parameters (40 to 270 µg TEQ/kg dw), and localized recontamination potential up to about 500 µg TEQ/kg dw (dense urban median) is possible given the LDW drainage basin's urban land uses (Figure J-4c).

J.2.5.4 Dioxins/Furans

In one regional study, Ecology analyzed surface soils throughout Washington State for dioxins/furans (as cited in Rogowski et al. 1999 and Yake et al. 2000). Concentrations ranged from 0.0078 to 19 ng TEQ/kg dw. All samples had detectable concentrations, including those from remote wilderness areas. Dioxin/furan concentrations were generally higher in urban areas (0.13 to 19 ng TEQ/kg dw) than in forested, open, and agricultural areas (0.0078 to 5.2 ng TEQ/kg dw). Three of the highest detected values were from urban areas, which is consistent with combustion processes being the primary source of dioxins/furans in the environment. The study concluded that dioxin/furan concentrations detected in Washington State soils were comparable to those reported in studies conducted in other parts of the world.

Cleverly et al. (1996 as cited in Yake 2001) found peak dioxin/furan concentrations (2 ng TEQ/kg dw) in sediment cores collected in remote Olympic Peninsula lakes (Lake Ozette and Beaver Lake, WA) associated with buried sediment dated in the mid-1950s. Surface intervals from these cores had dioxin/furan concentrations of approximately 1 ng TEQ/kg dw. Contrasting these data to the urban water body data reveals the influence of urban sources (urban-rural gradient). However, the identification of detectable levels of dioxins/furans in these remote lakes infers atmospheric transport of this chemical class.

The U.S. Environmental Protection Agency (EPA) analyzed dioxins/furans in surface sediment samples from 11 lakes and reservoirs removed from known sources. The range reported was 0.12 to 16.3 ng TEQ/kg dw, with a mean of 5.3 ng TEQ/kg dw (EPA 2000 as cited in Windward 2010).

In another study, analysis of 10 samples collected from catch basins and manholes in the storm drain system in the LDW drainage basin revealed dioxins/furans ranging from 6 to 26 ng TEQ/kg dw (Integral 2008). One street dirt sample from the same study had a dioxin/furan concentration of 91 ng TEQ/kg dw.

The Washington State studies support the full sensitivity range of long-term model predictions for dioxins/furans of 2 to 8 ng TEQ/kg dw (Table J-4 and Figure J-4d). Localized dioxin/furan concentrations could be expected in the range of 10 to 20 ng TEQ/kg dw (rounded from 19), based on data from Rogowski et al. (1999), Yake et al. (2000), and EPA (2000 as cited in Yake 2001).

J.2.5.5 Phthalates

Empirical data from sediment cleanups in Puget Sound suggest that some recontamination may occur in localized areas near large outfalls. Monitoring results from the Thea Foss and Wheeler-Osgood Waterways in Commencement Bay have shown elevated concentrations of phthalates (BEHP) and PAHs in designated "recovery" areas (City of Tacoma and Floyd|Snider 2007a and 2007b). These

concentrations may be attributable to the influence of localized effects from sources that are not controllable (e.g., BEHP and PAHs in urban stormwater).

Recent trends in Puget Sound have shown increasing concentrations of persistent, nonpoint source contaminants typically found in urbanized areas and often associated with street dirt, car exhaust, and asphalt paving. The Sediment Phthalate Work Group[8] recently concluded that phthalates are among several pervasive urban contaminants that follow the air-water-sediment pathway and are likely to pose greater problems as population and urban development increase (City of Tacoma et al. 2007).

Phthalates are not discussed as extensively in this appendix, because they were not identified as human health risk drivers for the LDW. Brief reviews of data from urban water bodies and of published literature were conducted for this appendix. Two phthalates were identified as having a high potential to cause recontamination on a model grid-cell basis, as discussed in Section J.3.2.1. Phthalate empirical data are also presented in Appendix F in the context of natural recovery potential.

J.3 LDW Evaluation

The types of probable contaminant pathways to the LDW that are cataloged in the RI (Windward 2010) and Ecology's Source Control Strategy (Ecology 2004) include: direct discharge into the LDW; surface water runoff or sheet flow; spills and/or leaks to the ground, surface water, or directly into the LDW; groundwater migration/discharge; bank erosion/leaching; and atmospheric deposition (see Figure J-1). In addition, contaminant pathways within the LDW include the resuspension and transport of contaminated sediments. In this FS, it is assumed that source control efforts and the remediation of sediment containing higher contaminant concentrations will sufficiently reduce point and nonpoint sources of contamination. This section describes the nature of sediment entering and depositing in the LDW receiving sediment to demonstrate long-term model-predicted contaminant concentrations that would occur following source control and remediation. This section also describes the areas with higher potential to recontaminate (as predicted by the BCM). Additionally, passive sampling of atmospheric deposition is presented to demonstrate that urban-source contaminants (PCBs, PAHs, and phthalates) are depositing within the LDW drainage basin. This section focuses on impacts to receiving sediments, as opposed to data collected from source media (e.g., groundwater, riverbank soils) because conditions in the receiving sediments reflect the influence of all internal and external contaminant sources to the LDW.

[8] The Sediment Phthalate Work Group includes representatives from the following agencies: City of Tacoma, City of Seattle, King County, Washington State Department of Ecology, and the U.S. Environmental Protection Agency.

J.3.1 Recent Surface Sediment Chemistry in Dredged and/or Capped Areas

Changes in surface sediment contaminant concentrations in maintenance dredged or capped areas after actions have been taken provide indications of potential recontamination. Analysis of contaminant concentrations in dredged areas, on sand caps, or on enhanced natural recovery (ENR) areas reveals the nature of recent sediments settling after the surface sediment has been removed or covered. The analysis allows legacy (historical) contamination to be separated from impacts associated with new sediment depositing on the remediated area; and provides an understanding of the chemical quality of material being deposited within the LDW, which is responsible for recontamination.

It is noted, however, that contamination may also exist in areas adjacent to the remediated areas, and this may be a component of the "new" sediment depositing in the remediated area. In addition, upland source control work in these areas is ongoing and was not complete at the time of sediment remediation. Sediments affecting actively remediated areas can originate from lateral sources, suspended material transported downstream from the Green/Duwamish River, or from LDW bed sediment that is resuspended and redeposited onto these areas. These data provide empirical evidence supporting the chemical nature of material depositing after sediment removal, capping, and/or thin-layer placement in the short term. The results discussed below may not be indicative of future trends at other outfalls. In addition, future trends may show further declines due to continued source control efforts.

J.3.1.1 Duwamish/Diagonal

The Duwamish/Diagonal Early Action Area (EAA, RM 0.5E) cleanup involved a combination of dredging and capping in 2003 to 2004 and thin-layer sand placement (ENR) in 2005. These actions were conducted by King County for the Elliott Bay/ Duwamish Restoration Program (EB/DRP), which was established in 1991 to implement a Natural Resource Damage Consent Decree. Surface sediment chemistry is being monitored on and adjacent to the actively remediated areas of the EAA; four years of post-ENR data (2006 through 2009) and five years of post-dredge/cap data (2005 through 2009) are available (Tables J-5a and J-5b, Figures J-5a and J-5b). Preliminary 2010 data have been collected by King County, but data were not available in time to be included in the database for this FS.

ENR Area

Following placement of the thin layer of sand (ENR) in February 2005 southwest of the Duwamish/Diagonal EAA, concentrations of contaminants of concern (COCs) reported for this ENR area are trending toward the range of concentrations predicted by the BCM. The ENR area is farther from the Duwamish/Diagonal CSO/storm drain (SD) outfalls than the dredged and capped areas. The initial sampling event in 2005 occurred approximately one month after ENR placement. Monitoring data in the four-year period following placement of the ENR sands show low concentrations of COCs were

present immediately following sand placement, indicating the clean nature of the sand material placed. Over time, concentrations have been increasing slightly, indicating they have been equilibrating to a mixture of upstream inputs, lateral inputs, and the surrounding area. Specifically:

- Total PCB concentrations in surface sediment in the ENR area have remained below the SQS, with the highest concentration measured in 2009 being 144 µg/kg dw (8.3 mg/kg organic carbon [oc]). Average total PCB concentrations in 2007 through 2009 were in the 60 to 70 µg/kg dw range, above the best-estimate long-term model-predicted concentrations of 40 to 50 µg/kg dw, but within the full sensitivity range of long-term model-predicted concentrations (Table J-5a; Figure J-5a).
- At all seven of the ENR monitoring locations, the arsenic concentrations were at or below 11 mg/kg dw in 2009, with average concentrations in 2007 through 2009 in the 7 to 8 mg/kg dw range, within the range of long-term model-predicted concentrations (Table J-5a; Figure J-5a).
- For cPAHs, the maximum concentration measured in 2009 was 150 µg TEQ/kg dw. The average concentrations in 2008 and 2009 were in the 60 to 110 µg TEQ/kg dw range, similar to the range of best-estimate long-term model-predicted concentrations of 100 to 120 µg TEQ/kg dw (Table J-5a; Figure J-5a).
- Six of the seven BEHP samples collected in 2009 were undetectable (U qualified), but the qualification was added because of blank contamination, not because of concentrations below the reporting limit. The one detected sample exceeded the SQS of 47 mg/kg oc. Average concentrations in 2007 and 2008 were in the 130 to 150 µg/kg dw range (Table J-5a; Figure J-5a). For reference, the upstream BCM input parameter is 120 µg/kg dw, and the lateral BCM input parameter is 15,475 µg/kg dw (Table 5-3 of the FS).
- A 2009 composite sample from the ENR area had a dioxin/furan concentration of 3.3 ng TEQ/kg dw, similar to the best-estimate long-term model-predicted concentration of 4 ng TEQ/kg dw (full sensitivity range of 2 to 8 ng TEQ/kg dw; Figures J-4d and J-5a).

Cap Data

Two sand caps were placed in adjacent areas of the Duwamish/Diagonal EAA in 2004, following dredging activities (Table J-5b; Figure J-5b). Monitoring of the sediment accumulating on top of these caps has been conducted annually since 2004. The initial sampling event occurred approximately 5 months after cap placement, and showed average total PCB concentrations of 22 and 77 µg/kg dw on Caps A and B, respectively. In 2005 and 2006, sediment concentrations on Cap A, which is located closer to shore, showed increases in total PCB concentrations. These increases are believed to be the

result of contamination from outfall discharges. Since 2006, total PCB concentrations have decreased on this cap, with an average of 62 µg/kg dw in 2009. Sediment concentrations on Cap B have shown similar averages over most years, and in 2009 had an average of 41 µg/kg dw. Both caps appear to be equilibrating to a level around 50 µg/kg dw, close to the best-estimate long-term model-predicted concentration range of 40 to 50 µg/kg dw.

Sediment concentrations of cPAH and BEHP on the caps follow similar trends, with the peak cPAH concentration measured on Cap A in 2006 (average of 375 µg TEQ/kg dw). Later cPAH concentrations on average trend toward the 110 to 230 µg TEQ/kg dw range for the caps, with Cap B having the lowest average concentrations. The highest BEHP average concentrations were measured on Cap A in 2005 and 2006 (averages of 1,933 and 1,485 µg/kg dw, respectively). Later BEHP concentrations on average trend toward the 300 to 750 µg/kg dw range for the caps, with Cap B having the lowest average concentrations.

Arsenic data for Cap B does not follow this trend. Concentrations on Cap B have been slightly higher than those on Cap A for 2007 through 2009. Arsenic concentrations started low (in 2004; cap material) and increased such that they equilibrated with upstream and lateral source inputs and surrounding areas.[9] At the eight cap monitoring locations, all arsenic samples were at or below 14 mg/kg dw in 2009. Arsenic data for both caps appear to be equilibrating to a concentration around 10 mg/kg dw.

Composite samples collected in 2009 on Caps A and B had dioxin/furan concentrations of 7.0 and 5.1 ng TEQ/kg dw, respectively, consistent with the full sensitivity range of long-term model-predicted concentrations of 2 to 8 ng TEQ/kg dw (Figure J-5b).

In summary, the ENR area and cap demonstrate that recontamination can occur at a very localized scale after cleanup (Tables J-5a and J-5b). However, with the exception of discharges from outfalls in the 2005/2006 wet season that resulted in higher concentrations of organic contaminants, contaminant concentrations are relatively low. The concentrations can be highly variable on a year-to-year basis. These data support the long-term model-predicted range of concentrations.

J.3.1.2 Norfolk Area

The Norfolk Area, located on the east bank at RM 4.9–5.0, encompasses two sediment removal actions. In 1999, King County conducted sediment removal and backfilling offshore of the Norfolk CSO/SD for the EB/DRP. At an adjacent, smaller area near the Boeing Developmental Center south storm drain, The Boeing Company conducted sediment removal and capping in 2003.

[9] For the BCM input parameters, a smaller range of concentrations was assigned for arsenic, which is consistent (appears to be reflected) in the cap data.

Norfolk CSO/SD Cleanup Area

Post-cleanup surface sediment samples from four general locations in the Norfolk CSO/SD cleanup area were collected annually from 1999 through 2004 by King County; the same four locations were resampled in 2006 as part of the RI. Three of the four locations were also sampled in 2008 by Ecology.

In 2001 (prior to the adjacent Boeing Developmental Center south storm drain cleanup), post-cleanup surface sediment samples in the Norfolk CSO/SD cleanup area[10] had total PCB concentrations ranging from 31 µg/kg dw to 1,330 µg/kg dw in the upper 10 cm of sediment and reached up to 1,900 µg/kg dw in the 0- to 2-cm samples. Following the adjacent south storm drain sediment removal and cap placement in 2003, total PCB concentrations at three of the four stations (NFK 501, 503, and 504) initially increased, but the concentrations at all four locations have subsequently decreased (Table J-6 and Figure J-6). The total PCB concentrations in the four samples collected on the cleanup area by Ecology in 2008 ranged from 2.2 to 7 µg/kg dw. In general, the total PCB concentrations remain low (in very sandy material), well below the long-term model-predicted range of 10 to 100 µg/kg dw.

The increase observed in Norfolk CSO/SD post-cleanup total PCB concentrations (prior to dredging and capping of the adjacent area offshore of the Boeing Developmental Center south storm drain in 2003) identifies the need to also look at adjacent sediment when evaluating recontamination potential. Recontamination is not only attributable to external sources (e.g., storm drains, upstream inflow) but can also be from internal sources (e.g., movement and redeposition of adjacent bed sediment, scour of subsurface sediment).

Arsenic concentrations in samples collected in April 1999 were all below 4 mg/kg dw. In 2004, all four of the 0 to 10 cm Norfolk samples were nondetect for arsenic. The arsenic concentrations from three samples collected on the cleanup area by Ecology in 2008 ranged from 6 to 15 mg/kg dw. These concentrations are within and close to the long-term model-predicted concentration range of 7 to 10 mg/kg dw.

In April 1999, cPAHs were not detected in any samples, but cPAH concentrations rose up to 286 µg TEQ/kg dw in 2004. In 2006, two samples were nondetect, and the other two had concentrations of 95 and 220 µg TEQ/kg dw. In 2006, the range for the three samples collected by Ecology was 23 to 230 µg TEQ/kg dw. One of these three samples had an SQS exceedance (for butyl benzyl phthalate). These data are within the long-term model-predicted concentration range of 50 to 320 µg TEQ/kg dw.

Visual observations of the Norfolk CSO/SD cleanup area by the King County Department of Natural Resources and Parks Department staff reveal that the nearshore and upstream portions of the EAA appear to be relatively stable, although two drainage

[10] This removal area was backfilled to grade so the backfilled area is sand placed to bring the area back to grade and not an engineered cap.

channels were observed to have been cut through the backfill by outflow from the Boeing Developmental Center south storm drain and the Norfolk CSO/SD outfall. The depths of these cuts were not measured, but samples collected in/near these channels in 2006 and 2008 were below 70 µg/kg dw for total PCBs (Table J-6). Because most of the contaminated sediment was removed during the 1999 dredging, with the exception of some material remaining deeper than 9 ft below mudline, the channels are not expected to expose contaminated sediment. The backfill was placed for two purposes: to isolate this deep (>9 ft) contamination left behind; and to return the dredged area back to the original grade. Because the backfill is 9 ft thick, there is minimal potential for exposure of buried contamination.

It was noted that once these channels were established (following backfill placement), they have not moved, indicating a relatively stable environment. Because the pedestrian bridge downstream of the Norfolk CSO/SD cleanup area limits access, large vessels are prevented from transiting this area (Mickelson, personal communication, 2009), thereby reducing scour potential from vessels in this area, although high-flow river scour would still occur. This area is upstream of the sediment transport model domain, so high-flow scour depths and net sedimentation rates could not be estimated in this area. However, evidence suggests that following cleanup of the adjacent Boeing Developmental Center south storm drain area, internal sources are not recontaminating the Norfolk CSO/SD cleanup area.

Boeing Developmental Center South Storm Drain Cap

In 2003, Boeing removed 60 cubic yards of sediment from a 0.04-acre area offshore of the Boeing Developmental Center south storm drain at RM 4.9E and backfilled the area with clean sand; this area is inshore of the Norfolk CSO/SD cleanup area. Surface sediment samples have been collected from three stations within the backfilled area on six occasions beginning in 2004 and analyzed for PCBs and total organic carbon (TOC; Table J-6; Figure J-6; CALIBRE 2009).

The results of these sampling events show that PCBs have never been detected at two of the stations (S02 and S03). The third station (S01) is located within a drainage channel that appears to originate at the terminus of the south storm drain outfall. Total PCB concentrations at that station have varied widely, from nondetect in February 2009 to 1,075 µg/kg dw (average of the two station samples; 1,310 and 840 µg/kg dw) in September 2009. The TOC in the sample with the total PCB concentration of 840 µg/kg dw was 14.2%, which is much higher than the LDW-wide average and higher than the TOC concentrations in the other samples (Table J-6; Figure J-6). This elevated TOC concentration may indicate that some disturbance or input affected this sample. The oc-normalized total PCB concentrations from Station S01, excluding September 2009 data, have varied between nondetect and 23 mg/kg oc over time (as compared to the SQS for total PCBs of 12 mg/kg oc).

Beginning in 2000, Boeing has conducted intensive investigations of PCBs within the south storm drain, with the intent of identifying potential sources and reducing the discharge of PCBs in stormwater to the river. Accumulated solids within the storm drain line have been cleaned out on multiple occasions, and a Vortechnics sediment trap was installed in the storm drain line in 2003. Stormwater solids have been collected annually from a manhole upstream of the sediment trap and analyzed for PCBs; total PCB concentrations have been highly variable (1,440 to 61,500 µg/kg dw). Solids samples retained in the sediment trap have had more consistent total PCB concentrations, ranging from 10,600 to 32,000 µg/kg dw. Stormwater solids have also been collected annually from a manhole downstream of the sediment trap and analyzed for PCBs; total PCB concentrations there (1,670 to 16,200 µg/kg dw) have been lower than in the upstream manhole or in the sediment trap. The results of this sampling suggest that the sediment trap has been effective at reducing the discharge of PCBs to the river from this outfall, although some PCBs, likely associated with very fine particulate matter not retained by the sediment trap, are still being discharged. Nevertheless, the mass loading of PCBs from this outfall has been estimated to be very small (average of only 0.25 g/yr) over the six years of data collection. Although such small mass loading may in part contribute to sediment concentrations that exceed the SQS in the immediate vicinity of the outfall, it is apparent that the effect is extremely localized, with sediment PCB concentrations less than 20 ft away being below detection limits. This points out the difficulty in reducing the discharge of contaminants like PCBs to such a degree that no recontamination will occur above very low target concentrations.

Summary

Both portions of the Norfolk cleanup area demonstrate that recontamination can occur at a very localized scale after cleanup. However, with the exception of one sample (and replicate) collected on the Boeing Developmental Center south storm drain cap in 2009, contaminant concentrations are relatively low, although they can be highly variable on a year-to-year basis. These data support the long-term model-predicted range of total PCB concentrations of 10 to 100 µg/kg dw.

J.3.1.3 Sediment Characterization in Maintenance Dredged Areas

Dredging occurs in the LDW for two purposes: to maintain depths necessary for berthing and navigation, and to remove contaminated sediments. The opportunity to evaluate changes in sediment chemistry from dredged areas is most evident in the frequently dredged area of the authorized navigation channel located at the upstream end of the LDW, from RM 4.0 to 4.75. A portion of this area from RM 4.3 to 4.75 and its associated data are discussed in detail as a line of evidence for upstream inputs in

Appendix C. The navigation channel is regularly dredged to an elevation of -17 ft MLLW.[11]

The navigation channel in the upstream reach of the LDW is dredged approximately every two to four years to maintain depths for navigation. The U.S. Army Corps of Engineers (USACE) Seattle District collects subsurface core samples prior to dredging and characterizes the material to evaluate disposal options. Because this area is frequently dredged, it is believed to represent material continually deposited into the LDW from upstream. Subsurface sediment data from 1991 to 2009 were provided by the USACE from their Dredged Analysis Information System and from the data report for the 2008 and 2009 data sampling events (USACE 2009a, 2009b).

Data from the USACE were evaluated by three sections of the navigation channel because spatial heterogeneity, grain size, and organic carbon, which vary among these areas, can have an effect on contaminant concentrations in the LDW (Figure J-7):

- **RM 4.0 to 4.3**: Total PCB concentrations (N = 51) averaged 74 µg/kg dw. Ten of the samples had concentrations greater than 100 µg/kg dw. These data were not used as lines of evidence for the BCM upstream input parameters because they may be impacted by inputs of sources to Hamm Creek and Slip 6.
- **RM 4.3 to 4.5**: Total PCB concentrations (N = 11) averaged 44 µg/kg dw. These data were used as a line of evidence for the BCM upstream input parameters.
- **RM 4.5 to 4.75**: Total PCB concentrations (N = 9) were consistently low, around 20 to 30 µg/kg dw. This area is dominated by coarse-grained sand, bed load material with low organic carbon content that settles primarily in the Upper Turning Basin above RM 4.5. These data were used as a line of evidence for the BCM upstream input parameters.

These trends demonstrate that the continual inflow of sediments that deposit from the Green/Duwamish River contain concentrations of PCBs below the SQS and in the 20 to 44 µg/kg dw range. It is less clear to what extent the lateral inputs or "fining" of deposited material are contributing to the concentration increases observed downstream of the Upper Turning Basin ("fining" or grading from coarse- to fine-grained size with increasing distance downstream from the Upper Turning Basin; see Section 5).

Farther downstream, surface sediment data collected following maintenance dredging events at private berthing areas were used to characterize the sediments resettling in the

[11] Sediment from cores is composited vertically and horizontally, with the depth of the sample collection targeting an elevation of -17 ft MLLW. This is the authorized maintenance depth of -15 ft MLLW, plus 2 ft for overdredging. Therefore, the depth below mudline of the bottom of the cores is dynamic such that they reach to a -17-ft MLLW elevation. Because of this sampling scheme, the data characterize sediment that deposited above the previous dredge cut (i.e., sediment sourced from upstream).

area and to evaluate recontamination potential.[12] In areas previously dredged to maintain vessel berthing depths,[13] surface sediment total PCB concentrations were at or below 240 µg/kg dw in 30 of 32 samples collected more than 5 years after dredging had occurred (Table J-7). The average total PCB concentration in these samples was 137 µg/kg dw total PCBs, with average concentrations increasing from 88 to 196 µg/kg dw as the time elapsed between dredging and sampling increased from 5 to more than 10 years (Table J-7). This demonstrates that surface sediment concentrations are relatively low following dredging but increase over time. This pattern is also observed with arsenic. However, some of these areas are near EAAs or are assigned as active remediation areas in this FS. Surface sediment concentrations observed in these areas may trend lower after active remediation is conducted in the LDW and as source control activities progress.

