APPENDIX A
GROUNDWATER MODEL REPORTS
Keta Waters
December 30, 2021 (base model report)
January 12, 2022 (ICS Interim Action – Subsurface Barriers), and
January 12, 2022 (ICS Interim Action – Sediment Cap Modelling)

FEASIBILITY STUDY REPORT
ICS/NWC RI/FS
SEATTLE, WASHINGTON

Dalton, Olmsted & Fuglevand, Inc.

Description of Groundwater Flow Model
Industrial Container Services, WA, LLC
Seattle, WA

December 30, 2021
Final Draft

Prepared for

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EXPIRES December 28, 2022

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1. Overview

This document describes the development and calibration of a steady-state groundwater flow model intended to support the evaluation of potential cleanup activities at the Industrial Container Services (ICS) site in Seattle, WA. The model was developed based on data and information included in draft Remedial Investigations (RI's) developed for the ICS site (DOF, 2020) and for the adjacent 7100 1st Avenue South Seattle site (GeoEngineers, 2016). Water level data collected by DOF in February of 2018 were used in model calibration (DOF, 2018).

The groundwater model is applicable for evaluating a range of containment and treatment options for the ICS site. Applications of the model for specific options are not included in this document but will be considered in separate memoranda.

2. Model construction

Model code

The USGS three-dimensional finite-difference groundwater-flow model MODFLOW-2005 (Harbaugh 2005) was used to simulate groundwater flow in the study area. MODFLOW-2005 is one of the industry standard software packages for groundwater modeling. The source code is free, public-domain software. MODFLOW-2005 solves the three-dimensional groundwater-flow equation for a porous medium using the finite-difference method. It uses modular packages to represent groundwater-flow system processes, such as recharge, groundwater flow, discharge, and interactions between the aquifer and surface-water bodies. The model was developed to run under the graphical user interfaces Groundwater Vistas Version 6.84.

The model was used to simulate average groundwater conditions in the vicinity of the ICS site. Water levels at the site are tidally-influenced. The model is used to describe groundwater flow directions and groundwater fluxes averaged over the tidal cycles.

Model location and grid

The model area encompasses approximately 80 acres along the Lower Duwamish Waterway, as shown in Figure 1. The ICS site is located in the central part of the model area adjacent to the small Embayment that is tributary to the Lower Duwamish Waterway. The site is located at approximately river mile (RM) 2.2.

A variable grid spacing is used in the model, as shown in Figure 2. The grid is rotated 48 degrees counterclockwise so that the axes of the grid are parallel and perpendicular to the Waterway. The grid spacing varies from 10 feet by 10 feet in the vicinity of the Embayment to 20 feet by 20 feet in the areas distal from the ICS site. The model is 6 layers thick, resulting in 89,316 active cells. The model uses material properties (e.g., hydraulic conductivity) that are averaged over each model cell. The model output (e.g., groundwater levels) also represents an average value over the model cell.

Model surface topography

The surface topography in the majority of the model is from the 1/9 arc-second National Elevation Dataset (NED) and is based on the 2000 Puget Sound LiDAR study (USGS, 2012). The horizontal spacing for the NED data is approximately 7.6 feet in the E/W direction and 11.2 feet in the N/S direction. The elevation for each cell in the model was assigned by averaging the NED data over the model cell. The elevations were checked against bare-earth LiDAR data from the Puget Sound LiDAR Consortium (PSLC, 2000). The elevations are closely matched.

The surface topography in the vicinity of the Embayment is from a survey conducted in July of 2018 (Bush, Roed, and Hitchings, 2018).[1] The survey results include 1,712 elevation measurements at discrete locations within and adjacent to the Embayment. The elevation for each cell in the model located within the survey area was assigned by averaging survey data over the model cell.

The surface topography is shown in Figure 3. Important features in terms of groundwater recharge and hydraulic boundaries are identified on this figure. These features include the Embayment, a tidally-influenced swale, and a closed-depression stormwater pond. The tidally-influenced swale appears to be disconnected from the Waterway based on the LiDAR surface topography. However, this is due to roadways and bridges that overlie the swale, as shown in Figure 4. The swale is continuous from the Waterway across the model. During high tides, water flows from the Waterway throughout the swale. The stormwater pond and swale represent areas of elevated groundwater recharge.

The bathymetry of the Lower Duwamish Waterway in the model area was obtained from King County (2018) and is from the survey by David Evans and Associates (2004). The bathymetry was used to assign boundary conditions for the Waterway, as described in more detail below.

Hydrostratigraphy

The model uses six layers to describe the hydrostratigraphy in the model area. The hydrostratigraphy is based on the information included in the Draft RI (DOF, 2020). An example cross section through the model is shown in Figure 5. Hydraulic conductivity values used in the model are listed in Table 1. These values were originally selected based on descriptions from well logs and narrative in the ICS RI and in Geoengineers (2016).[2] The values were adjusted as part of model calibration, as described below. A 10:1 ratio of horizontal to vertical hydraulic conductivity values is used throughout the model.

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[1] The results from the Bush, Roed and Hitchings survey were provided in an email from Matt Dalton on 3/26/2021.

[2] GeoEngineers (2016) estimate the hydraulic conductivity for the lower sand based on tidal analyses is 10 to 20 ft/day (MW-5, MW-9, MW-11, MW-12, MW-13, and MW-16). Their estimate for the upper sand based on slug tests is 1 to 1.5 ft/day (MW-2A, MW-14, and MW-16).

The first layer in the model (Layer 1) represents the upper sand described in the RI. The upper sand in this layer is divided into two zones, as shown in Figure 6. The majority of the layer is comprised of Zone 1 materials with a hydraulic conductivity of 2 ft/day. The northeast corner of the model is assigned a value of 10 ft/day (Zone 2 in Table 1). The higher conductivity in Zone 2 was identified based on observed water level data and tidal fluctuations in this area (DOF, 2020; DOF, 2018).

The second model layer (Layer 2) incorporates the fine-grained aquitard that underlies the western portions of the ICS property. A narrow zone of fine-grained material is also incorporated in layer 2 in the location of the former lagoon on the ICS site. The distribution of this fine-grained material, which corresponds to Zone 3 in Table 1, is shown in Figure 7.

Layer 3 in the model represents the upper portion of the lower sand unit. The hydraulic conductivity assigned to this layer is 40 feet per day, except for a portion of Layer 3 in the vicinity of the Embayment. A lower-conductivity zone is included in Layer 3 to reflect the presence of an aquitard under the Embayment. This aquitard is shown in Section I-I' included in a DOF technical memorandum dated June 9, 2021 (DOF, 2021a). A narrow extension of the lower conductivity zone south of the Embayment was also added to layer 3, based on Sections D, F, and G in the RI (DOF, 2020). Figure 8 shows the distribution of hydraulic conductivity zones used in layer 3 of the model.

The hydraulic conductivity assigned to Layers 4, 5, and 6 is 20 feet per day. The hydraulic conductivity in these lower three layers is uniform.

Early reconnaissance of the embayment identified a precipitate cap along the north embayment shoreline. During the seasonal lowest tides in June 2021, DOF surveyed the extent of the cap using a DGPS (DOF 2021b – in prep). This cap consists of low permeability silica cemented materials up to several feet in thickness. This cap was included in Layer 1 in the model by reducing the conductance of the Embayment boundary condition in the area of the cap. Figure 9 shows the location of cemented area in Layer 1. The red symbols in this figure denote locations along the Embayment boundary with cemented conditions while blue symbols denote areas along the Embayment boundary without cemented conditions. Yellow symbols denote drains. The conductance in the cemented area was reduced by a factor of 10,000 relative to the uncemented area (from 0.4 ft2/day to 4×10^{-6} ft2/day). There are 114 cells with cementation. The average elevation of the cemented cells is 0.73 ft NAVD88. The maximum is 3.67 ft and the minimum is -1.76 ft (NAVD88).

Boundary Conditions

Groundwater enters the modeled area through recharge at the land surface. Figure 10 illustrates four different recharge zones. The background recharge rate is 3 inches per year. This is a relatively low value that reflects the highly-developed nature of much of the modeled area with numerous streets, highways, and bridges. Paved areas on the ICS and Douglas properties that are connected to stormwater/sanitary collection systems are assigned a recharge value of zero. Much of the recharge in the modeled area is derived from the tidally-influenced swale and closed-depression stormwater pond shown in Figures 3 and 4. The recharge rate in the swale was assigned a value of 44 inches per year and the recharge in the stormwater pond was assigned a value of 66 inches per year. These values were selected as part of model calibration. The total inflow from the recharge boundaries is 4,200 cubic feet per day or 31,500 gallons per day.