Among samples in the post-dredge dataset, average cPAH concentrations were about 255 µg TEQ/kg dw within 5 years of dredging, then increased to 703 µg TEQ/kg dw from 6 to 10 years. However, because the subsets of data averaged in Table J-7 are not from the same areas of the LDW, these trends may be more indicative of spatial heterogeneity than of years elapsed after dredging (i.e., they may not be dependent on the temporal changes in concentration from accumulation of upstream materials). The average cPAH concentration among all samples was 469 µg TEQ/kg dw. Only two of the locations had dioxin/furan data, with an average of 10 ng TEQ/kg dw.

Figure J-8 shows all total PCB samples regardless of the number of years that elapsed between dredging and sample collection (N = 80; including samples in the navigation channel; the average is 208 µg/kg dw total PCBs). Based on these data, the short-term localized concentrations could be in the range of 100 to 200 µg TEQ/kg dw for total PCBs, 11 to 18 mg/kg dw for arsenic, and 250 to 700 µg/kg dw for cPAHs.

J.3.2 Sediment Recontamination Potential Using the BCM

For this FS, the potential impacts that source control and ongoing lateral inputs have on recontamination potential for remedial alternatives was evaluated. For these evaluations, the BCM was used in two ways:

- To estimate the model grid cells where recontamination above the SQS is more likely to occur within 10 years following a simulated remedy (Section J.3.2.1).

[12] The USACE does not regularly dredge the navigation channel farther downstream; therefore, private maintenance dredging events were used.

[13] This analysis used locations within and located 10 ft from the dredging footprints; the dredging mapping layer is not precise. It was mostly generated by hand-entering approximate locations from maps in dredging plans. These are the planned dredge prisms, not the "as-built" areas; hand-drawing these areas—usually without the aid of coordinates—makes these geographic information system (GIS) layers approximate.

- To evaluate the range of potential effects of lateral input values on the post-remedy surface sediment conditions; the range of lateral input parameters was used to predict total PCB and cPAH concentrations 30 years following a simulated remediation scenario. Alternative 5 was used for the purpose of this analysis because it actively remediates all areas above the SQS (Section J.3.2.2).

As discussed in Section J.1.1, the datasets used for estimating lateral and upstream inputs to the BCM are limited, and as such, the results presented below should be used with caution.

J.3.2.1 Recontamination of Model Grid Cells above the SQS

Model grid cells predicted to exceed the SQS 10 years following a simulated remedy across the entire LDW were identified by first setting the concentration of risk drivers in the surface sediment to zero[14] (Figures J-9a and J-9b). The BCM was then run for the 10-year condition, and areas predicted to exceed the SQS based only on the influence of lateral and upstream contributions were identified.

The BCM parameters used in this analysis were the recommended input parameters for representative SMS contaminants and the high lateral load and mid upstream input parameters for total PCBs and arsenic (see Section 5). cPAHs were also included in the analysis, though this calculated total does not have an SQS criterion. These values represent an approximate estimate of overall average lateral loading in the next 5 to 10 years based on lateral data compiled by the City of Seattle. It is recognized that some outfalls or tributaries may have higher or lower overall average lateral loads. Table J-8 identifies the specific SMS contaminants evaluated in this exercise and those having the potential to exceed the SQS within 10 years.

The SMS contaminants with the greatest potential for recontamination from lateral sources include BEHP, butylbenzyl phthalate, and to some extent total PCBs and zinc. The areas having the greatest number of SMS contaminants predicted to exceed the SQS are in the EAAs and the areas identified for active remediation in Alternative 2 (Figures J-9a and J-9b).

Although recontamination is modeled for some SMS contaminants, they do not always exceed the SQS in the FS baseline dataset, nor do they exceed the SQS in the Duwamish/Diagonal EAA post-cleanup data. Figures J-9a and J-9b show the locations exceeding the SQS in the FS baseline dataset and where recontamination potential is predicted by the BCM. Because the BCM uses the same lateral input parameter for every outfall, it does not account for geographic subbasin-specific differences in land uses, upland sources, and outfall discharges. The disparity in these instances between

[14] When evaluating remedial alternatives with the BCM (Section 9), sediment concentrations in actively remediated areas are set to the post-remedy bed sediment replacement value. In this exercise, the bed sediment concentrations were set to zero. This change isolates the effects of lateral sources, as predicted by the BCM.

model predictions (where exceedances are predicted) and baseline data (that do not demonstrate SQS exceedances for the SMS contaminants predicted to exceed the SQS) is a source of uncertainty that will likely need confirmation during remedial design.

J.3.2.2 Effects of Lateral Input Parameters on Recontamination Potential

The effects of the lateral input parameters on predicted total PCB and cPAH concentrations were evaluated in a series of 30-year BCM runs where the lateral input parameters were varied and the upstream and post-remedy bed sediment replacement values were held constant at the mid (recommended) values. For the human health risk drivers, a range of values was established for each BCM input parameter (upstream, lateral, and post-remedy bed sediment replacement value). The range of lateral input parameters represents various levels of potential, future source control activities (Appendix C, Part 3):

- **High –** conservative representation of current conditions assuming modest continued levels of source control and management of high priority sources already identified by the Source Control Work Group.
- **Input (Mid, Recommended) –** pragmatic assessment of what might be achieved in the future with anticipated continued levels of source control. This value is based on mean/median concentrations observed in the lateral dataset after control of medium priority sources.
- **Low –** best that might be achievable in 30 to 40 years with increased coverage and continued aggressive source control.

Recontamination potential was evaluated by first setting all of the area actively remediated in Alternative 5 to the mid post-remedy bed sediment replacement value (total PCBs = 60 µg/kg dw; cPAHs = 140 µg TEQ/kg dw). Six BCM runs were then completed for the two risk drivers using three lateral values. The site-wide SWACs and the predicted concentrations in each grid cell are shown in Figures J-10a through J-10c and J-11a through J-11c for total PCBs and cPAHs, respectively.

For total PCBs, the site-wide SWAC increases by 36% from that predicted with the mid lateral input parameter to that with the high (44 versus 60 µg TEQ/kg dw), but only decreases about 9% for the low lateral parameter. Even with the low lateral input parameter, a few localized areas of sediment are predicted to exceed 100 or 240 µg/kg dw total PCBs after remediation of the Alternative 5 footprint. Additionally, when the high lateral input parameter is used, the Reach 2 SWAC is predicted to be two times greater than when the low lateral input parameter is used (44 versus 89 µg/kg dw).

For cPAHs, the site-wide SWAC increase using the high BCM lateral input parameter is 42% (107 vs. 152 µg TEQ/kg dw). The SWAC increase for cPAHs is slightly greater than that for total PCBs because the range of lateral input parameters is wider for cPAHs (500 to 3,400 µg TEQ/kg dw) than for total PCBs (100 to 1,000 µg/kg dw). The cPAH

SWAC decreases about 20% using the low lateral parameter. A few localized areas are predicted to exceed about 380 µg TEQ/kg dw cPAHs, even when the low lateral input parameter is used, after remediation of the Alternative 5 footprint.

The areas identified as having the greatest recontamination potential for SQS exceedances (Section J.3.2.1) are similar to the areas identified using the high lateral input parameters. These areas are predicted to be affected the most by future source control efforts, which are represented by changes in the lateral input parameters. These areas are generally located near modeled outfalls, but surface sediment concentrations in portions of the navigation channel are also predicted to have a potential for recontamination (Figures J-10a through J-10c and J-11a through J-11c).

J.4 Discussion of Atmospheric Deposition

Atmospheric deposition can be an important pathway from ongoing sources both by way of particles depositing directly onto the surface water of the LDW and by way of particles depositing in the watershed and subsequently being delivered to the LDW through stormwater runoff. Data collected from regional and national atmospheric studies are discussed below.

J.4.1 King County Passive Atmospheric Sampling

King County conducted passive sampling of atmospheric deposition at stations within the LDW watershed and on Beacon Hill, a neighborhood located east of the LDW watershed. Two phases of sampling were conducted: one from January through May 2005 and the second from October 2005 through April 2007. Concentrations of PCBs, PAHs, and phthalates were quantified as daily fluxes collected by passive air particulate samplers. PCB concentrations (based on Aroclor® methods) were near method detection limits. When detected, PCB flux rates in the industrialized areas were on the order of 0.01 to 0.06 micrograms per square meter per day (µg/m^2/day; King County 2008; Table J-9).

The study found that BEHP fluxes were fairly similar at all stations, generally on the order of 2 µg/m^2/day. The highest values were found at several river valley stations, and the lowest values were at a station on Beacon Hill. Most of the stations had similar ranges and median values for benzo(a)pyrene, a PAH with median values on the order of 0.06 µg/m^2/day.

This indicates that urban-sourced contaminants, such as PCBs, PAHs, and phthalates, are continually introduced to the LDW sediments from the atmosphere (King County 2008). Most of this atmospheric deposition is already accounted for by the BCM input parameters, which were derived from separated stormwater basin and combined sewer basin source data influenced by atmospheric deposition.

J.4.2 National Studies of Atmospheric Deposition

Other studies (Table J-9) suggest that total PCB concentrations can vary geographically over small scales and that proximity to densely populated urban areas influences loading from non-point sources. This is tied to the observation that atmospheric deposition is an important and sometimes dominant source of PCBs to coastal waters and upland watersheds. Atmospheric PCB concentrations are generally greater in urban areas than in rural or suburban areas (Gingrich et al. 2001; Jamshidi et al. 2007; Offenberg and Baker 1997; Simcik et al. 1997; Totten et al. 2006; Wethington and Hornbuckle 2005). In studies conducted near Lake Michigan, PCB wet fluxes and concentrations determined for urban, overwater, and rural locations support the hypothesis that urban atmospheric PCBs are a major source to coastal Lake Michigan near Chicago, IL and Milwaukee, WI (Offenberg and Baker 1997; Simcik et al. 1997; Wethington and Hornbuckle 2005). The authors noted that urban and overwater total PCB wet deposition rates are highly variable, suggesting meteorology plays a significant role in controlling the magnitude of the urban wet deposition. This can result in small-scale depositional patterns driven largely by source location, season, precipitation, and prevailing wind patterns, a potentially important factor in the distribution of PCB sources to the LDW. Table J-9 summarizes atmospheric flux data from these studies.

J.5 Summary

This appendix examines potential long-term trends in surface sediment concentrations that may be expected following cleanup of the LDW sediments and associated source control, at both large and small spatial scales.

The range of LDW-wide concentrations predicted by the BCM is supported by data collected over the past 15 years from Puget Sound urban water bodies and the LDW. Published studies add additional context and support the empirical trends. Collectively, the multiple lines of evidence presented in this appendix compare favorably with the range of long-term model-predicted concentrations (site-wide SWACs) for LDW sediments listed below. The multiple lines of evidence also suggest the potential for concentrations up to those noted in parentheses near some sources.

- Total PCBs: 10 to 100 µg/kg dw (up to 200 µg/kg dw in smaller areas)
- Arsenic: 7 to 10 mg/kg dw (up to 20 mg/kg dw in smaller areas)
- cPAHs: 50 to 320 µg TEQ/kg dw (up to 500 µg TEQ/kg dw in smaller areas)
- Dioxins/furans: 2 to 8 ng TEQ/kg dw (up to 20 ng TEQ/kg dw in smaller areas).

As noted in Section 9.3.5, the range of these long-term predictions is most heavily influenced by uncertainties in the contaminant concentrations on incoming sediment loads and the amount of sediment deposited in the LDW.

This appendix also considers potential recontamination at local scales, through examination of empirical data at remediated LDW sites and through BCM predictions. In general, the BCM appears to be a useful tool for identifying those areas most likely to recontaminate above the SQS as a result of lateral inputs, and to bound the overall scale of the recontamination potential. Overall, relatively small areas of the LDW (roughly 5 to 10 acres in total) that are located near large lateral inputs have greater potential for recontamination above the SQS. The potential is greatest for phthalates and lesser for PCBs. Empirical data suggest that the BCM could be overpredicting the recontamination potential, both in spatial extent and number of SMS contaminants because of the simplifying assumptions used in the model.

As noted in Section J.1.1, the BCM uses lateral input parameters reflecting actual LDW-wide source tracing datasets from municipal storm drain solids and CSOs. It is important to note that these values may not be representative of all current lateral inputs. For example, a currently uncharacterized outfall that discharges stormwater with unusually high concentrations (and has not yet been addressed by source control actions) may pose a far higher recontamination potential than predicted by the BCM. In some cases, the BCM may overestimate a specific lateral source input or underestimate another. In addition, other sources such as contaminated groundwater or erosion of contaminated bank soils are not considered in the BCM. In concept, the BCM is intended to reflect future average conditions after source control is in place.[15]

The long-term concentrations in LDW sediments (at large and small scales) will depend upon active remediation of hot-spot areas (and sediments historically contaminated by point sources) and source control efforts in the drainage basin and regionally. Uncertainty analyses in this appendix and in Section 9.3.5 (for the sequencing analysis) demonstrate that success of both these efforts has a measurable effect on the site-wide long-term model-predicted concentrations, and could affect the ability to achieve concentrations within the lower end of the range of best estimate SWAC predictions.

The construction period and eventual effectiveness of source control work requires that the timing of in-water sediment remediation activities be considered. For example, if active remediation is undertaken in areas influenced by outfall discharges prior to completion of source control, there would be a greater potential for sediment recontamination. Conversely, active remediation may proceed in other areas regardless of source control status without significant risk of recontamination. In these areas, internal sources of recontamination (e.g., other surface sediments slated for remediation but not yet cleaned up) should be considered before an active remedy is commenced (sequencing).

[15] The BCM applies the same lateral concentration to each outfall. Section 5 discusses uncertainty associated with this model assumption. Actual inputs can differ for outfalls from different drainage basins.

The development of the remedial alternatives for the FS assumes that source control work will be sufficiently completed before construction begins. However, the progress of source control work could impact the timing and sequencing of sediment remediation. Location-specific remedial design should be coordinated with the source control action plans covering that area. It is expected that this coordination will include detailed analyses of source control actions implemented (and to be implemented) and assessments of location-specific data. Ultimately, the recontamination risk will need to be considered during remedial design and managed during remedy implementation and long-term maintenance.

J.6 References

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Table J-1 Summary of Puget Sound Area Urban Water Body Total PCB, Arsenic, and cPAH Data

Parameter and Urban Water Body Name	Number of Observations (number of detections)	Range of Concentrations					
		Minimum Detect	Maximum Detect	50th Percentile	Mean	90th Percentile	UCL95[a]
Total PCBs (µg/kg dw)							
Outer Elliott Bay	28 (7)	8.1	138	17	38	82	53
Inner Elliott Bay	37 (28)	33	800	99	190	576	255
Bellingham Bay	61 (6)	8.0	425	25	76	114	164
Commencement Bay	71 (49)	4.0	1,104	21	61	64	127
Lake Washington	17 (1)	26	26	47	87	217	137
Lake Sammamish	25 (25)	16	88	34	40	73	49
Arsenic (mg/kg dw)							
Outer Elliott Bay	31 (19)	2.4	14	4.1	5.1	9.8	6.4
Inner Elliott Bay	34 (25)	4.7	27	7.4	8.6	16	10.4
Bellingham Bay	162 (160)	1.5	19	9.2	9.2	13	9.6
Commencement Bay	133 (131)	1.4	45	8.7	9.6	17	12
Lake Washington	29 (25)	2.0	27	6.3	7.2	13	8.9
Lake Sammamish	29 (29)	1.8	72	8.7	15	38	59
cPAHs (µg TEQ/kg dw)							
Outer Elliott Bay	21 (15)	22	327	79	116	292	152
Inner Elliott Bay	66 (64)	14	4,780	269	583	1,410	1,080
Bellingham Bay	64 (53)	5.8	593	32	76	185	108
Commencement Bay	45 (45)	8.8	1,700	115	223	527	345
Lake Washington	33 (30)	43	5,290	216	374	904	635
Lake Sammamish	20 (11)	57	1,870	92	234	574	407

Notes:
1. Excludes data from listed CERCLA or MTCA sites and from disposal sites. Elliott Bay data are post-1991 and exclude data on the Pier 51/52 and Denny Way caps.
2. Urban bay data queried from EIM in January 2007 (PCBs and arsenic) and January 2008 (cPAHs) are from 1990 to 2004.
3. One-half of RLs used for nondetect values in summary statistics calculated with ProUCL v.4.0.
4. Total PCB, arsenic, and cPAH data reported in Tables 7-15 to 7-17 of the Final RI (Windward 2010).

a. Reported value is the UCL95 recommended by ProUCL 4.00.04.

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; EIM = Environmental Information Management system; kg = kilogram; µg = micrograms; µg/kg dw = micrograms per kilogram dry weight; mg = milligram; MTCA = Model Toxics Control Act; PCB = polychlorinated biphenyl; RL = reporting limit; TEQ = toxic equivalent; UCL95 = 95% upper confidence limit on the mean

Table J-2 Dioxin/Furan Concentrations in Surface Sediment Collected from Areas Immediately Offshore of Storm Drains and from Other Areas Receiving Runoff in the Greater Seattle Metropolitan Area

General Location in Greater Seattle Area	Sample Location Name	Dioxin/Furan Concentration (ng TEQ/kg dw)		Concentrations included in Calculation of Statistics in RI (ng TEQ/kg dw)
Elliott Bay (Terminal 91)[a]	EB-SS2a	13.7 J		16.3
	EB-SS2b	18.9 J		
Lake Union (Interstate 5 bridge)[a]	LU-SS9a	5.46 J		15.8
	LU-SS9b	26.1 J		
Lake Washington (Bothell)	LW-SS3	13.2 J[b]		13.2
Lake Washington (Bellevue)	LW-SS4	14.7 J		14.7
Lake Washington (Renton)[a]	LW-SS5a	14.1 J		14.3
	LW-SS5b	14.5 J		
Ship Canal (Salmon Bay)[a]	SC-SS1a	187 J		Samples excluded from calculations
	SC-SS1b	63.1 J		
Union Bay (Laurelhurst)	UB-SS8	53.4 J		
Statistics for Greater Seattle Locations	*Count*	*11*	*10*[c]	*5*
	Mean	*38.6*	*23.7*[c]	*14.9*
	90th Percentile	*63.1*	*54.4*[c]	*16.3*
	95% Upper Confidence Limit on the Mean	*91.2*	*37.7*[c]	*16.0*

Notes:

1. Data reported in Table 7-18 of Final Remedial Investigation (Windward 2010); statistics with full dataset and n=10 dataset generated by AECOM using ProUCL 4.00.05.

a. Two samples were collected: one approximately 30 to 50 ft from the outfall and the other approximately 100 to 120 ft from the outfall.
b. Reported concentration is the average of two replicate field samples.
c. Sample at 187 ng TEQ/kg dw was excluded, as indicated by gray shading.

ft = feet; J = estimated concentration; ng TEQ / kg dw = nanograms toxic equivalent per kilogram dry weight; RI = remedial investigation

Table J-3 Open Water Disposal Site and Elliott Bay Puget Sound Assessment and Monitoring Program Sediment Data for Dioxins/Furans

Urban Water Body Name	Number of Observations		Range of Concentrations (ng TEQ/kg dw)					
			Minimum Detect		Maximum Detect		Mean	
	on site	*off site*	*on site*	*off site*	*on site*	*off site*	*on site*	*off site*
Elliott Bay 2005 and 2007 Disposal Site [a]	6	11	4	1	12	17	6	8
Port Gardner 2006 Disposal Site [a]	3	9	1	3	3	5	2	4
Bellingham Bay 2007 Disposal Site [a]	1	10	6	4	6	22	6	8
Commencement Bay 2007 Disposal Site [a]	3	10	1	1	14	5	5	2
Anderson-Ketron 2005 Disposal Site [a]	8	0	2	—	7	—	—	—
Anderson-Ketron 2006 and 2008 Disposal Site [a]	19		1		7		3	
Elliott Bay 2008 PSAMP [b]	13		1		14		5	

Notes:

a. Data collected 2005 to 2008 provided by Dredged Material Management Program in 2009 in a series of public meetings discussing guidelines for open water disposal of dioxin/furan-containing dredged material. Dredged material site monitoring reports are available by request from the Dredged Material Management Office (DMMO), Seattle District.

b. Data provided by Tom Gries, Washington State Department of Ecology. Statistics are reported for 0- to 10-cm samples collected >250 ft from shore only; values of 87 and 97.6 ng TEQ/kg dw are outliers and are therefore excluded from the summary statistics.

dw = dry weight; kg = kilogram; ng = nanogram; PSAMP = Puget Sound Assessment and Monitoring Program (formerly the Puget Sound Ambient Monitoring Program); TEQ = toxic equivalent

Table J-4 Contaminant Concentrations Cited in Regional and National Trend Studies

Source	Study Title	Media	Concentrations Cited [page, figure, or table where cited]	Regional/ National
Total PCBs (µg/kg dw)				
Cleverly et al. 1996 as summarized in Yake 2001 (Ecology)	A time-trends study of the occurrences and levels of CDDs, CDFs, and dioxin-like PCBs in sediment cores from 11 geographically distributed lakes in the United States In: *The Use of Sediment Cores to Track Persistent Pollutants in Washington State: A Review*	subsurface sediment	Concentrations in two Olympic Peninsula lakes (Ozette and Beaver) peaked at 60 and 175 in the mid-1960s. By the mid-1970s, concentrations had fallen to 40 and 100 [p. 13]	R
Lefkovitz et al. 1997 (NOAA Battelle/Marine Sciences Laboratory)	*Historical Trends in the Accumulation of Chemicals in Puget Sound, NOAA Technical Memorandum NOS ORCA 111*	subsurface sediment	Six cores; range from nondetect (pre-industrial) to maximum of 35 in the mid-1970s; average of 8 in surface intervals [p. 52, Fig 3.23]	R
McCain et al. 2000 (NOAA)	*National Benthic Surveillance Project Pacific Coast. Organic chemical contaminants, Cycles I to VII (1984-90). NOAA Technical Memorandum NMFS-NWFSC-40*	surface sediment	Elliott Bay ~1,000; Nisqually ~10 [Fig. 5]	R
USGS 2000 as summarized in Yake 2001 (Ecology)	Reconstructed Trends National Synthesis Study In: *The Use of Sediment Cores to Track Persistent Pollutants in Washington State: A Review*	subsurface sediment	Concentrations in Lake Ballinger (non-urban lake) and Lake Washington peaked at 220 and 265 in the late 1960s. Concentrations fell to 40 and 75 by 1980 [p. 30, Fig. 12]	R
Van Metre and Mahler 2005 (USGS)	Trends in Hydrophobic Organic Contaminants in Urban and Reference Lake Sediments across the United States, 1970-2001 (In:*ES&T, vol. 39, 5567 - 5574)*	subsurface sediment	1965 to 1975 median of 65 in all lakes; 275 in dense urban; and 51 in light urban; nondetect in reference areas [Table 1]	N
			post-1990 median of 43 in all lakes; 108 in dense urban; and 15 in light urban; nondetect in reference areas [Table 1]	N
Arsenic (mg/kg dw)				
Lefkovitz et al. 1997 (NOAA Battelle/Marine Sciences Laboratory)	*Historical Trends in the Accumulation of Chemicals in Puget Sound, NOAA Technical Memorandum NOS ORCA 111*	subsurface sediment	Cores dated from 1970 to 1997: 10 to 20; buried maximum concentration of 28; pre-industrial 5 to 10 [p. 33, Fig. 3.11]	R
Meador et al. 1994 (NOAA)	*National Benthic Surveillance Project. Analyses of Elements in Sediment and Tissue Cycles I to V (1984-88). NOAA Technical Memorandum NMFS-NWFSC-16*	surface sediment	Most Pacific coast site means range 0.63 to 13; reference location (Dana Point, CA) = 9.3 [Fig. 13]	R
Partridge et al. 2005 (Ecology)	*Temporal Monitoring of Puget Sound Sediments: Results of the Puget Sound Ambient Monitoring Program 1989 - 2000*	surface sediment	Median of data collected from 1989 to 1996 was around 10; all samples below 10 during 2000 sampling event [p.100, Fig. 11]	R