Groundwater leaves the modeled area through discharge to the Embayment and discharge to the Waterway. The boundary conditions associated with these features are shown on Figure 11. The Waterway is treated as a river boundary in the model. The water level assigned to this boundary is 4.75 feet NAVD.[3] This is the average tide level based on the water level data collected on February 6, 2018, as described in the model calibration section below. The hydraulic conductivity of the river boundary was assigned a value of 0.004 ft/day. This results in a conductance value in range of 0.4 to 1.6 ft2/day, depending upon the length of the river within a model cell.

The deeper portions of the Embayment are treated as river boundaries with the same water level as the Waterway described above. The outer edges of the Embayment that are at elevations above the average tide level are treated as a drainage boundary where the groundwater discharge is determined based on the difference between the groundwater level and the elevation of the drain. The drain elevations are assigned from the topography data. The conductance of the drain boundaries used to represent these outer edges is assigned a value of 500 ft2/day. This conductance value was assigned as part of model calibration.

3. Model calibration

The model was calibrated by comparing model calculations with observed water levels. The parameters that were adjusted during the calibration included variables that describe the connection between groundwater and the Waterway and the Embayment (i.e., conductance values), variables that describe the hydrogeologic characteristics of the hydrostratigraphy (i.e., hydraulic conductivity values), and variables describing recharge from the swale and stormwater pond.

The model was calibrated using water level data collected on February 6, 2018 (DOF, 2018). Data were collected near high tide and near low tide at 52 locations. The average of these two datasets was used to represent steady-state or average conditions. These averages are listed in Table 2. Calculated values from the calibrated model are also listed in Table 2. The residual values listed in Table 2 are equal to the observed value minus the calculated value.

Calibration statistics are presented in Table 3. A residual mean of near zero indicates little bias in the model. The root-mean-square (RMS) error of 1.10 feet represents 27% of the range of observations. This value is higher than ideal, and may be due in part to the effects of

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[3] The average tide level for the Seattle station (NOAA station 9447130 in Elliot Bay) is 4.32 feet NAVD and the average level as USGS station 12113415 is 5.42 feet based on data collected from 2/20/15 through 8/15/2018. The USGS station is at approximately river mile 5 and the ICS site is at river mile 2.2. A Waterway elevation of 4.75 feet at the ICS site is reasonably close to the average water level of 4.87 feet based on the Seattle NOAA station (4.32 feet) and the USGS station (5.42).

averaging tidally-influenced water levels using only two data points (near high tide and near low tide). Uncertainty associated with parameters that describe the hydraulic connection between groundwater and surface water at the site contribute to model error. The available data describing water level responses to tidal fluctuations show that these hydraulic connection parameters vary across the site. The RMS error could be reduced by adding additional heterogeneity or complexity to the model. This approach was not taken given the overall objective of the modeling effort to evaluate the effects of remedial measures at a conceptual level.

Figure 12 shows residuals for wells located in the upper sand unit. A positive value for these residuals denotes locations where the model under-predicts the observed level. The average residual for these 13 locations is 0.02 feet. The maximum residual, 1.54 feet, is located inland from the Embayment.

Figures 13 and 14 show residuals for wells located in the lower sand unit. The results in Figure 13 are for layer 3 in the model. This layer corresponds to the upper part of the lower sand unit. The results from layer 4 in the lower sand unit are shown in Figure 14. The residuals for wells on the 7100 1st Avenue South (Douglas) site are all positive, indicating that the model is under-predicting water levels in this area. The residuals on the ICS site are mostly negative, indicating the model over-predicts water levels.[4] Over-predicting water levels on the ICS site would tend to over-predict discharge from the site to the Embayment. This may result in conservative (i.e., over-estimated) values for contaminant fluxes to the Embayment. The average residual for the 39 wells located in the lower sand unit is 0.15 feet.

4. Model results

Figures 15 and 16 illustrate simulated water level contours in the upper sand unit (model layer 1) and lower sand unit (model layer 4). Water levels in the upper unit show discharge from the ICS site to the Embayment. The deeper water levels in Figure 16 show discharge to the Lower Duwamish Waterway. A comparison of the levels shown on these figures indicate a downward hydraulic gradient over much of the ICS site. The groundwater contours for model Layer 1 shown on Figure 15 are similar to those shown on Figure 4-18b (low tide measurements in the water table zone) in DOF (2020).

The overall water balance is summarized in Table 4. The total recharge is equal to 4,197 ft3/day. Approximately 7.1% (300 ft3/day) of this recharge discharges to the Embayment and the remaining 92.9% (3,899 ft3/day) discharges to the Waterway. Discharge to the Embayment occurs from Layers 1, 2, and 3, as indicated in Table 4. The difference between inflow (4197.4) and outflow (4199.0) is 1.6 ft3/day. This corresponds to a mass balance error is 0.00038 or 0.038%.

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[4] The average observed water level for the 20 wells on the Douglas site located in model layers 3 and 4 is 7.3 feet while the average for the 26 wells on the ICS site is 5.8 feet. The physical basis for such a difference is not clear.

References

Bush, Roed, and Hitchings, 2018. Topographic Survey, Dalton Olmsted & Fuglevand, 7152 1st Avenue South, Seattle, Washington. August 30, 2018.

DOF, Dalton Olmsted and Fuglevand, 2016. Remedial Investigation Report, Industrial Container Services, WA, LLC (former NW Cooperage Site), Seattle, WA. Agency Draft, September, 2016.

DOF, Dalton Olmsted and Fuglevand, 2018. Groundwater Level Analysis, February 6, 2018 Measurements, ICS/NWC RI. Memorandum to V. Sutton, Washington Dept. of Ecology, Draft, February 27, 2018.

DOF, 2020. Remedial Investigation Report, Industrial Container Services, WA, LLC [former NW Cooperage Site], Seattle, WA, Public review draft: February 2020.

DOF, 2021a. Revisions to Draft RI Figures, ICS Remedial Investigation Report, February 2020. Technical memorandum to Vicki Sutton, Washington Dept. of Ecology, June 9, 2021 (includes revised Section I-I').

DOF, 2021b. Revised Extent of Embayment Precipitate Cap. Technical memorandum to Vicki Sutton, Washington Dept. of Ecology, June 28, 2021.

David Evans and Associates, Inc.,2004. Lower Duwamish waterway bathymetric survey. Prepared for Windward Environmental LLC under contract to the US Environmental Protection Agency and the Washington State Department of Ecology.

Harbaugh, A.W., 2005. MODFLOW-2005, the U.S. Geological Survey modular ground-water model -- the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16.

King County, 2018. ftp://ftp.kingcounty.gov/water. Accessed 3/15/2018.

PSLC, 2000. Bare Earth LiDAR DEM, https://pugetsoundlidar.ess.washington.edu/lidardata/restricted/be_ascii/pslc2000/

U.S. Geological Survey, 2012. USGS NED ned19_n47x75_w122x50_wa_puget_sound_2000 1/9 arc-second 2012 15 x 15 minute IMG: U.S. Geological Survey. https://www.sciencebase.gov/catalog/item/581d2eece4b08da350d68401

GeoEngineers, 2016. Ecology Review Draft, Remedial Investigation Report for 7100 1st Avenue South Seattle, LLC. December 30, 2016.

Tables

Table 1. Hydraulic conductivity values used in the model

	Hydraulic conductivity (ft/day)		**Description**	**Layers**
Zone	Horizontal	Vertical		
1	2	0.2	Upper sand/water table	1,2
2	10	1.0	Upper sand/water table	1
3	0.01	0.001	Fine-grained unit	2
4	40	4.0	Lower sand	3
5	20	2	Lower sand	4,5,6