Table J-4 Contaminant Concentrations Cited in Regional and National Trend Studies (continued)

Source	Study Title	Media	Concentrations Cited [page, figure, or table where cited]	Regional/ National
Rice 1999 (USGS)	Trace-Element Concentrations in Streambed Sediment Across the Conterminous United States (In: *ES&T, vol. 33, 2499-2504)*	streambed sediment	Median of 6.3 and range 1 to 200, all samples detected [Table 1]	N
		soil	Median values of nonurban soil datasets evaluated: 4.8-21 [Table 2]	N
USGS 2000 as summarized in Yake 2001 (Ecology)	Reconstructed Trends National Synthesis Study In: *The Use of Sediment Cores to Track Persistent Pollutants in Washington State: A Review*	subsurface sediment	Lake Washington rose from 10 and peaked at 36 in late 1930s; Lake Washington and Lake Ballinger at 10 to 25 from post-1950s to 2000 [p. 31, Fig. 17]	R
2007 query of soil data by AECOM from EIMS	*Tacoma Smelter Plume (TSP) King County Child Use Study, TSP Tracer Study, TSP King County Extended Footprint, TSP Phase II Mainland Footprint Study*	soil	Mean is 10, and 90th percentile is 20	R
Benzo(a)pyrene (µg/kg dw)				
Lefkovitz et al. 1997 (NOAA Battelle/Marine Sciences Laboratory)	*Historical Trends in the Accumulation of Chemicals in Puget Sound, NOAA Technical Memorandum NOS ORCA 111*	subsurface sediment	Puget Sound cores pre-industrial (1900) first detections; peaking in 1950s; leveling off to 100 (1980s)	R
Mauro et al. 2006	*Survey of the Distribution and Sources of PAHs in Urban Surface Soils*	soil	average 495; median 130 [p. 516, Table 1]	N
Partridge et al. 2005 (Ecology)	*Temporal Monitoring of Puget Sound Sediments: Results of the Puget Sound Ambient Monitoring Program 1989 - 2000*	surface sediment	Median of data collected from 1989 to 1996 was around 33 and mean was 143; during the 2000 sampling event median was 38 and mean was 100 [p.195, Table 9]. Abstract discusses increases in individual PAHs, total PAHs, and HPAHs over time in most water bodies sampled [p. xv]	R
Van Metre et al. 2000 as summarized in Yake 2001 (Ecology)	Urban Sprawl Leaves its PAH Signature In: *The Use of Sediment Cores to Track Persistent Pollutants in Washington State: A Review*	subsurface sediment	Lake Washington peak at 104 in 1973; Lake Ballinger increasing over time and 1,000-3,000 in upper depths [pp. 29 and 31, Fig. 15]	R
Van Metre and Mahler 2005 (USGS)	Trends in hydrophobic organic contaminants in urban and reference lake sediments across the United States, 1970-2001 (In:*ES&T, vol. 39: 5567-5574)*	subsurface sediment	1965 to 1975 median of 81 in all lakes, 580 in dense urban, and 50 in light urban; nondetect in reference areas [Table 1]	N
			post-1990 median of 350 in all lakes, 1,500 in dense urban, and 120 in light urban; nondetect in reference areas [Table 1]	N

Table J-4 Contaminant Concentrations Cited in Regional and National Trend Studies (continued)

Source	Study Title	Media	Concentrations Cited [page, figure, or table where cited]	Regional/ National
Dioxins / Furans (ng TEQ / kg dw)				
Cleverly et al. 1996 as summarized in Yake 2001 (Ecology)	A time-trends study of the occurrences and levels of CDDs, CDFs, and dioxin-like PCBs in sediment cores from 11 geographically distributed lakes in the United States In: *The Use of Sediment Cores to Track Persistent Pollutants in Washington State: A Review*	subsurface sediment	Concentrations in two Olympic Peninsula lakes (Ozette and Beaver) peaked around 2 (in mid 1950s); mid-1970s concentrations around 1 [p. 12]	R
EPA 2000 as reported in Windward 2010	*Exposure and Human Health Reassessment of 2,3,7,8-tertachlorodibenzo-p-dioxin (TCDD) and Related Compounds*	surface sediment	Eleven lakes and reservoirs removed from known sources; range was 0.12 to 16.3; mean was 5.3 [p. 523]	N
Integral 2008	*Toxic Equivalent Concentrations of TCDD in Source Sediments and Street Dirt*	street & catch basin dirt in LDW basin	Ten catch basin and manhole samples range from 6.2 to 26.3; mean of 16.8; one street dirt sample at 90.5; all samples collected in the LDW drainage basin [Table 2]	R
Rogowski et al. 1999 (Ecology)	*Final Report: Screening Survey for Metals and Dioxins in Fertilizer Products and Soils in Washington State*	soil	Concentrations range from 0.033 to 19; geometric mean ranged from 0.23 to 14 [Tables 3 and 4]	R
Yake et al. 2000 (Ecology)	Dioxins in Washington State Soils (In: *Dioxin 2000: 20th International Symposium on Halogenated Environmental Organic Pollutants & POPs, Monterey, CA. August 13-17, 2000. Volume 46, pp. 342-345)*	soil	In 14 urban samples, concentrations ranged from 0.13 to 19; in 70 samples from other land uses (forest, open, and agricultural) the range was 0.0078 to 5.2 [Table 2].	R

Notes:

CDD = chlorinated dibenzodioxin; CDF = chlorinated dibenzo-p-dioxin; Ecology = Washington State Department of Ecology; ES&T = Journal of Engineering, Science and Technology; HPAH = high molecular weight polycyclic aromatic hydrocarbon; µg/kg dw = micrograms per kilogram dry weight; mg/kg dw = milligrams per kilogram dry weight; NMFS = National Marine Fisheries Service; ng TEQ/kg dw = nanograms toxic equivalent per kilogram dry weight; N = national; NOAA = National Oceanic and Atmospheric Administration; NOS = National Ocean Service; ORCA = Office of Ocean Resources Conservation and Assessment; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyls; POPs = persistent organic pollutants; R = regional; TCDD= 2,3,7,8-tetrachlorodibenzo-p-dioxin; TPAH = total polycyclic aromatic hydrocarbon; TSP = Tacoma Smelter Plume; TSS = total suspended solids; USGS = U.S. Geological Survey

Table J-5a Duwamish/Diagonal Post-remedy ENR Data – Total PCBs, Arsenic, cPAHs, and BEHP

Station ID	Total PCBs (µg/kg dw)					Total PCBs (mg/kg oc)				
	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009
DUD_3C	1.5	29	80	141	109	n/a	n/a	6.5	11	6.8
DUD_4C	2.7	23	41	35	49	n/a	n/a	4.9	n/a	7.9
DUD_5C	3	26	39	39	34	n/a	4.4	5.2	7.5	2.8
DUD_6C	2	35	33	14	29	n/a	n/a	4.7	n/a	5.2
DUD_7C	2.9 U	6.4	78	57	47	n/a	n/a	5.7	4.9	2.8
DUD_14C	32	26	121	128	144	n/a	n/a	12	9.8	8.3
DUD_15C	1.4	12	43	70	31	n/a	n/a	2.8	6.5	1.9
Average by Year	*6.3*	*23*	*62*	*69*	*63*	*n/a*	*4.4*	*6.0*	*7.9*	*5.1*

Station ID	Arsenic (mg/kg dw)				
	2005	2006	2007	2008	2009
DUD_3C	1.5	2.9	9.4	9.0	10
DUD_4C	1.45	7.4	6	4.6	4
DUD_5C	1.35	3.5	5.5	4.7	7
DUD_6C	1.4	3.3	5.1	3.1	4.4
DUD_7C	1.45	7.05	10	8.4	11
DUD_14C	1.45	3.5	7.3	9.1	11
DUD_15C	1.45	3	9.6	9.1	10
Average by Year	*1.4*	*4.4*	*7.6*	*6.9*	*8*

Table J-5a Duwamish/Diagonal Post-remedy ENR Data – Total PCBs, Arsenic, cPAHs, and BEHP (continued)

Station ID	cPAHs (µg TEQ/kg dw)				
	2005	2006	2007	2008	2009
DUD_3C	4.6	58	108	150	62
DUD_4C	8.0	47	60	62	46
DUD_5C	9.0	47	70	84	45
DUD_6C	7.3	56	54	29	39
DUD_7C	4.5	16	106	69	38
DUD_14C	39	51	142	210	150
DUD_15C	2.1	26	81	160	44
Average by Year	*11*	*43*	*89*	*109*	*61*

Station ID	BEHP (µg/kg dw)					BEHP (mg/kg oc)				
	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009
DUD_3C	9.1	82	200	204	264 U	n/a	n/a	16	16	16.5 U
DUD_4C	13	64	91	121	519	n/a	n/a	11	n/a	83
DUD_5C	15	105	83	130	381 U	n/a	18	11	25	30.7 U
DUD_6C	12	93	74	66	151 U	n/a	n/a	11	n/a	27 U
DUD_7C	9.0	29	155	104	219 U	n/a	n/a	11	9.0	13 U
DUD_14C	70	82	165	222	274 U	n/a	n/a	16	17	15.7 U
DUD_15C	8.7	52	141	237	588 U	n/a	n/a	9.2	22	36.3 U
Average by Year	*20*	*72*	*130*	*155*	*208*	*n/a*	*18*	*12*	*18*	*22*

Notes:

1. The ENR sands were placed in February 2005 after capping of adjacent areas in 2004. Baseline ENR data were collected in March 2005, one month after placement.

n/a = not applicable because total organic carbon was not within appropriate range for normalizing concentrations or because location not sampled.

BEHP = bis(2-ethylhexyl)phthalate; cPAH = carcinogenic polycyclic aromatic hydrocarbons; ENR = enhanced natural recovery; µg/kg dw = micrograms per kilogram dry weight; mg/kg dw = milligram per kilogram dry weight; mg/kg oc = milligram per kilogram organic carbon; PCB = polychlorinated biphenyl; U = undetected value, one-half of this value was used in the percent change calculation

Table J-5b Duwamish/Diagonal Post-remedy Cap Data – Total PCBs, Arsenic, cPAHs, and BEHP

	Station ID	Total PCBs (µg/kg dw)						Total PCBs (mg/kg oc)					
		2004	2005	2006	2007	2008	2009	2004	2005	2006	2007	2008	2009
Cap A	DUD_1A	18.5	294	422	148	28	57	n/a	n/a	19	11	n/a	3.5
	DUD_2A	47	231	306	143	139	103	8.2	7.8	10	4.9	3.9	3.6
	DUD_3A	n/a	273	191	82	94	85	n/a	12	10	4.0	4.3	4.4
	DUD_4A	20	41	93	51	77	53	n/a	n/a	12	3.9	5.3	3.4
	DUD_5A	1.6	12	5.0	17	8.5	10	n/a	n/a	n/a	n/a	n/a	n/a
	Average by Year	*22*	*170*	*203*	*88*	*69*	*62*	*8*	*10*	*13*	*6*	*4*	*4*
Cap B	DUD_1B	120	94	118	99	166	58	n/a	14	6.7	7.0	11	3.2
	DUD_2B	80	74	70	67	115	45	n/a	5.7	4.6	3.4	5.4	2.5
	DUD_3B	31	n/a	49	62	130	22	n/a	n/a	2.7	3.0	5.7	1.2
	Average by Year	*77*	*84*	*79*	*76*	*137*	*41*	*n/a*	*10*	*5*	*4*	*7*	*2*
All	*Average by Year*	*45*	*146*	*157*	*84*	*95*	*54*	*8*	*9.9*	*9.3*	*5.3*	*6.0*	*3.1*

Table J-5b Duwamish/Diagonal Cap Post-remedy Data – Total PCBs, Arsenic, cPAHs, and BEHP (continued)

	Station ID	Arsenic (mg/kg dw)					
		2004	2005	2006	2007	2008	2009
Cap A	DUD_1A	1.5	5.7	5.5	4.8	3.4	6.6
	DUD_2A	1.5	11	15	14	16	14
	DUD_3A	n/a	9.9	14	12	14	12
	DUD_4A	1.5	1.7	5.2	6.0	7.4	7.6
	DUD_5A	1.5	1.5	7.3	5.2	2.4	3.1
	Average by Year	*1.5*	*5.9*	*9.4*	*8.4*	*8.7*	*8.7*
Cap B	DUD_1B	3.5	4.7	12	9	9.2	11
	DUD_2B	5.9	6.8	7.2	13	13	12
	DUD_3B	1.3	n/a	7.3	13	13	12
	Average by Year	*3.6*	*5.8*	*8.8*	*11.7*	*11.7*	*11.7*
All	*Average by Year*	*2.4*	*5.9*	*9.2*	*9.6*	*9.8*	*9.8*

	Station ID	cPAH (µg TEQ/kg dw)					
		2004	2005	2006	2007	2008	2009
Cap A	DUD_1A	65	668	931	247	66	410
	DUD_2A	86	471	463	292	410	220
	DUD_3A	n/a	562	312	120	290	250
	DUD_4A	57	93	158	165	440	210
	DUD_5A	20	14	13	31	29	62
	Average by Year	*57*	*362*	*375*	*171*	*247*	*230*
Cap B	DUD_1B	87	190	271	136	230	120
	DUD_2B	82	n/a	197	153	260	130
	DUD_3B	43	n/a	129	129	300	77
	Average by Year	*71*	*190*	*199*	*139*	*263*	*109*
All	*Average by Year*	*63*	*333*	*309*	*159*	*253*	*185*

Table J-5b Duwamish/Diagonal Post-remedy Cap Data – Total PCBs, Arsenic, cPAHs, and BEHP (continued)

	Station ID	BEHP (µg/kg dw)						BEHP (mg/kg oc)					
		2004	2005	2006	2007	2008	2009	2004	2005	2006	2007	2008	2009
Cap A	DUD_1A	442	5490	3660	1210	722	876	n/a	n/a	161	87	n/a	54
	DUD_2A	374	2360	2210	1990	1870	974	65.3	80	74	68	52	34
	DUD_3A	n/a	1520	835	426	1100	527	n/a	65	45	21	51	27
	DUD_4A	140	272	709	851	1110	620	n/a	n/a	92	65	77	40
	DUD_5A	17	24	8.8	74	76	52 U	n/a	n/a	n/a	n/a	n/a	n/a
	Average by Year	*243*	*1,933*	*1,485*	*910*	*976*	*749*	*65*	*73*	*93*	*60*	*60*	*39*
Cap B	DUD_1B	158	255	567	229	417	269	n/a	38	32	16	28	15
	DUD_2B	168	181	498	436	707	301	n/a	14	33	22	33	17
	DUD_3B	89	n/a	460	502	991	303	n/a	n/a	25	25	44	17
	Average by Year	*138*	*218*	*508*	*389*	*705*	*291*	n/a	*26*	*30*	*21*	*35*	*16*
All	*Average by Year*	*198*	*1,443*	*1,118*	*715*	*874*	*553*	*65*	*49*	*66*	*43*	*47*	*29*

Notes:

1. Dredging and capping occurred in 2003 and 2004. ENR sands were placed in February 2005. Baseline data were collected in June 2004, approximately four months after cap placement.
2. Underlined values exceed the Sediment Quality Standard (12 mg/kg oc for total PCBs; 47 mg/kg oc for BEHP). All arsenic post-cap monitoring data were below the SQS.

n/a = not applicable because total organic carbon was not within appropriate range for normalizing concentrations or because location was not sampled.

BEHP = bis(2-ethylhexyl)phthalate; cPAH = carcinogenic polycyclic aromatic hydrocarbons; µg/kg dw = micrograms per kilogram dry weight; ng TEQ / kg dw = nanograms toxic equivalent per kilogram dry weight; mg/kg oc = milligram per kilogram organic carbon; PCB = polychlorinated biphenyl; U = undetected value, one-half of this value was used in the percent change calculation

Table J-6 Post-Remedy Total PCBs and Total Organic Carbon in the Norfolk Area

Norfolk CSO/SD

Month-Year	Total PCBs (µg/kg dw)					Total Organic Carbon (%)			
	NFK501	NFK502	NFK503	NFK504	Average by Year	NFK501	NFK502	NFK503	NFK504
Oct-99	21	71	190	5.7	72	0.3	0.4	0.3	0.2
Apr-00	508	10	180	13	178	0.2	0.1	0.2	0.3
Apr-01	36	94	1330	31	373	0.9	0.5	0.4	0.9
Apr-02	174	4.9	777	52	252	2.1	0.1	2.6	1.3
Apr-03	90	21	193	4.7	77	2.2	0.3	2.4	0.1
Apr-04	470	5	470	5.3	238	0.3	0.2	2.6	0.3
Oct-06	67	13.5	50	9.0	35	2.7	1.7	2.1	1.4
May-08	7.0	3.6	—	2.2	4.3	5.4	0.7	—	1.9

Boeing Developmental Center South Storm Drain

Month-Year	Total PCBs (µg/kg dw)						Total Organic Carbon (%)				
	S01	S01 duplicate	S02	S02 duplicate	S03	Average by Year[a]	S01	S01 duplicate	S02	S02 duplicate	S03
Sep-04	27	—	19 U	19 U	20 U	16	0.2	—	0.3	0.1	0.2
Nov-05	353	32 U	31 U	—	31 U	72	1.6	1.5	1.3	—	0.5
Jun-07	280	163	19 U	—	20 U	80	1.7	2.2	1.3	—	1.2
Sep-07	138	204	20 U	—	19 U	64	1.0	1.2	0.8	—	1.6
Feb-09	33 U	32 U	32 U	—	32 U	32 U	1.7	2.6	1.4	—	1.7
Sep-09	1,310	840[b]	32 U	—	33 U	370	3.9	14.2	1.6	—	3.1

Notes:

1. Only PCBs were analyzed on the Boeing Developmental Center south storm drain cap.
2. Norfolk dredging and backfilling occurred in 1999; Boeing Developmental Center dredging and capping occurred in 2003.

a. Average calculated by first calculating location-specific averages (average of parent and duplicate), then by averaging resulting data with other location data. One-half of the reporting limit was used for undetected data.

b. Although this dry weight value is an exceedance of the SQS, when this value is oc-normalized, the resulting value, 6 mg/kg oc, is not an exceedance of the SQS.

U = not detected at reporting limit listed.

— = not sampled or not analyzed.

CSO/SD = combined sewer overflow/ storm drain; µg/kg dw = micrograms per kilogram dry weight; mg/kg oc = milligrams per kilogram organic carbon; PCB = polychlorinated biphenyl

Table J-7 Surface Sediment Human Health Risk-Driver Data Collected More than Five Years after Dredging in Berthing Areas

Location	River Mile	Sampling Event	Year Sampled	Total PCBs (µg/kg dw)	Total PCBs (mg/kg oc)	Arsenic (mg/kg dw)	cPAHs (µg TEQ/kg dw)	Dioxins/ Furans (ng TEQ/kg dw)	Dredge Year	Years Elapsed
LDW-SS307	0.2	LDWRI Round 3	2006	231	11	14	960	n/a	1980	26
DR003	0.2	EPA SI	1998	267	13	12	600	n/a	1980	18
DR004	0.3			168	6.6	11	440	n/a		
EST232	0.3	NOAA Site Characterization	1997	140	8.4	n/a	n/a	n/a	1980	17
TRI-056T	1.4	Ecology SPI	2006	170	6.2	15	360	n/a	1993	13
SPI-125	1.8			240	8.8	18	380	n/a		
LDW-SS55	1.4	LDWRI Round 1	2005	24	1.6	17	190	n/a	1993	12
LDW-SS53	1.4	LDWRI Round 2	2005	220	8.3	40	670	n/a	1993	12
SG22	2.9	Slip 4 – Early Action	2004	145	5.2	n/a	n/a	n/a	1992	12
LDW-SS63	1.7	LDWRI Round 1	2005	95	4.0	10	190	n/a	1994	11
Average of data with more than 10 years elapsed				*196*	*8*	*18*	*457*	*n/a*		
DR-181	2.9	Ecology SPI	2006	460	14	20	320	n/a	1996	10
TRI-095T	2.7			97	4.1	13	220	n/a	1998	8
LDW-SS336	2.7	LDWRI Round 3	2006	190	9.1	14	300	n/a	1998	8
SG14	2.8	Slip 4 – Early Action	2004	200	7.2	n/a	n/a	n/a	1996	8
SG16				126	15	n/a	n/a	n/a		
SG18				130	4.1	n/a	n/a	n/a		
SG20				179	5.8	n/a	n/a	n/a		
SG21				158	5.3	n/a	n/a	n/a		
SG24				99	3.4	n/a	n/a	n/a		
SG25				116	4.6	n/a	n/a	n/a		
SG27				77	2.5	n/a	n/a	n/a		

Table J-7 Surface Sediment Human Health Risk-Driver Data Collected More than Five Years after Dredging in Berthing Areas (continued)

Location	River Mile	Sampling Event	Year Sampled	Total PCBs (µg/kg dw)	Total PCBs (mg/kg oc)	Arsenic (mg/kg dw)	cPAHs (µg TEQ/kg dw)	Dioxins/ Furans (ng TEQ/kg dw)	Dredge Year	Years Elapsed
LDW-SS95	2.7	LDWRI Round 2	2005	198	7.5	17	3,100	n/a	1998	7
WRC-SS-B1	2.5	Boyer Towing	2004	10	1.2	7 U	110	n/a	1998	6
WRC-SS-B2				23	1.6	10 U	410	n/a		
WRC-SS-B3				18	n/a	6 U	77	n/a		
Average of data with 6 - 10 years elapsed				*116*	*6*	*15*	*703*	*n/a*		
DR121	1.4	EPA SI	1998	98	4.1	6	160	8.1	1993	5
DR126	1.5			181	5.9	18	350	n/a		
DR092	1.6			64	9.1	13	630	n/a		
DR154	1.8			101	4.3	11	230	12		
DR205	3.4			35	1.6	10	78	n/a		
DR227				25	1.3	8	82	n/a		
WST325	3.0	NOAA Site Characterization	1997	110	5.9	n/a	n/a	n/a	1992	5
Average of data with 5 years elapsed				*88*	*5*	*11*	*255*	*10*		
Average of all data (n = 32)				*137*	*6.1*	*15*	*469*	*10*		

Notes:

1. All total PCBs, cPAHs, and dioxin/furan data were detected. The three arsenic data with "U" qualifiers were not detected and are listed at the reporting limit.