Table 2. Groundwater levels used in model calibration

Well	**North**	**East**	**TOC elev. (ft)***	**Surface Elev. (ft)**	**Screen Depth (feet)**	**Screen Elevation (feet)**	**Zone**	**Model layer**	**Observed Level (ft)**	**Calculated level (ft)**	**Residual (ft)**
ICS-MWAp	200173	1269797	13.08	13.5	4.5-9.5	+9.0/+4.0	Water table	1	8.73	8.11	0.62
ICS-MWBp	200095	1269852	15.60	15.9	5.5-10.5	+10.4/+5.4	Water table	1	8.80	8.01	0.79
ICS-MWCp	199995	1269943	13.69	14.0	3.5-8.5	+10.5/+5.5	Water table	1	9.09	7.57	1.52
ICS-MWDp	200271	1269723	13.53	13.8	5-10	+8.8/+3.8	Water table	1	8.63	8.05	0.58
LNAP-1	200212	1270040	12.24	12.6	5-10	+7.6/+2.6	Water table	1	6.14	6.56	-0.42
LNAP-2	200254	1269921	11.96	12.2	4.4-9.7	+7.8/+2.5	Water table	1	6.26	6.67	-0.41
DOF-MW1	199988	1270151	13.74	14.1	12-17	+2.1/-2.9	Upper	3	6.41	6.60	-0.19
DOF-MW2	199928	1269979	16.80	17.1	14.8-19.8	+2.3/-2.7	Upper	3	5.65	6.86	-1.21
DOF-MW3	199878	1269775	16.79	17.2	17-22	+0.2/-4.8	Upper	3	5.45	7.11	-1.66
DOF-MW4	199985	1269797	15.54	16.0	17-22	-1.0/-6.0	Upper	3	5.53	7.00	-1.47
DOF-MW5	200064	1269721	15.14	15.6	17-22	-1.4/-6.4	Upper	3	5.53	7.02	-1.49
DOF-MW6	200248	1269827	11.53	11.9	13-18	-1.1/-6.1	Upper	3	5.66	6.76	-1.10
DOF-MW7	200184	1269970	12.67	13.0	12.7-17.7	+0.3/-4.7	Upper	3	5.61	6.64	-1.03

Well	North	East	TOC elev. (ft)*	Surface Elev. (ft)	Screen Depth (feet)	Screen Elevation (feet)	Zone	Model layer	Observed Level (ft)	Calculated level (ft)	Residual (ft)
DOF-MW8	200098	1270037	13.51	13.8	12.9-17.9	+0.9/-4.1	Upper	3	5.84	6.64	-0.80
SA-MW1	200268	1269944	12.57	13.0	4-24	+9.0/-11.0	Upper	3	6.37	6.60	-0.23
SA-MW2	200311	1270090	11.97	12.3	4-24	+8.3/-11.7	Upper	3	7.30	6.29	1.01
SA-MW3	200249	1270174	12.57	13.0	4-24	+9.0/-11.0	Upper	3	5.42	6.27	-0.85
HC-B1	200304	1270043	13.74	12.9	16-21	-3.1/-8.1	Upper	3	6.31	6.23	0.08
ICS-MWB2R	200186	1270108	12.50	12.8	4.5-9.5	+8.3/+3.3	Upper	1	5.67	6.44	-0.77
ICS-MWDu	200273	1269723	13.57	13.8	11-21	+2.8/-7.2	Upper	3	5.62	6.87	-1.25
ICS-MWEu	200297	1270058	11.83	12.2	4.5-14.5	+7.7/-2.3	Upper	2	6.31	6.22	0.09
ICS-MWFu	200170	1270230	12.68	13.1	4.5-14.5	+8.6/-1.4	Upper	2	5.01	6.30	-1.29
ICS-MWGu	200055	1270222	13.13	13.5	4.5-14.5	+9.0/-1.0	Upper	2	5.28	6.44	-1.16
ICS-MWJu	200282	1270134	12.18	12.5	5-15	+7.5/-2.5	Upper	2	6.45	6.23	0.22
ICS-MWKu	199927	1270348	11.59	12.0	4.5-14.5	+7.5/-2.5	Upper	2	5.39	6.46	-1.07
ICS-MWLu	199901	1270258	11.69	12.0	4.5-14.5	+7.5/-2.5	Upper	2	7.86	6.58	1.28
ICS-MWFL	200168	1270230	12.80	13.1	19.5-29.5	-6.4/-16.4	Lower	4	5.21	6.30	-1.09
ICS-MWGL	200055	1270221	13.32	13.7	19.6-29.6	-5.9/-15.9	Lower	4	5.31	6.45	-1.14
ICS-MWHL	200269	1269831	11.73	11.9	19.6-29.6	-7.7/-17.7	Lower	4	5.56	6.73	-1.17
ICS-MWIL	200248	1270172	12.59	12.9	24.5-34.5	-11.6/-21.6	Lower	4	5.13	6.27	-1.14
ICS-MWKL	199925	1270348	11.57	11.9	19.7-29.7	-7.8/-17.8	Lower	4	5.41	6.45	-1.04
ICS-MWLL	199899	1270260	11.65	12.1	19.5-29.5	-7.4/-17.4	Lower	4	5.47	6.57	-1.10
Wells on 7100 1st Avenue South (Douglas) site											
DMC-MW-1	200452	1269870	17.54	18.06	10-20	+8.1/-1.9	Upper	3	6.41	6.41	1.25
DMC-MW-2R	200473	1269973	17.37	17.79	7-22	+10.8/-4.2	Upper	3	6.26	6.25	0.67
DMC-MW-3	200482	1269932	17.46	18.34	10-20	+8.3/-1.7	Upper	3	6.30	6.30	1.13
DMC-MW-4	200540	1269936	16.72	17.87	10-20	+7.9/-2.1	Upper	3	6.25	6.25	1.79
DMC-MW-5	200609	1269978	15.67	16.56	10-20	+6.6/-3.4	Upper	3	6.13	6.13	0.84
DMC-MW-8	200400	1270060	17.16	17.51	10-20	+7.5/-2.5	Upper	3	6.21	6.03	1.23