Ecology = Washington State Department of Ecology; EPA = Environmental Protection Agency; LDWRI = Lower Duwamish Waterway Remedial Investigation; µg TEQ/kg dw = micrograms per kilogram toxic equivalent dry weight; mg/kg oc = milligrams per kilogram organic carbon; n/a = risk driver not analyzed in sample; ng TEQ /kg dw = nanograms toxic equivalent per kilogram dry weight; NOAA = National Oceanic and Atmospheric Administration; PCBs = polychlorinated biphenyls; SI = site investigation; SPI = sediment profile imaging

Table J-8 Model-predicted Minimum Lateral Percentage of Lateral Source Sediment Required to Result in Year 10 Concentrations >SQS

Risk Driver	Unit (dw)	BCM Input Parameters		SQS[a] (dw)	SQS (mg/kg oc)	Year 10 Lateral Percentage Needed in the Sediment Bed to Exceed SQS in 10 Years[b]
		Upstream	Lateral			
SMS Contaminants						
Acenaphthene	µg/kg	8	209	320	16	N/P
Bis(2-ethylhexyl)phthalate		120	15,475	940	47	5.4
Butyl benzyl phthalate		11	972	98	4.9	9.1
Chrysene		49	1,807	2,200	110	N/P
Fluoranthene		190	3,989	3,200	160	79.5
Indeno(1,2,3-cd)pyrene		31	675	680	34	N/P
Phenanthrene		53	2,010	2,000	100	99.7
Phenol		10	237	420	n/a	N/P
Total PCBs (recommended BCM input)		35	300	240	12	98.2
Total PCBs (high lateral BCM input)		35	1,000	240	12	21.5
Arsenic (recommended BCM input)	mg/kg	9	13	57	n/a	N/P
Arsenic (high lateral BCM input)		9	30	57	n/a	N/P
Mercury		0.10	0.14	0.41	n/a	N/P
Zinc		64	626	410	n/a	62.2
Other						
cPAH (mid BCM inputs)	µg TEQ/kg dw	70	1,400	1,000[c]	n/a	70.2
cPAH (mid upstream BCM input and high lateral BCM input)		70	3,400	1,000[c]	n/a	28.1

Notes:

a. Concentration in dry weight (dw) units or dw equivalent for oc-normalized SQS using 2% TOC conversion from SQS oc-normalized values.
b. In receiving sediment STM grid cell
c. AOPC 1 cPAH site-wide RAL used, but grid cells predicted to exceed for cPAH not shown on Figures J-9a and J-9b.

$(Bed_c*Bed_f)+(Lat_c*Lat_f)+(Up_c*Up_f) = SQS$ (Year 10 Concentration)

Assume upstream percentage plus lateral percentage = 94 (because average Year 10 bed percentage is 6).

Assume bed concentration is zero. Solve for lateral fraction (Lat_f).

$(SQS - 0.94Up_c) / (Lat_c - Up_c) = Lat_f$

Orange shading = likelihood of recontamination based on lateral percentage below 30.

AOPC = area of potential concern; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbons; mg/kg oc = milligrams per kilogram organic carbon; N/P= not possible to exceed SQS because BCM lateral input parameter <SQS; RAL = remedial action level SQS = sediment quality standards; TOC = total organic carbon

Table J-9 Contaminant Concentrations Cited in Atmospheric Studies

Source	Study Title	Media	Concentrations Cited	Study Location
Gingrich et al. 2001	Atmospherically Derived Organic Surface Films along an Urban-Rural Gradient (In: *ES&T*, vol. 35, 4031-4037)	organic surface films	Surface films (concentrations from rural to urban) PCBs 1.8 to 95 ng/m^2 TPAHs 210 to 6,100 ng/m^2	Toronto, Ontario, Canada
Jamshidi et al. 2007	Concentrations and Chiral Signatures of Polychlorinated Biphenyls in Outdoor and Indoor Air and Soil in a Major U.K. Conurbation (In: *ES&T*, vol. 41, 2153-2158)	air, soil	PCBs in surface soils range 0.36 to 13.3 µg/kg dw at city center; up to 0.4 mg/kg oc. In air, PCBs average concentrations range from <100 in rural areas to 600 pg/m^3 at the city center.	West Midlands, U.K.
King County 2008	*Passive Atmospheric Deposition Sampling. Lower Duwamish Waterway. Monitoring Report* – October 2005 to April 2007	wet and dry deposition	PCBs were detected in the industrialized areas at flux rates on the order of 0.01 to 0.06 µg/m^2/day; BEHP on the order of 2 µg/m^2/day; B(a)P on the order of 0.06 µg/m^2/day (median).	Duwamish Valley and Beacon Hill, King County, WA
Offenberg and Baker 1997	Polychlorinated Biphenyls in Chicago Precipitation: Enhanced Wet Deposition to Near-Shore Lake Michigan (In: *ES&T*, vol. 31, 1534-1538)	rain water	PCBs in Chicago precipitation: 4.1 ng/L to 189 ng/L. Precipitation falling over Lake Michigan: 2 to 360 times greater than the regional background concentrations measured at South Haven, MI (0.17 and 0.02 ng/L, July 20 and 21, 1994). PCBs in rainwater from the rural site were lower than the volume-weighted mean PCB concentration measured by the IADN network at Sleeping Bear Dunes, MI (1.05+/-0.23 ng/L), suggesting that the regional background signal was sampled at South Haven. Volume-weighted mean at 3 locations (Chicago, IL; Lake Michigan; South Haven, MI) were 29.3, 5.8, and 0.1 ng/L, respectively.	Chicago, IL
Simcik et al. 1997	Urban Contamination of the Chicago/Coastal Lake Michigan Atmosphere by PCBs and PAHs during AEOLOS (In: *ES&T*, vol. 31, 2141-2147)	air	TPAHs and PCBs in Chicago were approximately 4 times the concentration measured over Lake Michigan. The gas phase PAHs are dominated by phenanthrene and fluorene, while the particulate phase is dominated by benzofluoranthenes, chrysene, fluoranthene, and pyrene. Total PCBs in Chicago (urban) range from 270 to 14,200 pg/m^3 and are highest during July.	Chicago, IL

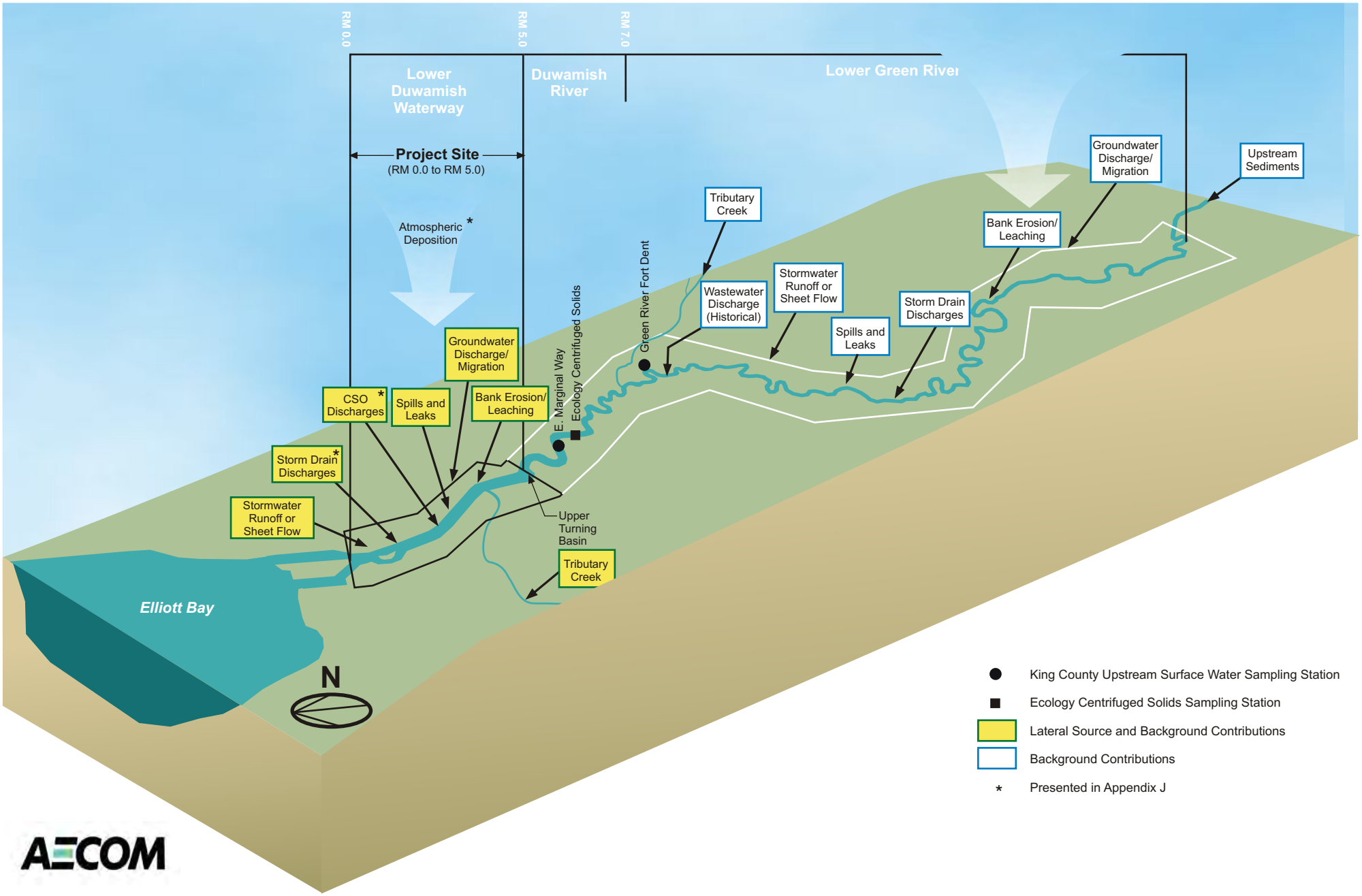
Table J-9 Contaminant Concentrations Cited in Atmospheric Studies (continued)

Source	Study Title	Media	Concentrations Cited	Study Location
Totten et al. 2006	Measurement and modeling of urban atmospheric PCB concentrations on a small (8 km) spatial scale (In: *Atmospheric Environment*, vol. 40, 7940-7952)	air	During a year of simultaneous sampling, average gas-phase total PCB concentrations were 1,600 pg/m^3 at Bayonne and 930 pg/m^3 at Jersey City. These concentrations are typical of those measured over a longer time period (Oct. 1998 to Jan. 2001) for Jersey City: average 1,260 pg/m^3. Concentrations of gas-phase total PCB measured at more remote regions of New Jersey average 150 to 220 pg/m^3.	NJ
Wethington III and Hornbuckle 2005	Milwaukee, WI as a Source of Atmospheric PCBs to Lake Michigan (In: *ES&T*, vol. 39, 57-63)	air	The average PCB gas-phase concentration in Milwaukee was 1,900 pg/m^3, similar to other urban areas and higher than background levels. IADN reports gas-phase concentrations of 620, 2,700, and 1,600 pg/m^3 for 3 samples collected in Chicago. 1996, Baltimore, 20 to 3,400 pg/m^3. 1997 to 1999, suburban New Jersey, 86 to 2,300 pg/m^3. Gas-phase PCB concentrations measured during the Milwaukee study are about 8 times higher than atmospheric concentrations in air collected over Lake Michigan.	Milwaukee, WI

Notes:

AEOLOS = Atmospheric Exchange Over Lakes and Oceans Study; B(a)P = benzo(a)pyrene; BEHP = bis(2-ethylhexyl)phthalate; ES&T = Journal of Engineering, Science and Technology; IADN = Integrated Atmospheric Deposition Network; µg/kg dw = micrograms per kilogram dry weight; mg/kg oc = milligrams per kilogram organic carbon; ng/L = nanograms per liter; ng/m^3 = nanograms per cubic meter; ng/m^2 = nanogram per square meter; oc = organic carbon normalized; PCBs = polychlorinated biphenyls; pg = picograms; TPAH = total polycyclic aromatic hydrocarbon

Figure J-1 Conceptual Model of External Sources of Recontamination



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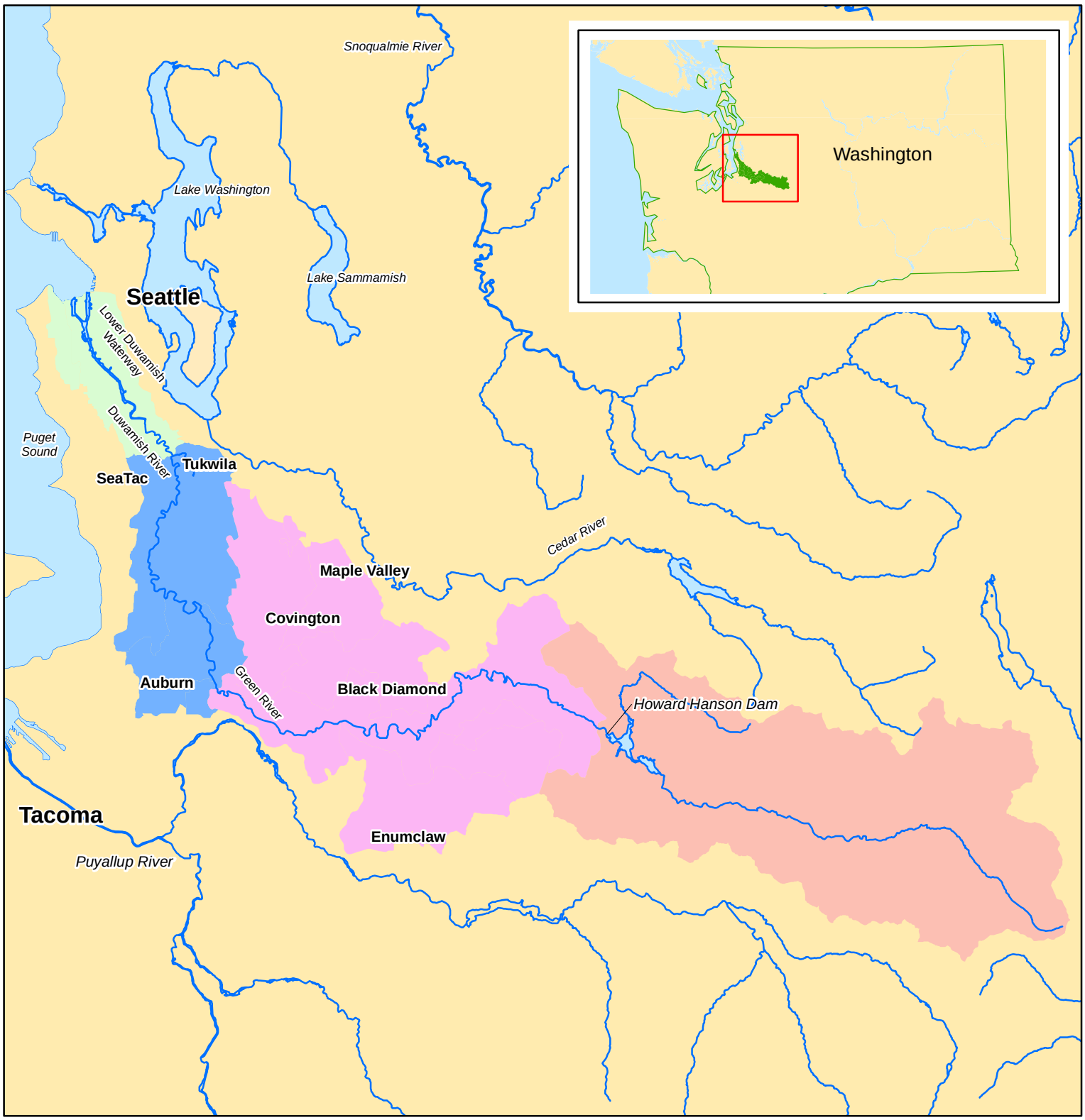

Notes:
1. Subwatersheds derived from the major hydrological basin boundaries as defined by King County Dept of Natural Resources and Parks, Water and Lands Resource Division (King County 2005).

Legend

Duwamish/Green River Subwatershed

- Upper Green River
- Middle Green River
- Lower Green River
- Duwamish Estuary

- River/Stream
- Water Body

0 1.25 2.5 5 Miles

N

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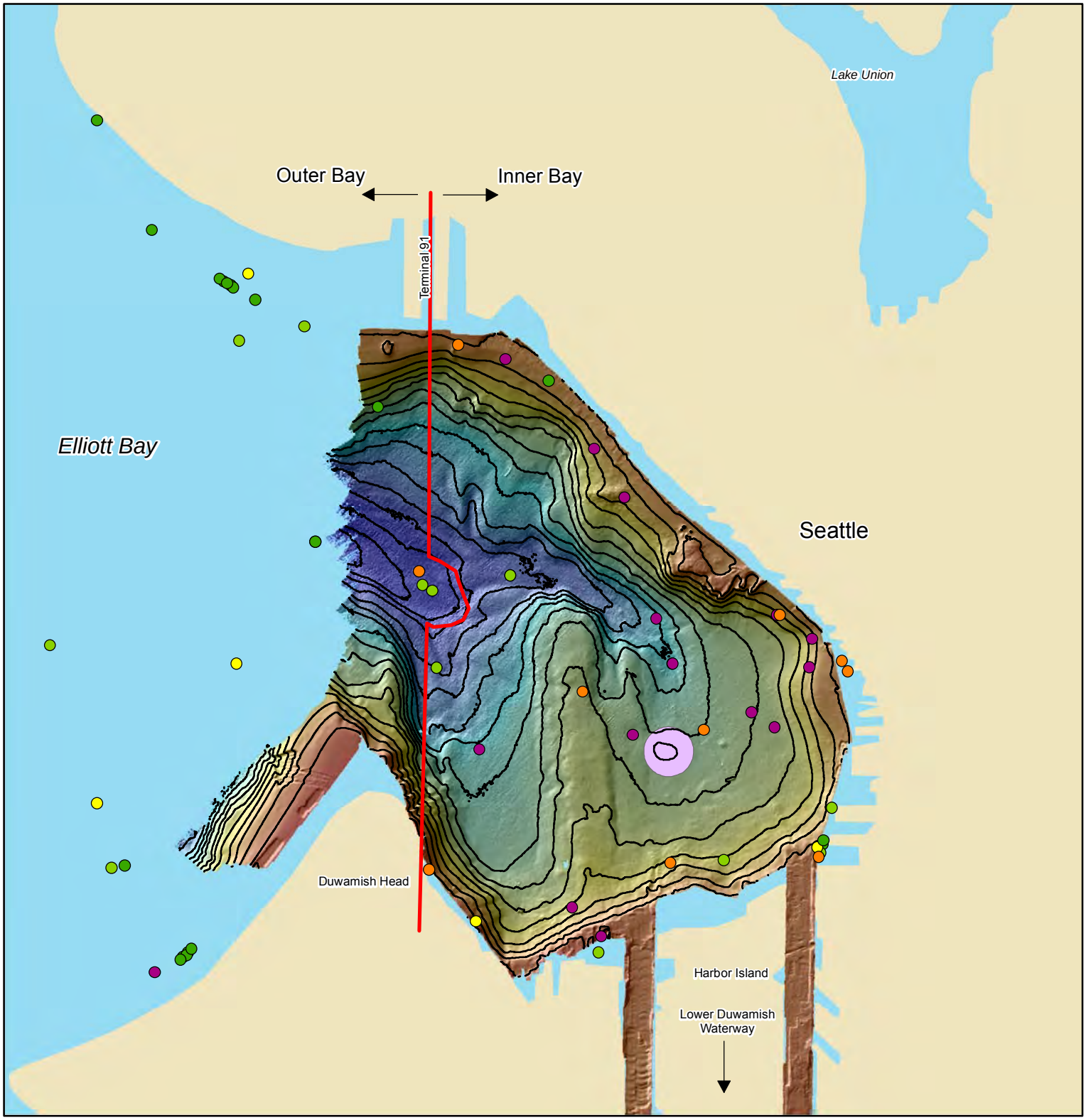
Lower Duwamish Waterway Final Feasibility Study 60150279-14.49			**Subwatersheds of the Green/Duwamish River Watershed**
DATE: 10/31/12	DWRN:MVI/sea	Revision: 0	**FIGURE J-2**

L:\Lower Duwamish FS\FS_Final_GIS\Oct2012\FS_GIS_MXDs_Oct12\Appendix J\FigureJ-2Watershed.mxd



Notes:
1. Bathymetric survey from 2001 NOAA Multibeam Mapping of the Major Deltas of the Southern Puget Sound, Washington.
2. Inner Elliott Bay defined as stations east of line from Duwamish Head to Terminal 91, with the exception of three stations at elevations below -150 m, MLLW.
3. Stations within 250 ft of the shoreline, on the open-water disposal site, and associated with listed MTCA or CERCLA sites are excluded.
4. The Open Water Dredged Material Disposal Site Target Area was generated using the location (Long: 122° 21.45, Lat: 47° 35.91 NAD83) and extent (1,200-ft radius circle) in Figure 11-2 of the 2008 Dredged Material Evaluation and Disposal Procedures manual (USACE 2008).

Legend

Total PCBs in Surface Sediment (µg/kg dw)

- ≤ 10
- > 10 - 50
- > 50 - 100
- > 100 - 200
- > 200

Mudline Elevation (meters, MLLW)

Value

High : -1.74992

Low : -179.795

Mudline Elevation (meters, MLLW)

Open Water Dredged Material Disposal Site Target Area

Miles
0 0.1 0.2 0.4

N

AECOM

Lower Duwamish Waterway Group

Lower Duwamish Waterway Final Feasibility Study 60150279-14.49			Inner and Outer Elliott Bay Total PCB Stations
DATE: 10/31/12	DWRN:MVI/sea	Revision: 0	FIGURE J-3

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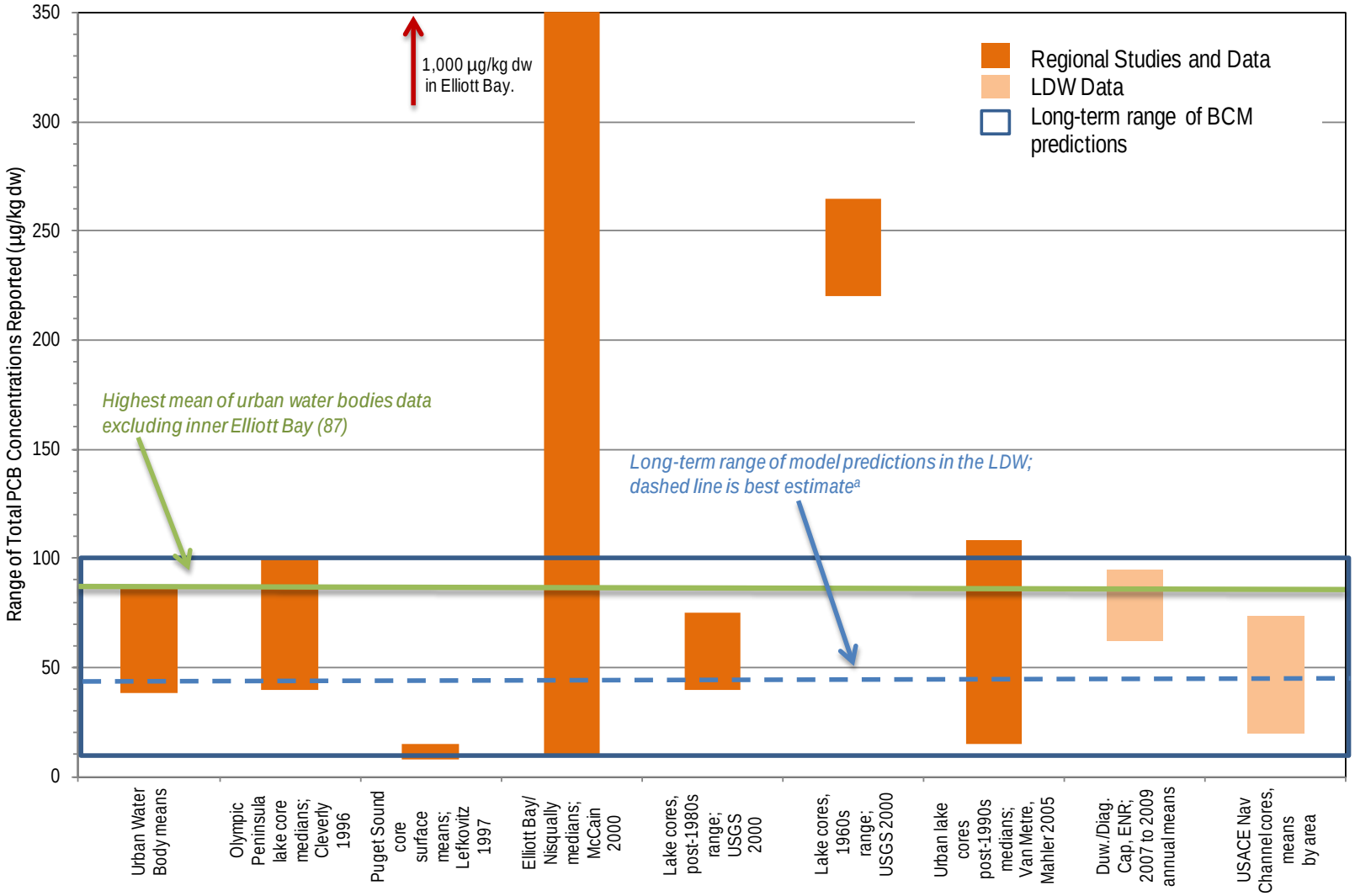
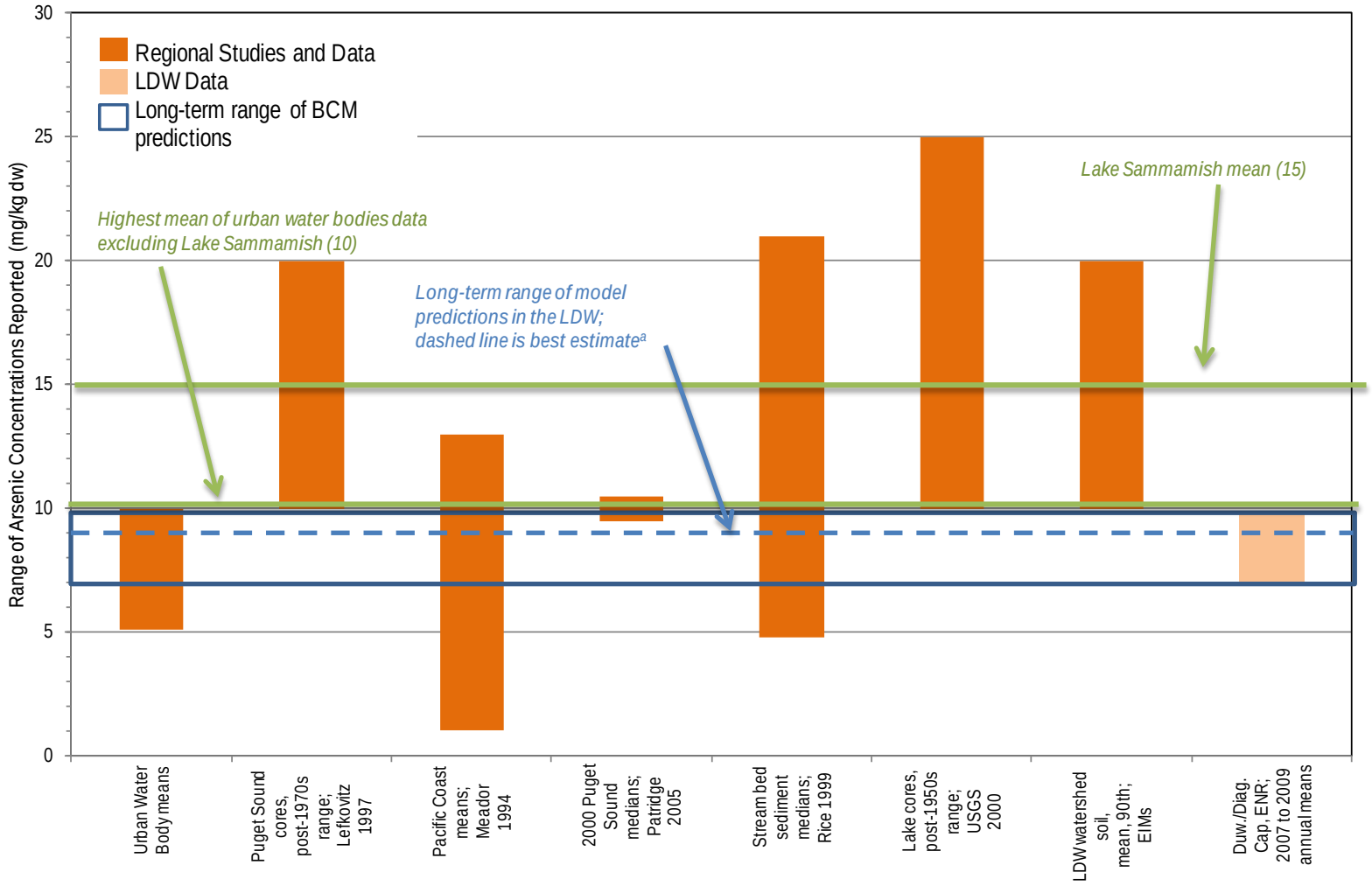
Figure J-4a Regional and Local Range of Total PCB Concentrations



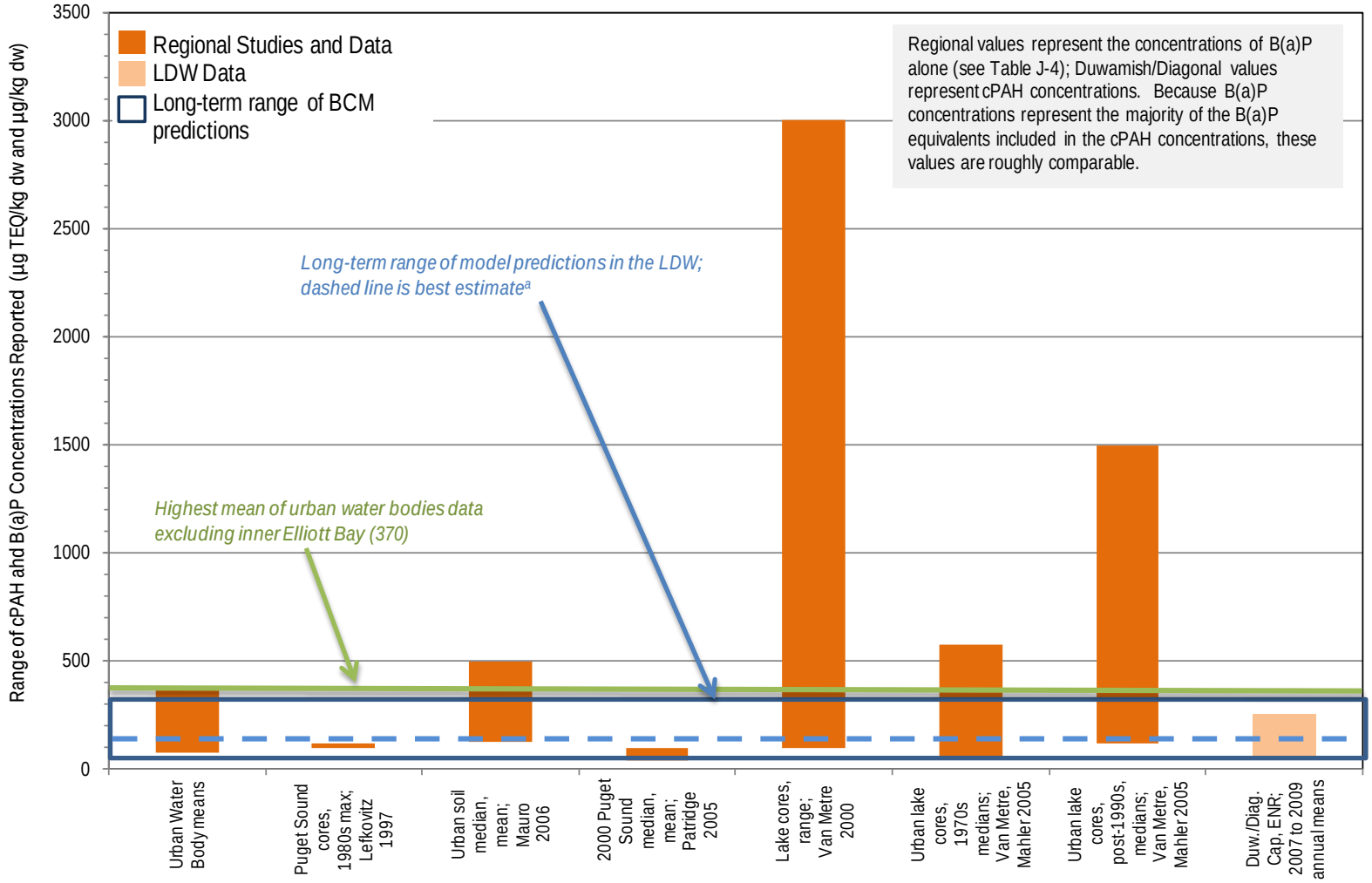
Notes: 1. Media are surface sediments, unless otherwise noted. See Tables J-1, J-4, J-5a, and J-5b for data.
a. Long-term range of BCM predictions is based on the 45-year site-wide SWAC after remediation of Alternative 6R, using the low and the high input parameters.

Figure J-4b Regional and Local Range of Arsenic Concentrations



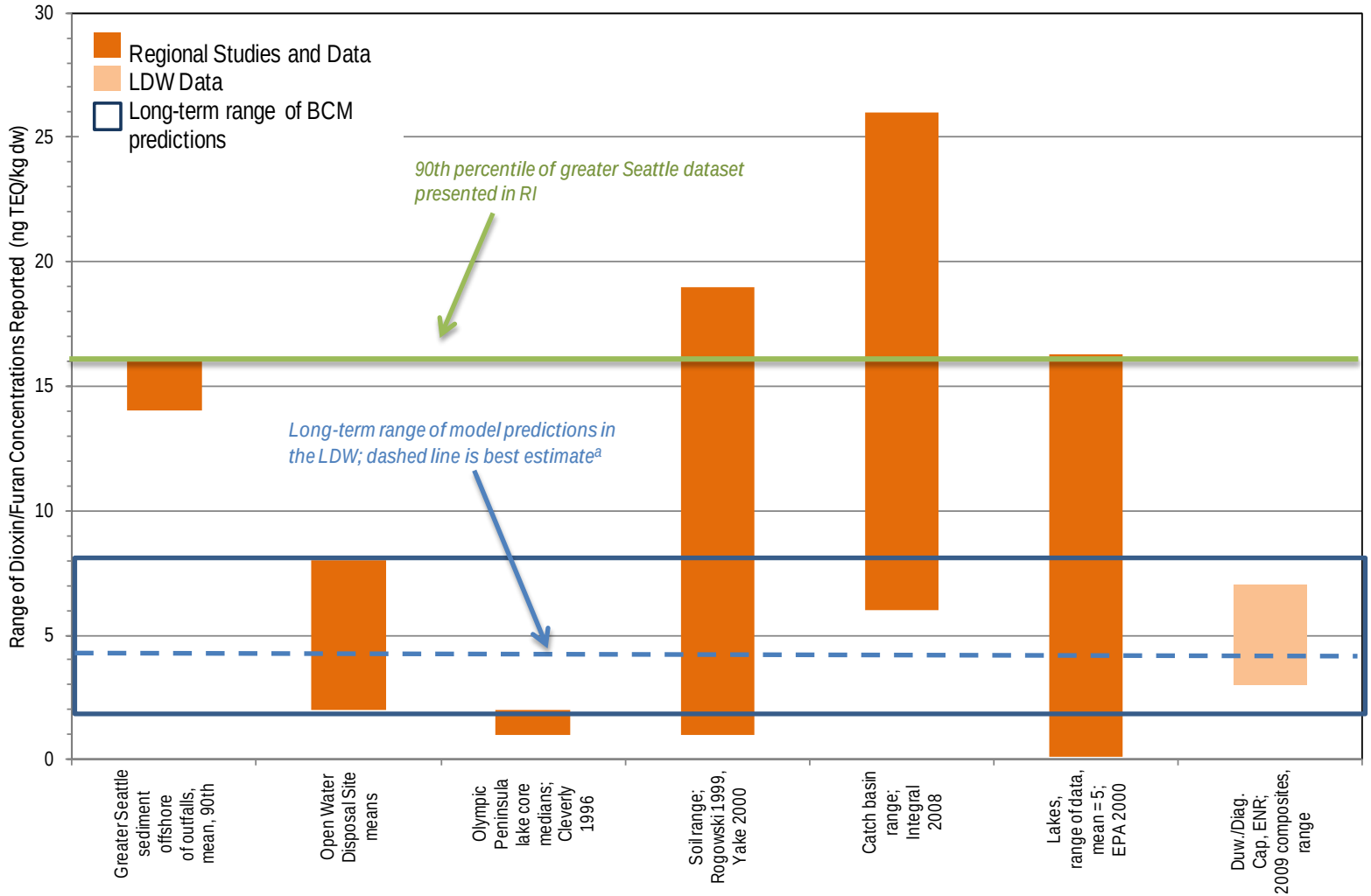
Notes: 1. Media are sediments, unless otherwise noted. See Tables J-1, J-4, J-5a, and J-5b for data.
a. Long-term range of BCM predictions is based on the 45-year site-wide SWAC after remediation of Alternative 6R, using the low and the high input parameters.

Figure J-4c Regional and Local Range of cPAH and B(a)P Concentrations

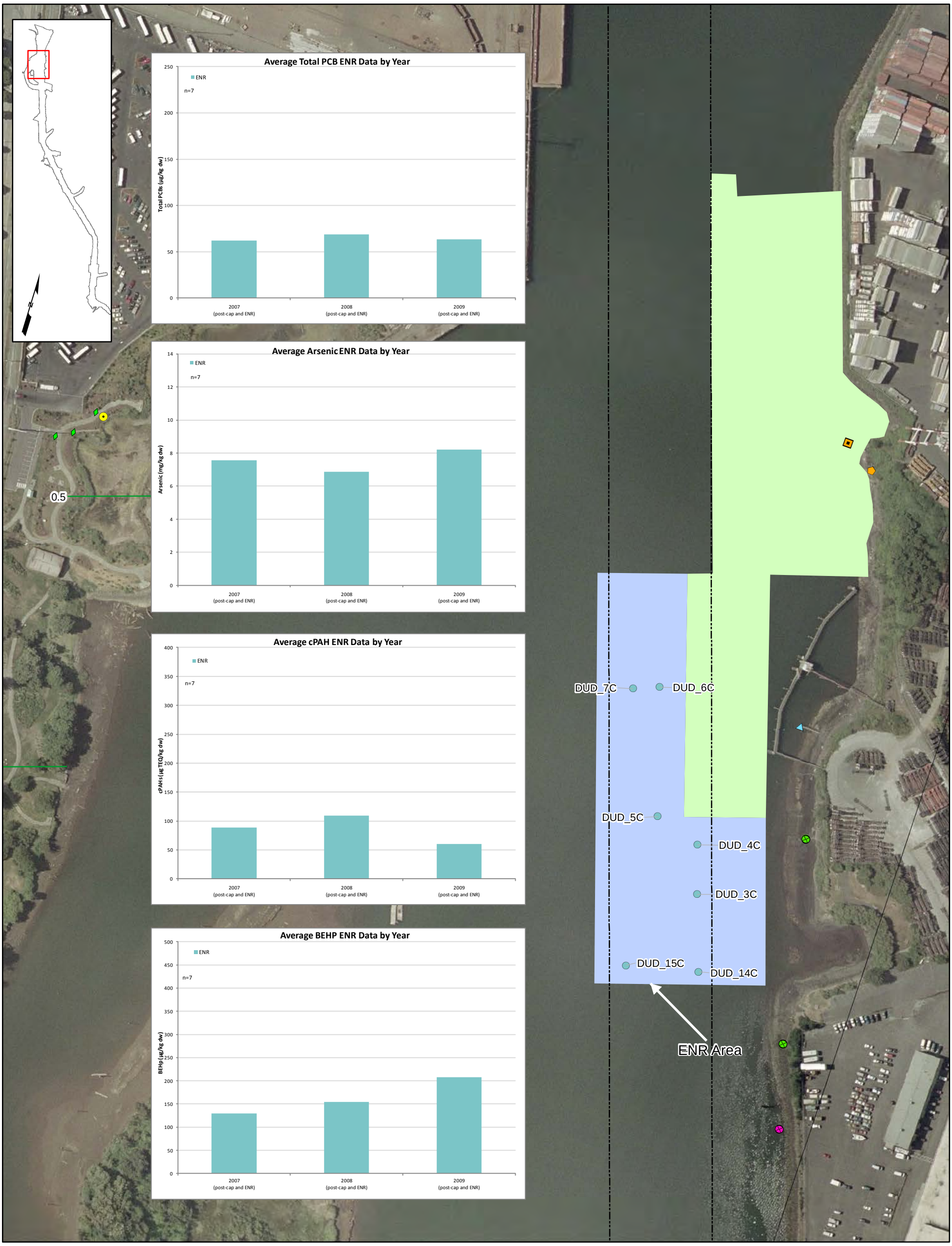


Notes: 1. Media are sediments, unless otherwise noted. See Tables J-1, J-4, J-5a, and J-5b for data.
a. Long-term range of BCM predictions is based on the 45-year site-wide SWAC after remediation of Alternative 6R., using the low and the high input parameters.

Figure J-4d Regional and Local Range of Dioxin/Furan Concentrations



Notes: 1. Media are sediments, unless otherwise noted. See Tables J-2, J-3, and J-4 for data.
a. Long-term range of BCM predictions is based on the 45-year site-wide SWAC after remediation of Alternative 6R, using the low and the high input parameters.



Notes:
1. USGS 2002 photograph provided by Windward Environmental.
2. CSO= combined sewer overflow; EOF= emergency overflow; ENR= enhanced natural recovery.
3. A 2009 dioxin/furan composite sample on the ENR area had a concentration of 3.3 ng TEQ/kg dw.
4. Cap data are shown on Figure J-5b.
5. Data from 2005 and 2006 not shown because storm drain cleaning caused elevated concentrations in 2006. The 2007 through 2009 data shown are more indicative of recontamination potential.

Outfall Location

- Private storm drain
- Permitted private storm drain
- Public storm drain
- CSO/storm drain
- EOF
- Abandoned
- Pipe of unresolved origin and/or use

Legend

- Dredge and Cap (2003-2004)
- Thin-layer Sand Placement; ENR (2005)

Sampling Location

- ENR
- River Mile Marker
- Navigation Channel

0 120 240 480 Feet

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Post-Remedy Surface Sediment Averages Over Time on the Duwamish/Diagonal ENR Area

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FIGURE J-5a

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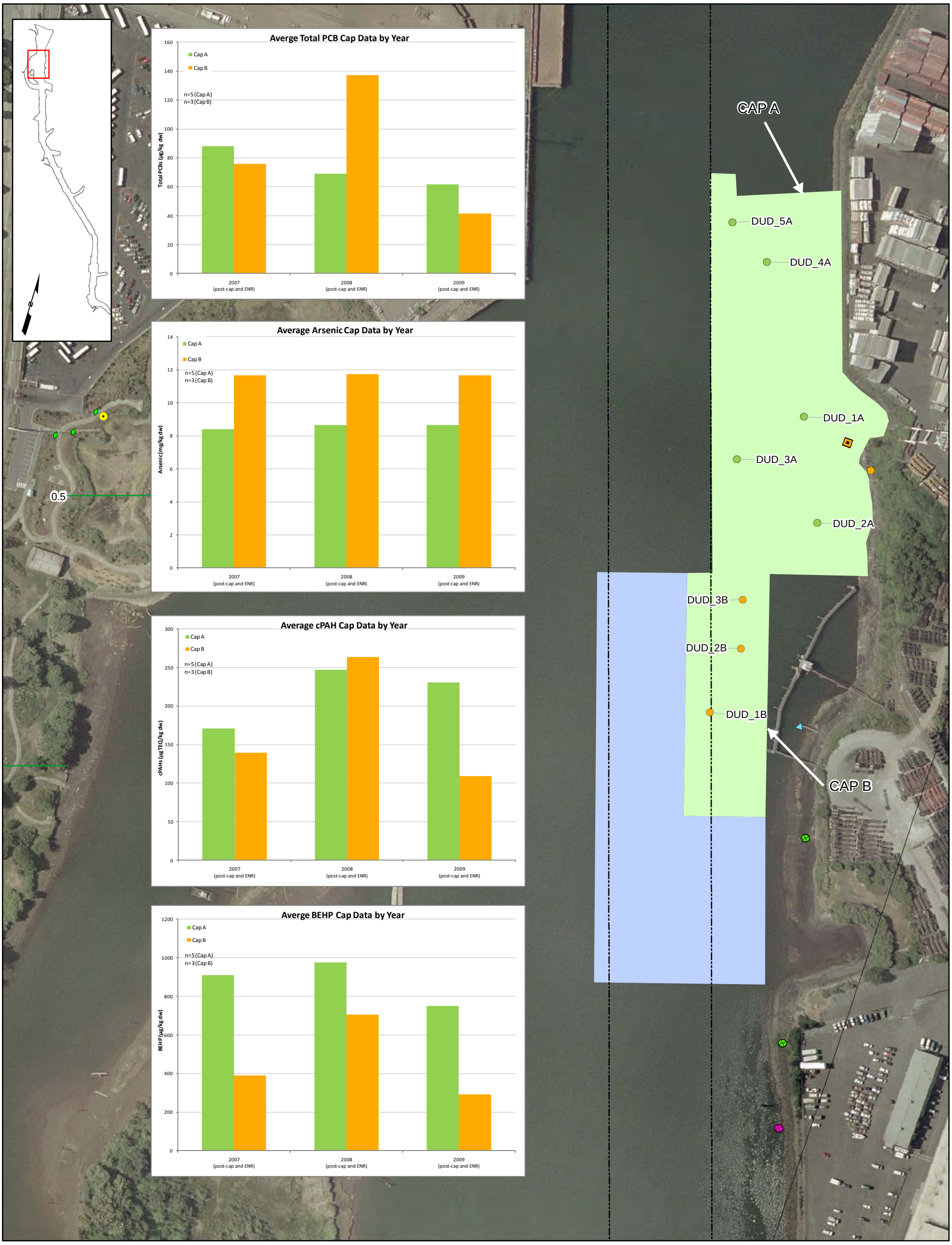

Notes:
1. USGS 2002 photograph provided by Windward Environmental.
2. CSO= combined sewer overflow; EOF= emergency overflow; ENR= enhanced natural recovery.
3. Two dioxin/furan composite samples on Caps A and B had concentrations of 7.0 and 5.1 ng TEQ/kg dw, respectively.
4. ENR data are shown on Figure J-5a.
5. Data from 2005 and 2006 not shown because storm drain cleaning caused elevated concentrations in 2006. The 2007 through 2009 data shown are more indicative of recontamination potential.

Outfall Location

- Private storm drain
- Permitted private storm drain
- Public storm drain
- CSO/storm drain
- EOF
- Abandoned
- Pipe of unresolved origin and/or use

0 120 240 480 Feet

Legend

- Dredge and Cap (2003-2004)
- Thin-layer Sand Placement; ENR (2005)

Sampling Location

- Cap A
- Cap B

- River Mile Marker
- Navigation Channel

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Post-Remedy Surface Sediment Averages Over Time on the Duwamish/Diagonal EAA Caps

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

FIGURE J-5b

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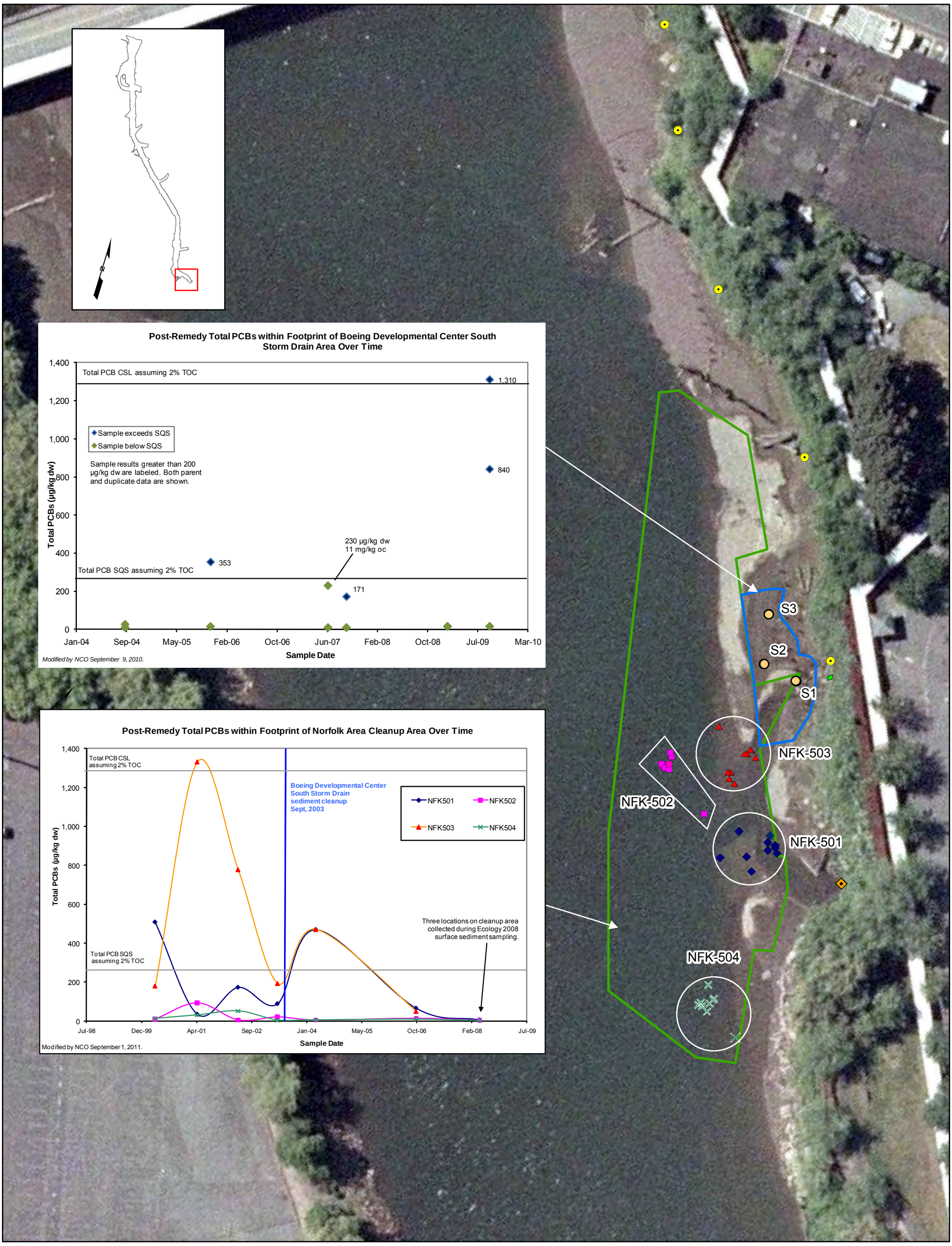

Notes:
1. USGS 2002 photograph provided by Windward Environmental.
2. Data in the FS Access database.
3. Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System (NPDES) permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and LDWG personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications.
4. CSO = combined sewer overflow, BDC SSD = Boeing Developmental Center south storm drain, SD = storm drain.

Outfall Location

- CSO/SD
- Permitted private storm drain
- Pipe of unresolved origin and/or use

0 25 50 100 Feet

Legend

- Boeing Developmental Center (BDC) South Storm Drain Sediment Cleanup Area (2003)
- BDC SSD Sample Location
- Norfolk CSO/SD Sediment Cleanup Area (1999)
- NFK501 Sample Location
- NFK502 Sample Location
- NFK503 Sample Location
- NFK504 Sample Location

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Post-Remedy Surface Sediment Total PCB Trends at Norfolk Area

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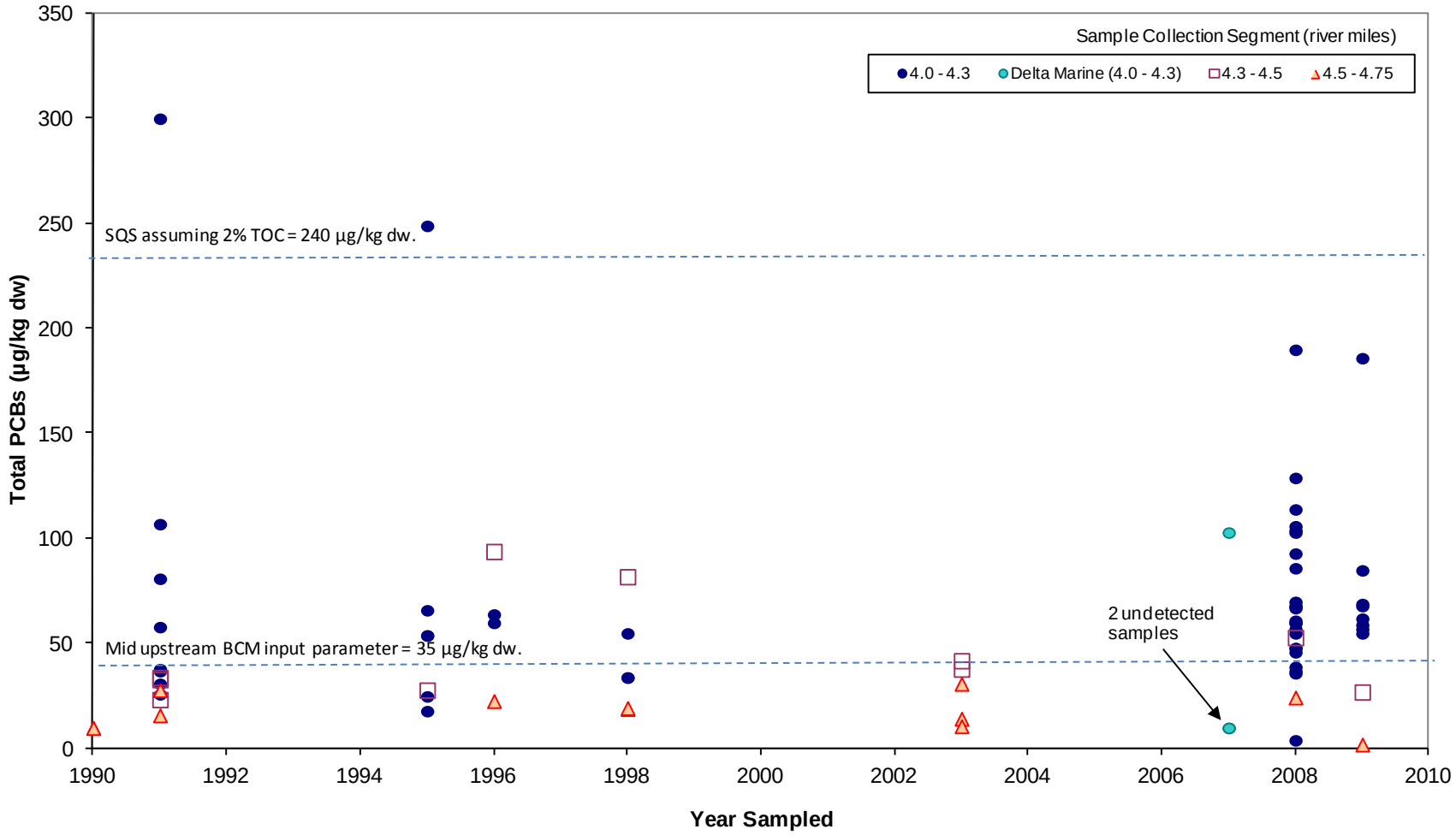
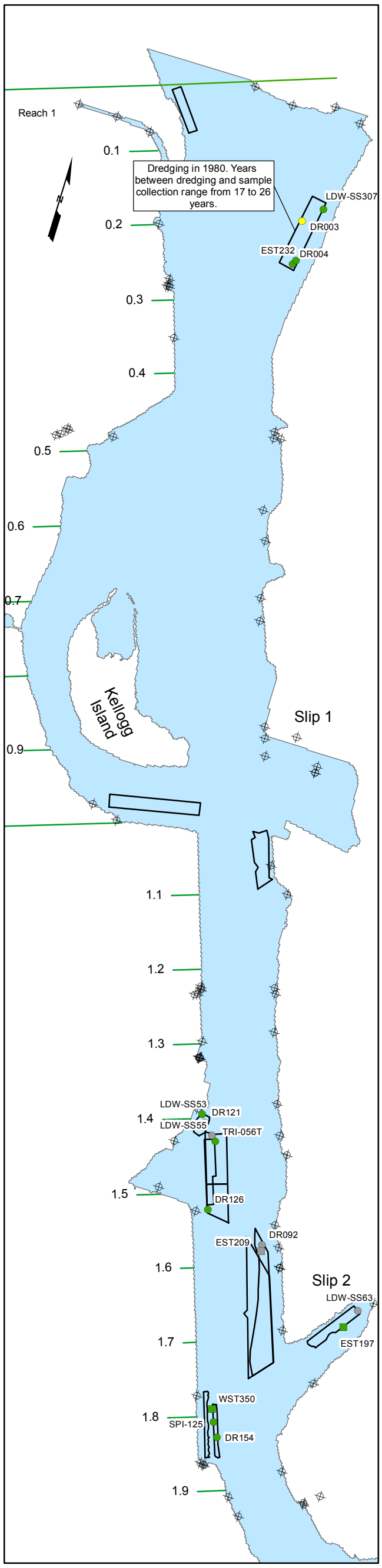
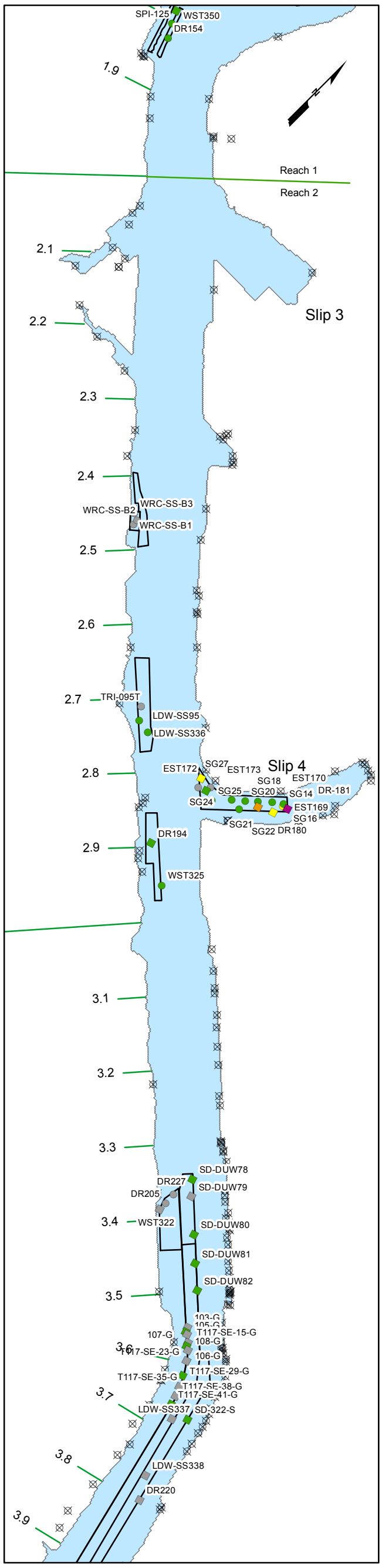
FIGURE J-6

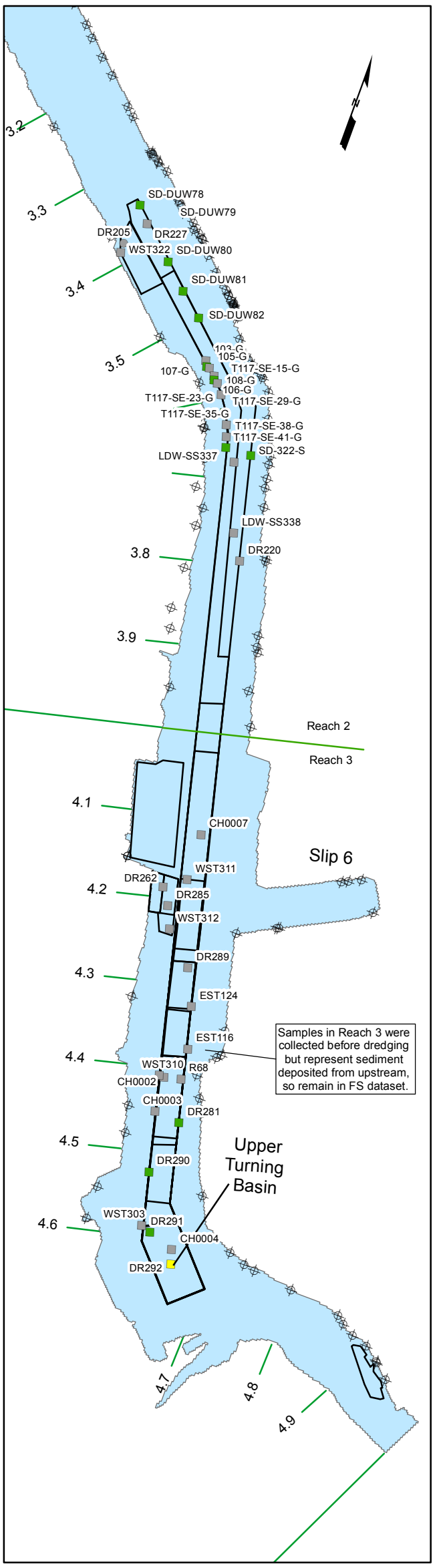
L:\Lower Duwamish FS\FS_Final_GIS\Oct2012\FS_GIS_MXDs_Oct12\Appendix J\Figure J-6NorfolkCSO.mxd

Figure J-7 Dredged Material Characterization Data – Total PCBs by Location and Year in Navigation Channel above RM 4.0









Legend

FS Surface Sediment Sample Location In/Within 10 ft of Dredging Footprint

Total PCBs µg/kg dw

- ≤ 100
- > 100 - 240
- > 240 - 700 (> SQS)
- > 700 - 1,300
- > 1,300 (> CSL)

Years elapsed between dredging and sample collection

- ≥ 5
- < 5

Outfall Location

Maintenance Dredging Event Within Last 30 Years

Road

Navigation Channel

River Mile Marker

Notes:
1. Time elapsed between dredging and sample collection ranges from 1 to 26 years.
2. SQS value of 240 µg/kg dw based on conversion of 12 mg/kg oc to a dry weight value using 2% TOC.
3. Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System (NPDES) permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and LDWG personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications.

Feet
0 200 400 800

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Surface Sediment Total PCB Data Collected After Maintenance Dredging

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FIGURE J-8

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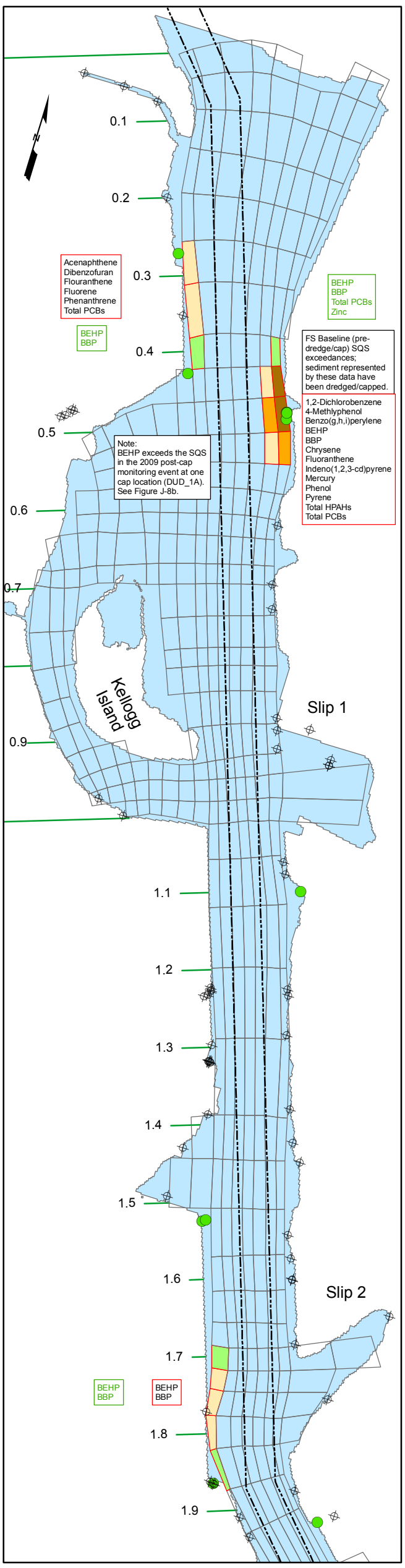

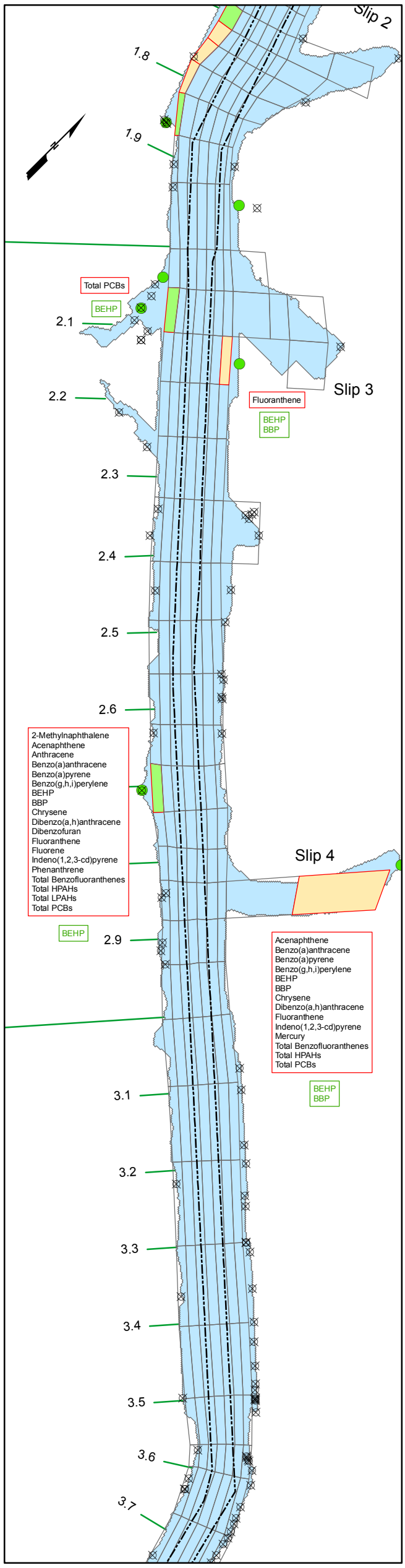

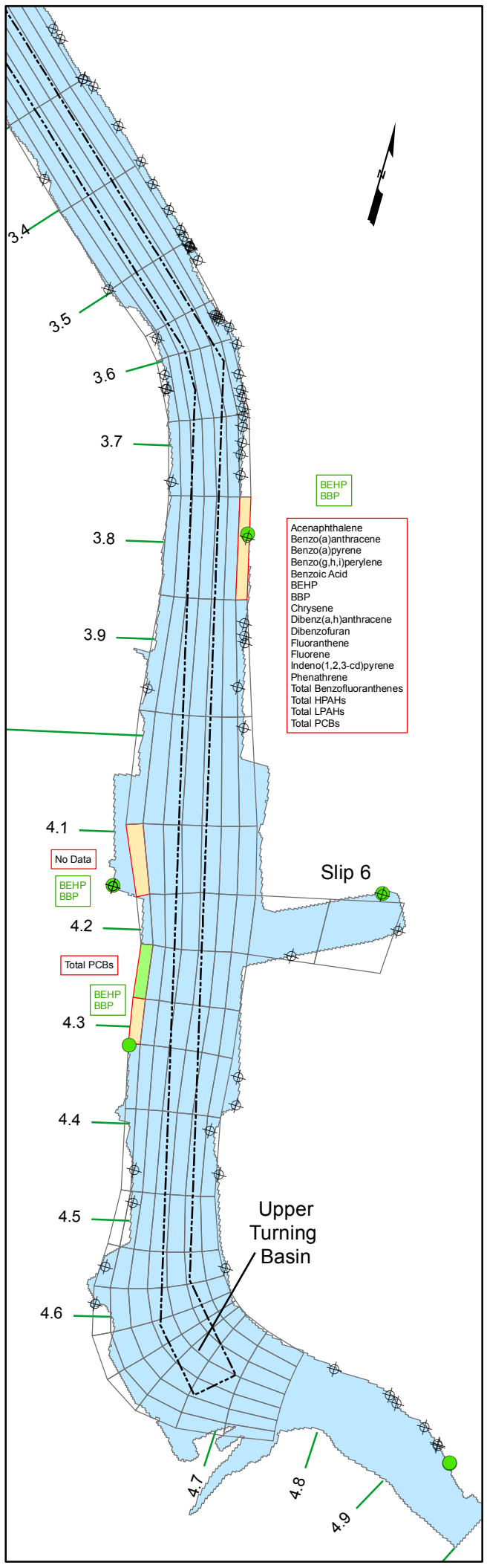

Legend

Risk Drivers Predicted to have Greater Potential to Exceed SQS at Year 10

- None
- BEHP
- BEHP and BBP
- BEHP, BBP, and Total PCBs
- BEHP, BBP, Total PCBs, and Zinc
- Grid Cell with ≥ 5.4% Lateral Source at Year 10

Modeled Redistributed Lateral Load Discharge Location

- Individual Discharge Location (CSOs, Storm Drains, and Tributaries)
- Waterfront Area Modeled Location
- Navigation Channel
- River Mile Marker

Notes:
1. STM GIS shapefile from 10-year run (QEA Feb. 2009); see Section 5.
2. Calculations to determine the minimum lateral percentage required to result in a Year 10 exceedance of the SQS, when the bed concentration is assumed to be zero.
3. Used high BCM lateral values for total PCBs and arsenic and recommended BCM input parameters for other risk drivers. These vary by risk driver; see Table J-8.
4. BEHP = bis(2-ethylhexyl)phthalate; BBP = butylbenzyl phthalate; CSO = combined sewer overflow; HPAHs = high molecular weight polycyclic aromatic hydrocarbons; LPAHs = low molecular weight polycyclic aromatic hydrocarbons; STM = sediment transport model.

Risk Driver	Estimated Lateral Percentage (required to cause possible SQS exceedance)
BEHP	5.4
Butyl Benzyl Phtalate	9.1
Total PCB	21.5
Zinc	62.2

0 200 400 800 Feet

Risk drivers predicted to exceed SQS with year 10 predictions — BEHP, BBP

BEHP, BBP, Total PCBs — Risk drivers exceeding the SQS in the FS dataset, in grid cells predicted to have greater recontamination potential

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STM Grid Cells With Greater Potential for Recontamination

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FIGURE J-9a

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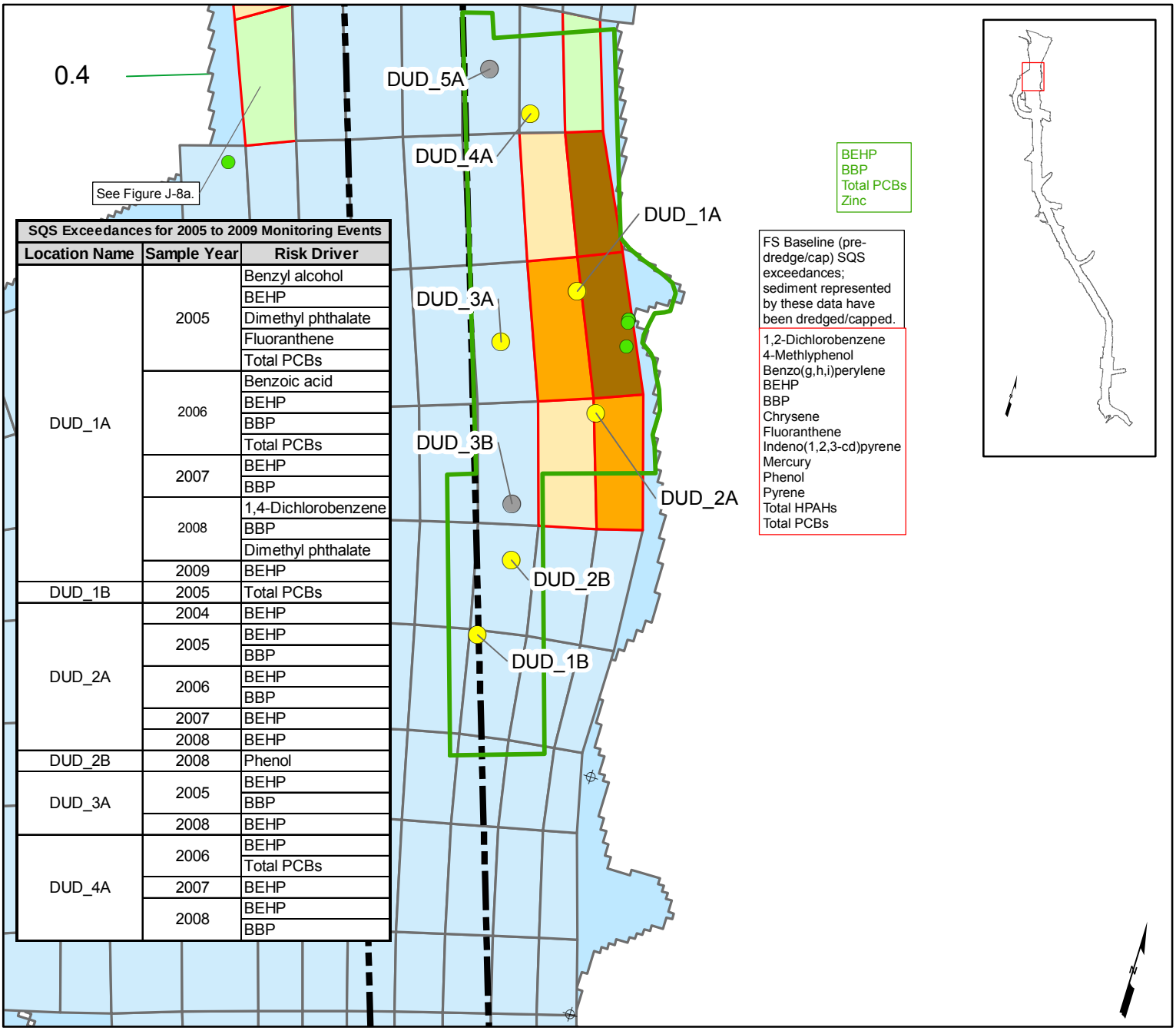

SQS Exceedances for 2005 to 2009 Monitoring Events		
Location Name	**Sample Year**	**Risk Driver**
DUD_1A	2005	Benzyl alcohol
		BEHP
		Dimethyl phthalate
		Fluoranthene
		Total PCBs
	2006	Benzoic acid
		BEHP
		BBP
		Total PCBs
	2007	BEHP
		BBP
	2008	1,4-Dichlorobenzene
		BBP
		Dimethyl phthalate
	2009	BEHP
DUD_1B	2005	Total PCBs
DUD_2A	2004	BEHP
	2005	BEHP
		BBP
	2006	BEHP
		BBP
	2007	BEHP
	2008	BEHP
DUD_2B	2008	Phenol
DUD_3A	2005	BEHP
		BBP
	2008	BEHP
DUD_4A	2006	BEHP
		Total PCBs
	2007	BEHP
	2008	BEHP
		BBP

Notes:
1. STM GIS shapefile from 10-year run (QEA Feb. 2009); see Section 5.
2. Calculations to determine the minimum lateral percentage required to result in a Year 10 exceedance of the SQS, when the bed concentration is assumed to be zero.
3. Used high BCM lateral values for total PCBs and arsenic and recommended BCM input parameters for other risk drivers. These vary by risk driver; see Table J-8.
4. BEHP = bis(2-ethylhexyl)phthalate; BBP = butylbenzyl phthalate; CSO = combined sewer overflow; EAA=early action area; HPAHs = high molecular weight polycyclic aromatic hydrocarbons; STM = sediment transport model.

Risk Driver	Estimated Lateral Percentage (required to cause possible SQS exceedance)
BEHP	5.4
Butyl Benzyl Phtalate	9.1
Total PCB	21.5
Zinc	62.2

Risk drivers predicted to exceed SQS with year 10 predictions — BEHP, BBP

Risk drivers exceeding the SQS in the FS dataset, in grid cells predicted to have greater recontamination potential — BEHP, BBP, Total PCBs

Redistributed Lateral Load Discharge Location

- Discharge Location (CSOs, Storm Drains, and Tributaries) Modeled in STM
- Waterfront Area Modeled Location
- Navigation Channel
- River Mile Marker

Legend

Risk Drivers Predicteded to have Greater Potential to Exceed SQS at Year 10

- None
- BEHP
- BEHP and BBP
- BEHP, BBP, and Total PCBs
- BEHP, BBP, Total PCBs, and Zinc
- Grid Cell with ≥ 5.4% Lateral Source at Year 10
- Duwamish/Diagonal EAA

Monitoring Location and SQS Status during 2005 to 2009 Post-cap Monitoring Events

- > SQS for at least 1 Risk Driver
- ≤ SQS for all Risk Drivers

Feet
0 55 110 220

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STM Grid Cells With Greater Potential for Recontamination in the Duwamish/Diagonal EAA

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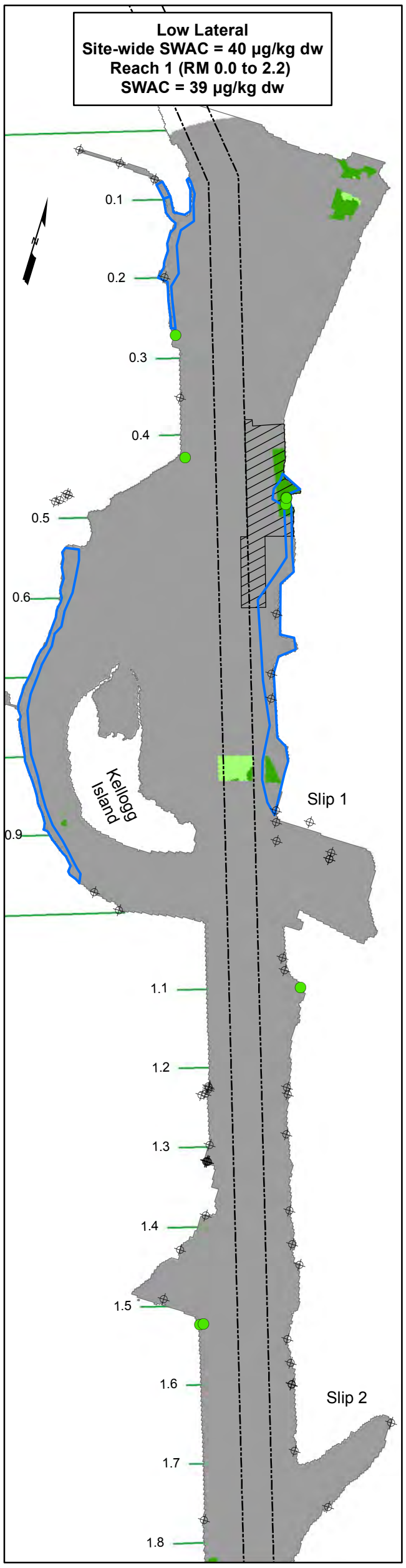
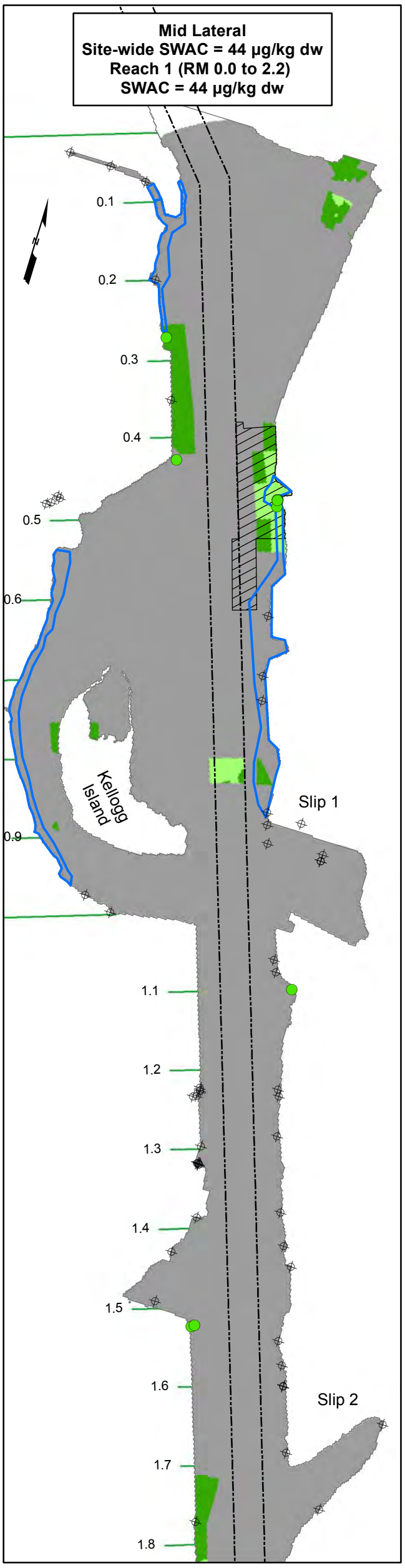
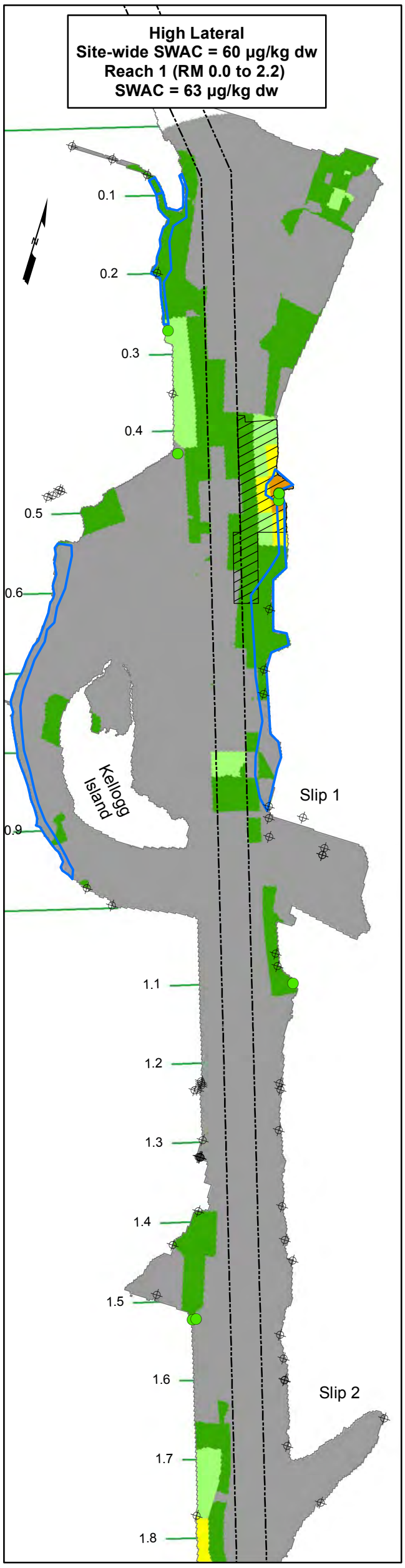
FIGURE J-9b

L:\Lower Duwamish FS\FS_Final_GIS\Oct2012\FS_GIS_MXDs_Oct12\Appendix J\FigureJ-9b_10YSTMLateralbyChem.mxd







Notes:
1. STM GIS shapefile from 30-year run (QEA Feb. 2009).
2. Year 30 total PCB concentrations calculated using the following input parameters (µg /kg dw):
   a. Mid upstream: 35
   b. Low, mid, high lateral: 100, 300, 1,000
   c. Post-remedy bed sediment replacement: 60

Early Action Area

Beach Play Area

Modeled Redistributed Lateral Load Discharge Location

Individual Discharge Location (CSOs, Storm Drains, and Tributaries)

Waterfront Area Modeled Location

Navigation Channel

River Mile Marker

Feet
0 200 400 800

Legend

Interpolated Total PCB Concentration (µg/kg dw)

- ≤ 60
- > 60 to 100
- > 100 to 240
- > 240 to 480
- > 480 to 720
- > 720 to 1,300
- > 1,300

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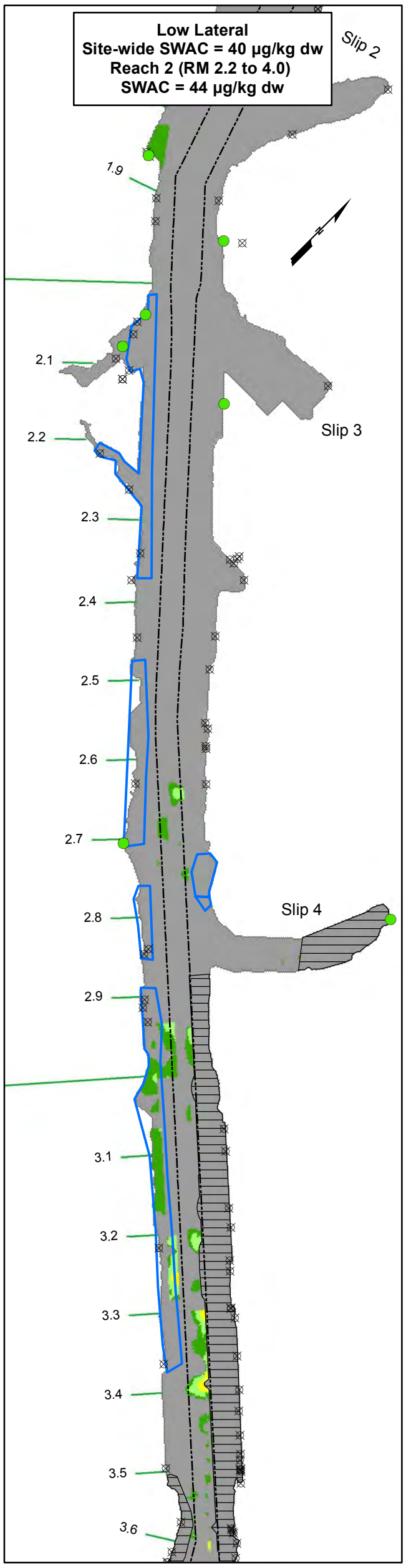
Lower Duwamish Waterway
Final Feasibility Study
60150279-14.48

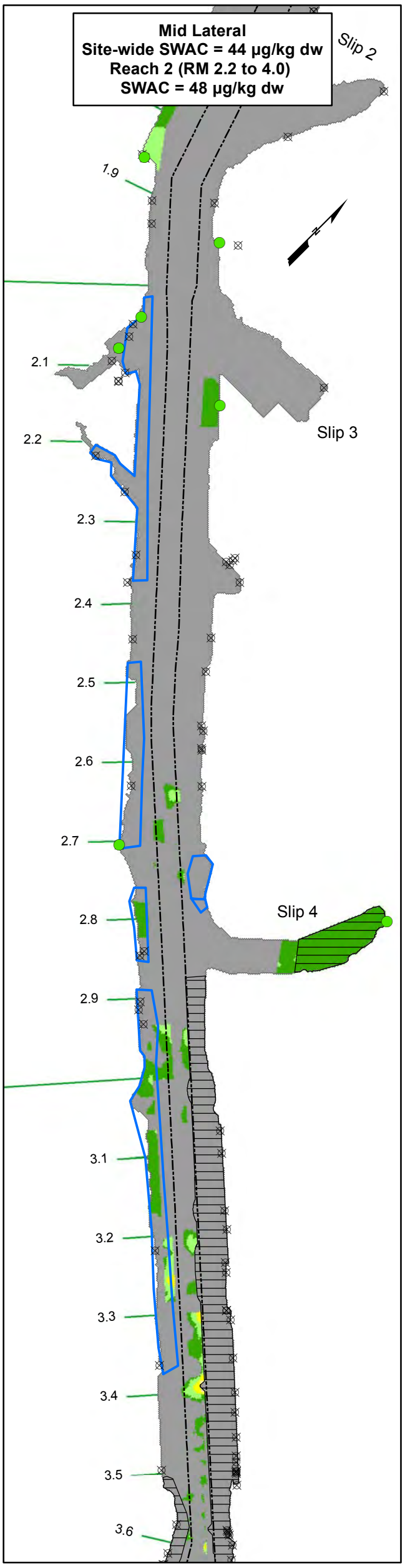
Predicted Total PCB Surface Sediment Concentrations 30 Years after Remediation of Alternative 5 with Varying Lateral Inputs (RM 0 to 1.8)

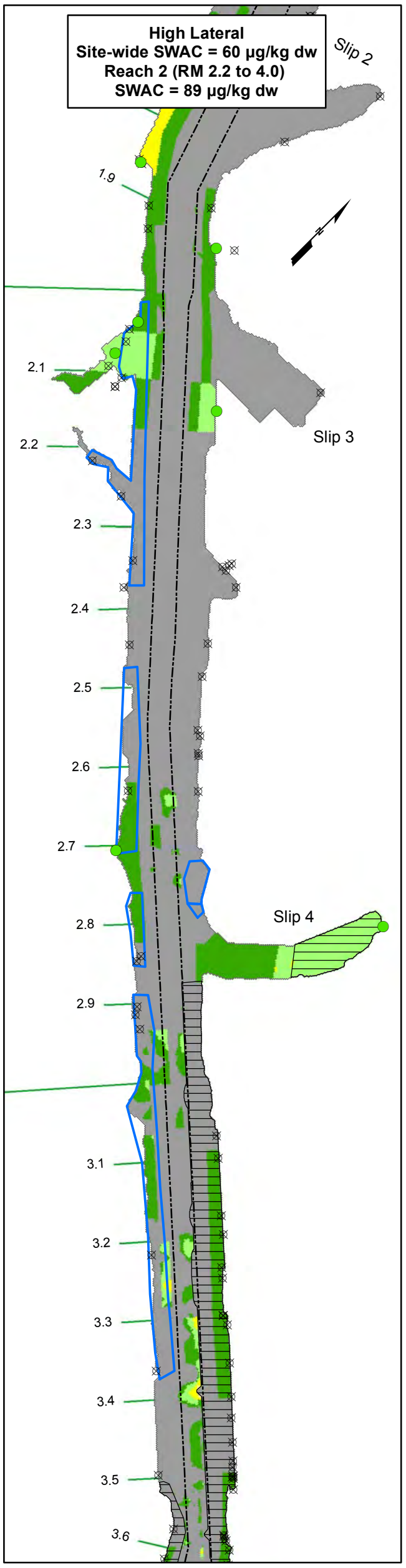
DATE: 10/31/12 | DWRN:MVI/sea | Revision: 0

FIGURE J-10a

L:\Lower Duwamish FS\FS_Final_GISOct2012\FS_GIS_MXDs_Oct12\Appendix J\FigureJ-10aComparisonPostAlt5PCBReach1.mxd







Notes:
1. STM GIS shapefile from 30-year run (QEA Feb. 2009).
2. Year 30 total PCB concentrations calculated using the following input parameters (µg /kg dw):
   a. Mid upstream: 35
   b. Low, mid, high lateral: 100, 300, 1,000
   c. Post-remedy bed sediment replacement: 60

Early Action Area
Beach Play Area

Modeled Redistributed Lateral Load Discharge Location
Individual Discharge Location (CSOs, Storm Drains, and Tributaries)
Waterfront Area Modeled Location

Navigation Channel
River Mile Marker

0 200 400 800 Feet

Legend

Interpolated Total PCB Concentration (µg/kg dw)
- ≤ 60
- > 60 to 100
- > 100 to 240
- > 240 to 480
- > 480 to 720
- > 720 to 1,300
- > 1,300

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Lower Duwamish Waterway
Final Feasibility Study
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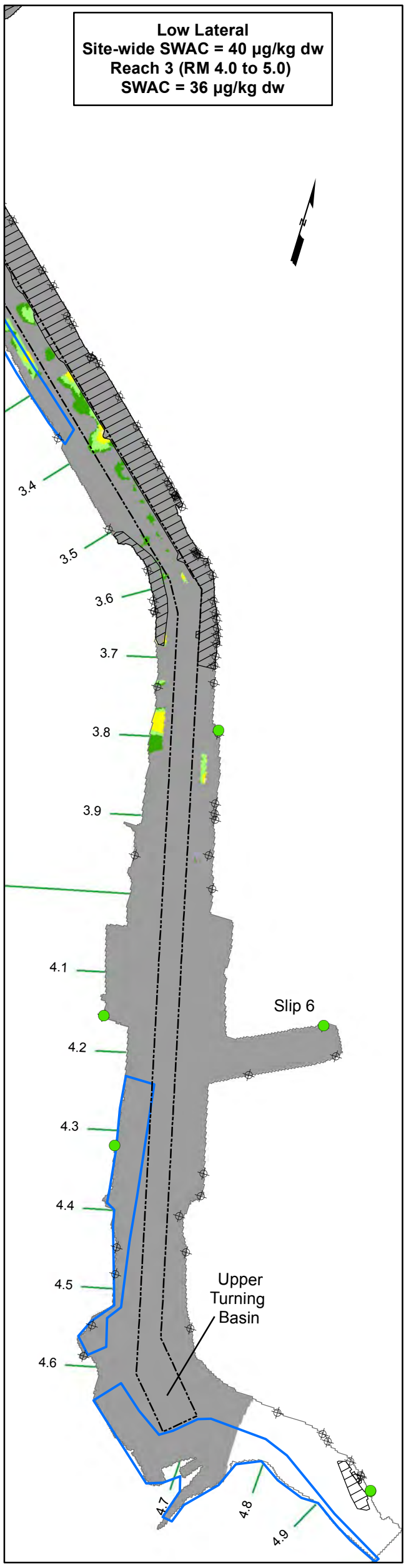
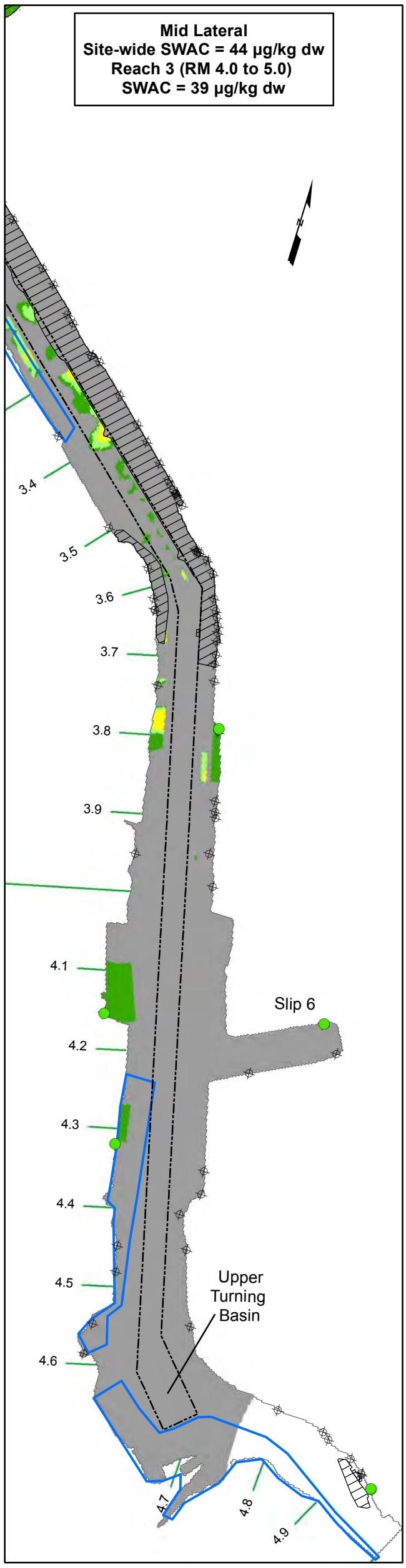
Predicted Total PCB Surface Sediment Concentrations 30 Years after Remediation of Alternative 5 with Varying Lateral Inputs (RM 1.8 to 3.6)

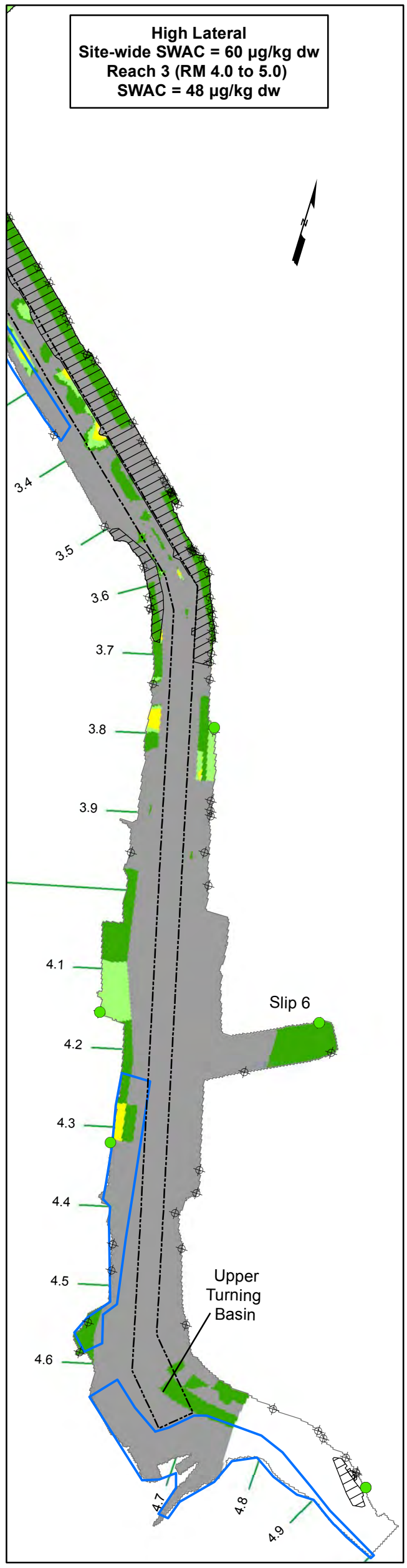
DATE: 10/31/12 | DWRN:MVI/sea | Revision: 0

FIGURE J-10b

L:\Lower Duwamish FS\FS_Final_GISOct2012\FS_GIS_MXDs_Oct12\Appendix J\FigureJ-10bComparisonPostAlt5PCBReach2.mxd







Notes:
1. STM GIS shapefile from 30-year run (QEA Feb. 2009).
2. Year 30 total PCB concentrations calculated using the following input parameters (µg /kg dw):
   a. Mid upstream: 35
   b. Low, mid, high lateral: 100, 300, 1,000
   c. Post-remedy bed sediment replacement: 60

Early Action Area
Beach Play Area

Modeled Redistributed Lateral Load Discharge Location
Individual Discharge Location (CSOs, Storm Drains, and Tributaries)
Waterfront Area Modeled Location

Navigation Channel
River Mile Marker

Legend
Interpolated Total PCB Concentration (µg/kg dw)
≤ 60
> 60 to 100
> 100 to 240
> 240 to 480
> 480 to 720
> 720 to 1,300
> 1,300

0 200 400 800 Feet

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Predicted Total PCB Surface Sediment Concentrations 30 Years after Remediation of Alternative 5 with Varying Lateral Inputs (RM 3.6 to 4.75)

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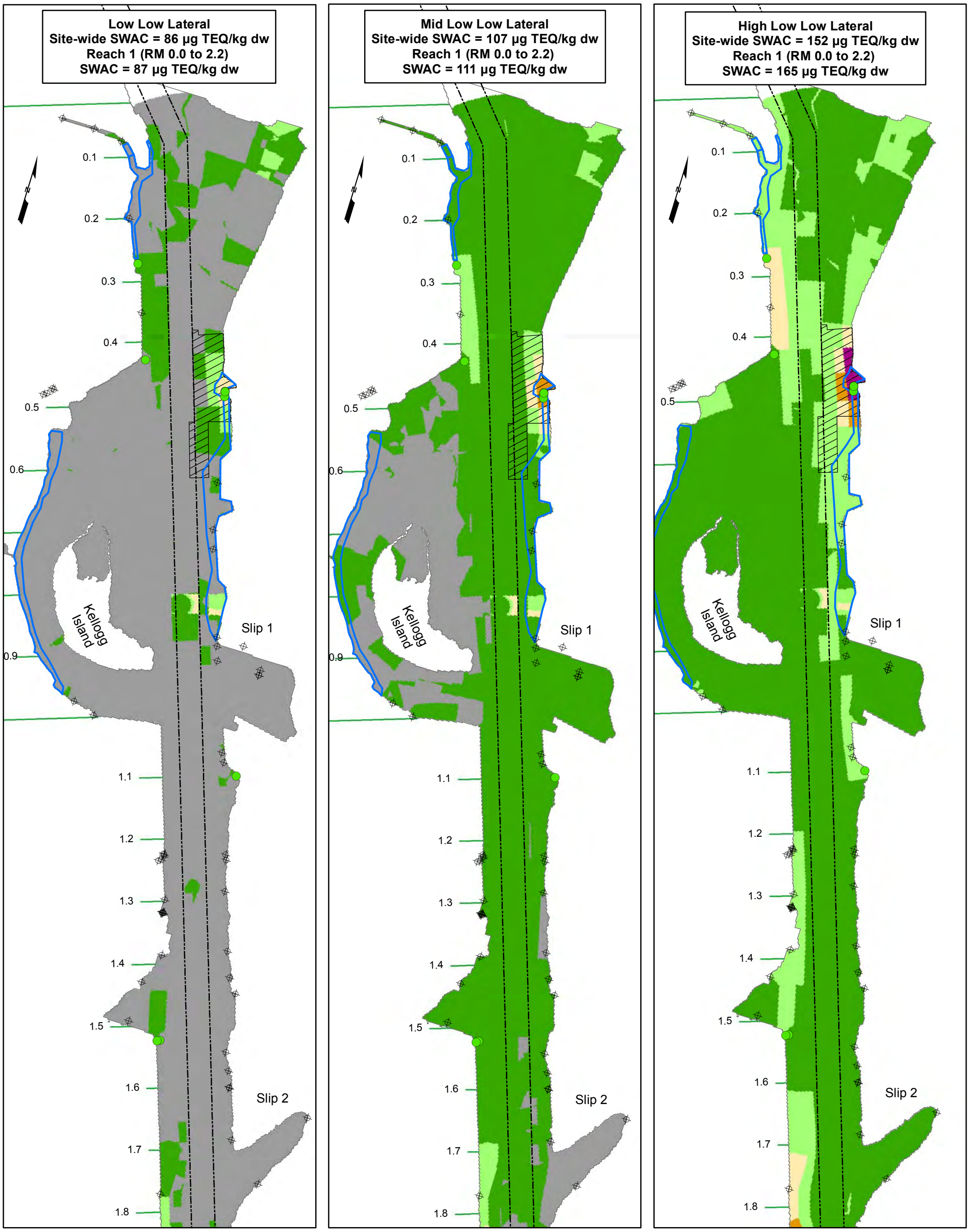
FIGURE J-10c

L:\Lower Duwamish FS\FS_Final_GISOct2012\FS_GIS_MXDs_Oct12\Appendix J\Figure J-10cComparisonPostAlt5PCBReach3.mxd



Notes:
1. STM GIS shapefile from 30-year run (QEA Feb. 2009).
2. Year 30 cPAH concentrations calculated using the following input parameters (µg TEQ/kg dw):
   a. Mid upstream: 70
   b. Low, mid, high lateral: 500, 1,400, 3,400
   c. Post-remedy bed sediment replacement: 140

Modeled Redistributed Lateral Load Discharge Location

- Individual Discharge Location (CSOs, Storm Drains, and Tributaries)
- Waterfront Area Modeled Location
- Navigation Channel
- River Mile Marker

Legend

Interpolated cPAH Concentration (µg TEQ/kg dw)

- ≤ 90
- > 90 to 150
- > 150 to 380
- > 380 to 900
- > 900 to 1,500
- > 1,500
- Early Action Area
- Beach Play Area

Feet
0 200 400 800

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Predicted cPAH Surface Sediment Concentrations 30 Years after Remediation of Alternative 5 with Varying Lateral Inputs (RM 0 to 1.8)

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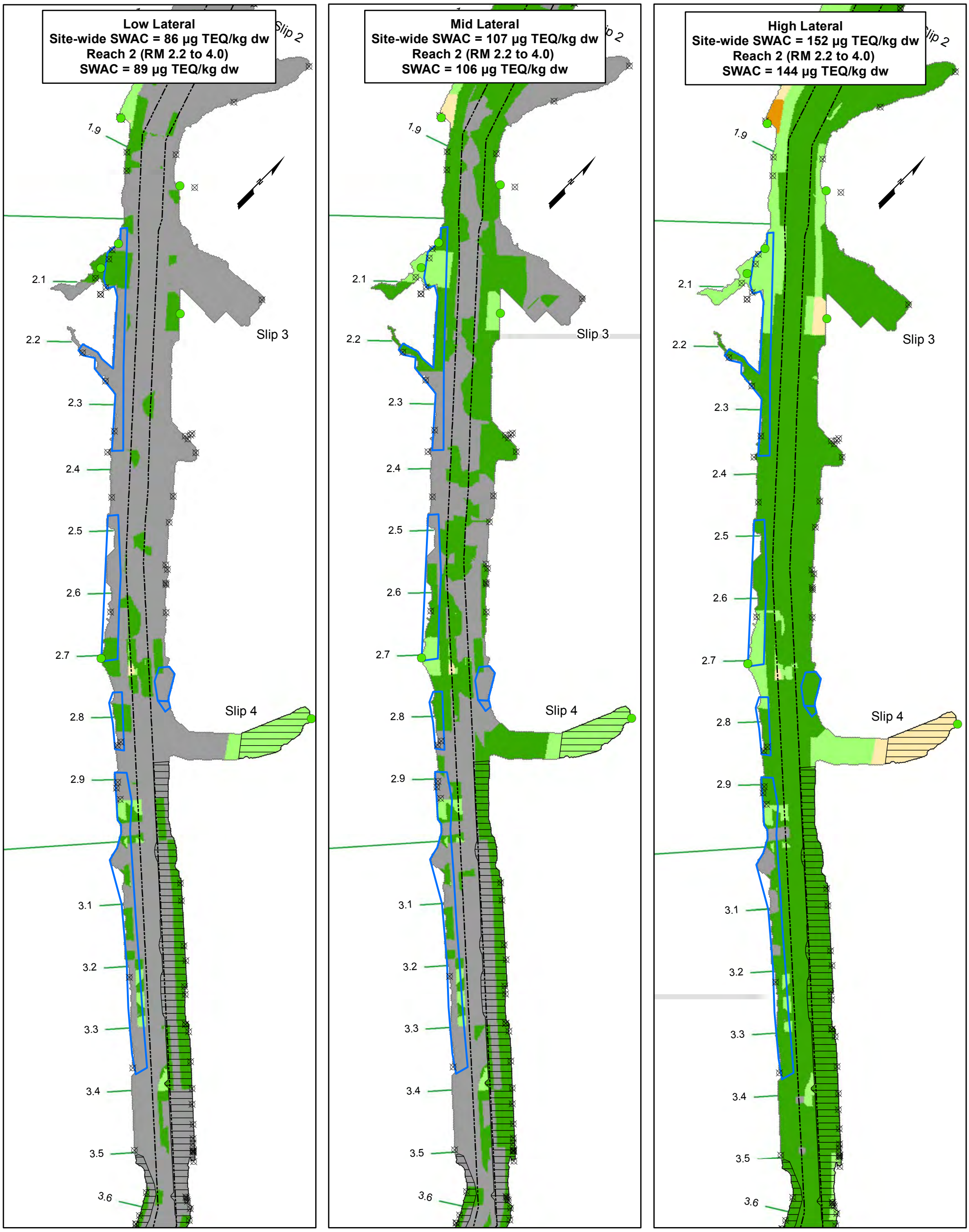
FIGURE J-11a

L:\Lower Duwamish FS\FS_Final_GISOct2012\FS_GIS_MXDs_Oct12\Appendix J\Figure J-11aComparisonPostAlt5cPAHReach1.mxd



Notes:
1. STM GIS shapefile from 30-year run (QEA Feb. 2009).
2. Year 30 cPAH concentrations calculated using the following input parameters (µg TEQ/kg dw):
   a. Mid upstream: 70
   b. Low, mid, high lateral: 500, 1,400, 3,400
   c. Post-remedy bed sediment replacement: 140

Modeled Redistributed Lateral Load Discharge Location

- Individual Discharge Location (CSOs, Storm Drains, and Tributaries)
- Waterfront Area Modeled Location
- Navigation Channel
- River Mile Marker

Legend

Interpolated cPAH Concentration (µg TEQ/kg dw)

- ≤ 90
- > 90 to 150
- > 150 to 380
- > 380 to 900
- > 900 to 1,500
- > 1,500
- Early Action Area
- Beach Play Area

Feet
0 200 400 800

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Predicted cPAH Surface Sediment Concentrations 30 Years after Remediation of Alternative 5 with Varying Lateral Inputs (RM 1.8 to 3.6)

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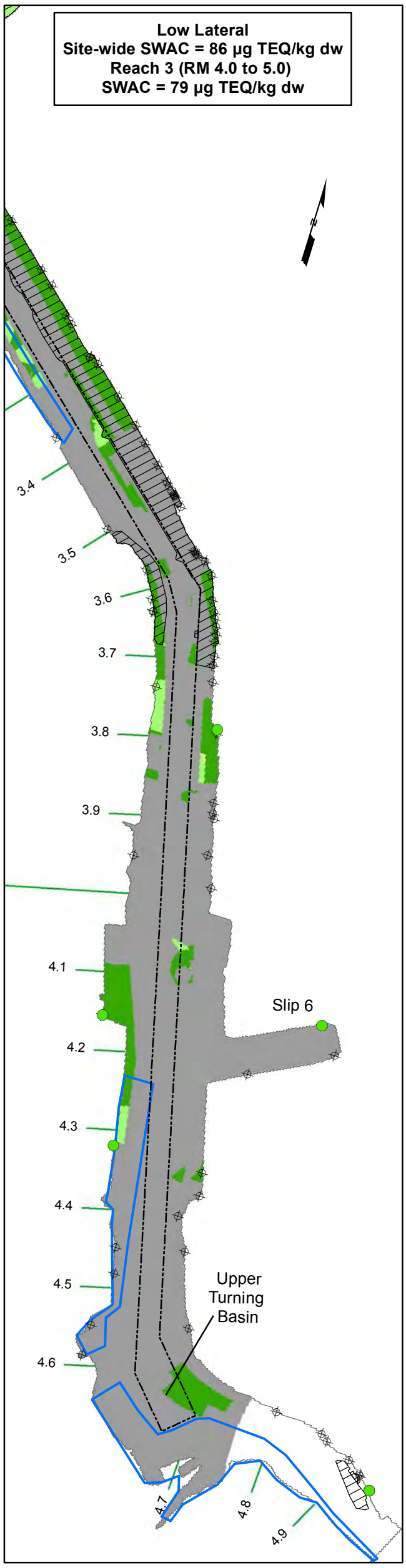
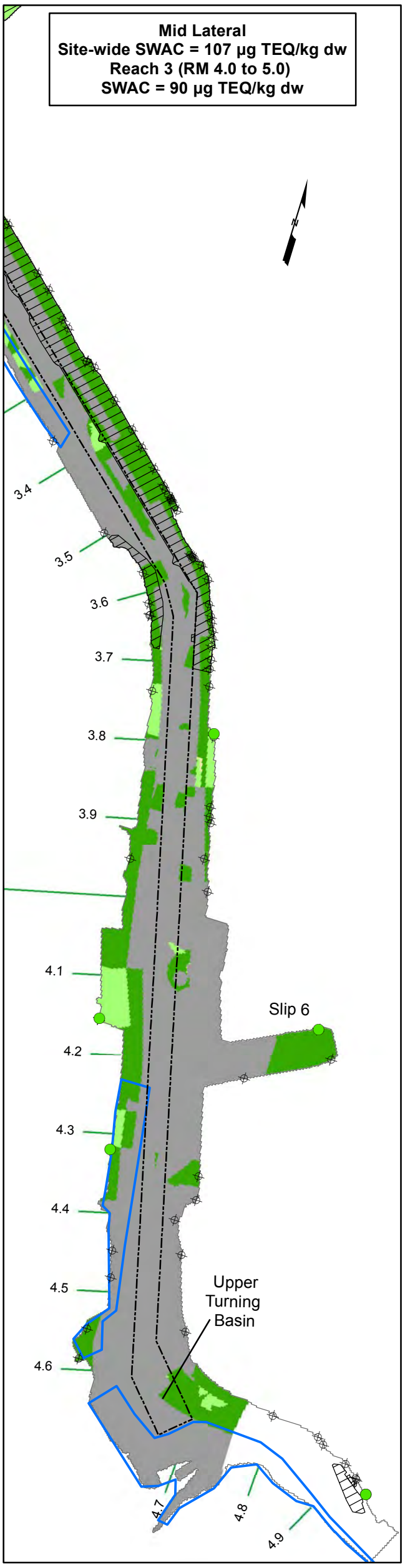
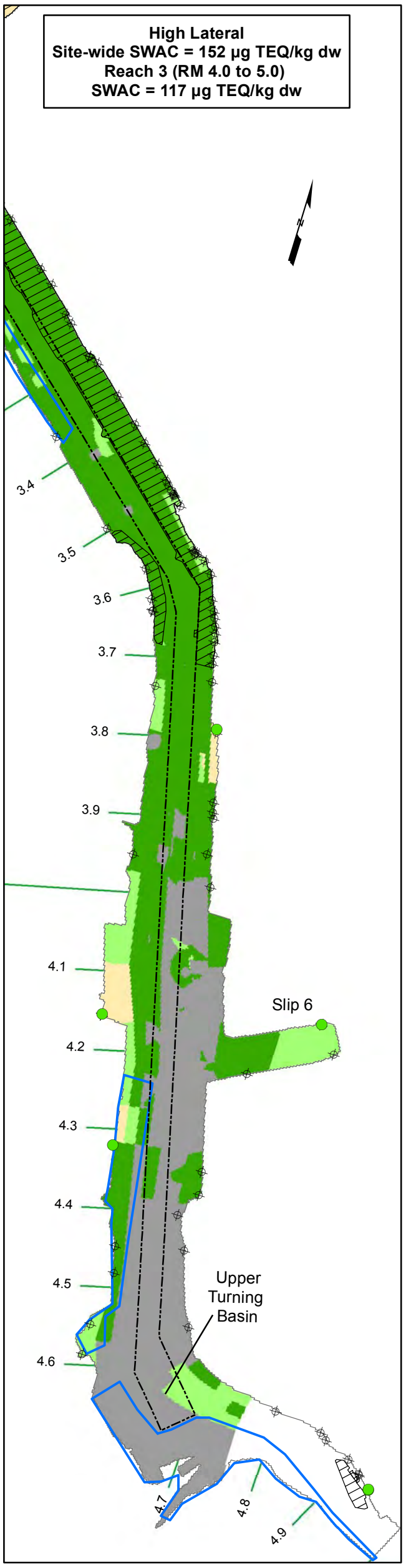
FIGURE J-11b

L:\Lower Duwamish FS\FS_Final_GIS\Oct2012\FS_GIS_MXDs_Oct12\Appendix J\FigureJ-11bComparisonPostAlt5cPAHReach2.mxd







Notes:
1. STM GIS shapefile from 30-year run (QEA Feb. 2009).
2. Year 30 cPAH concentrations calculated using the following input parameters (µg TEQ/kg dw):
   a. Mid upstream: 70
   b. Low, mid, high lateral: 500, 1,400, 3,400
   c. Post-remedy bed sediment replacement: 140

Modeled Redistributed Lateral Load Discharge Location

- Individual Discharge Location (CSOs, Storm Drains, and Tributaries)
- Waterfront Area Modeled Location
- Navigation Channel
- River Mile Marker

Legend

Interpolated cPAH Concentration (µg TEQ/kg dw)

- ≤ 90
- > 90 to 150
- > 150 to 380
- > 380 to 900
- > 900 to 1,500
- > 1,500
- Early Action Area
- Beach Play Area

0 200 400 800 Feet

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Predicted cPAH Surface Sediment Concentrations 30 Years after Remediation of Alternative 5 with Varying Lateral Inputs (RM 3.6 to 4.75)

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

FIGURE J-11c

L:\Lower Duwamish FS\FS_Final_GIS\Oct2012\FS_GIS_MXDs_Oct12\Appendix J\FigureJ-11cComparisonPostAlt5cPAHReach3.mxd