Well	North	East	TOC elev. (ft)*	Surface Elev. (ft)	Screen Depth (feet)	Screen Elevation (feet)	Zone	Model layer	Observed Level (ft)	Calculated level (ft)	Residual (ft)
DMC-MW-9	200384	1269980	16.47	16.92	10-20	+6.9/-3.1	Upper	3	6.33	6.15	1.56
DMC-MW-10	200387	1269915	16.90	17.18	10-20	+7.2/-2.8	Upper	3	6.41	6.30	0.63
DMC-MW-11	200408	1269834	17.83	18.06	10-20	+8.1/-1.9	Upper	3	6.50	6.49	1.23
DMC-MW-12	200465	1269908	18.04	18.35	10-20	+8.4/-1.6	Upper	3	6.35	6.35	0.88
DMC-MW-13	200441	1270168	17.60	18.00	7-22	+11/-4.0	Upper	3	6.04	6.01	1.25
DMC-MW-14	200571	1270057	16.16	16.56	7-22	+9.6/-5.4	Upper	3	6.07	6.06	1.21
DMC-MW-15	200653	1269985	15.49	15.94	7-22	+8.9/-6.1	Upper	3	6.08	6.08	1.85
DMC-MW-16	200515	1269912	17.59	18.24	7-22	+11.2/-3.8	Upper	3	6.30	6.30	1.63
DMC-MW-17	200611	1269897	16.51	17.01	7-22	+10.0/-5.0	Upper	3	6.23	6.24	1.90
DMC-MW-18	200467	1270048	17.60	17.90	7-22	+10.9/-4.1	Upper	3	6.17	6.15	0.85
DMC-MW-19	200514	1269976	16.99	17.49	7-22	+10.5/-4.5	Upper	3	6.22	6.21	1.08
MW-A	200383	1269955	17.10	17.7	20.1-30.1	-2.4/-12.4	Lower	3	6.36	6.19	0.30
MW-B	200402	1270066	18.00	18.4	23.2-33.2	-4.8/-14.8	Lower	4	6.20	6.20	-0.47
MW-C	200398	1270179	17.48	17.8	19.1-29.1	-1.3/-11.3	Lower	3	6.05	5.98	1.26

*TOC elevation datum is NAVD

Table 3. Statistics describing model calibration

Residual Mean	0.10
Absolute Residual Mean	1.01
Residual Std. Deviation	1.10
Sum of Squares	63.22
RMS Error	1.10
Min. Residual	-1.66
Max. Residual	1.90
Number of Observations	52
Range in Observations	4.08
Scaled Residual Std. Deviation	0.27
Scaled Absolute Residual Mean	0.25
Scaled RMS Error	0.27
Scaled Residual Mean	0.02

Table 4. Summary of water balance

Component	**Value (ft3/day)**
Inflow from recharge boundaries	4,197.4
Total discharge to Embayment	300.4
From layer 1:	143.0
From layer 2:	135.0
From layer 3:	22.4
Total discharge to Waterway	3,898.6
From layer 1:	1,189.8
From layer 2:	210.9
From layer 3:	222.3
From layer 4:	2,275.6

Figures

Figure 1. Area included in the groundwater model

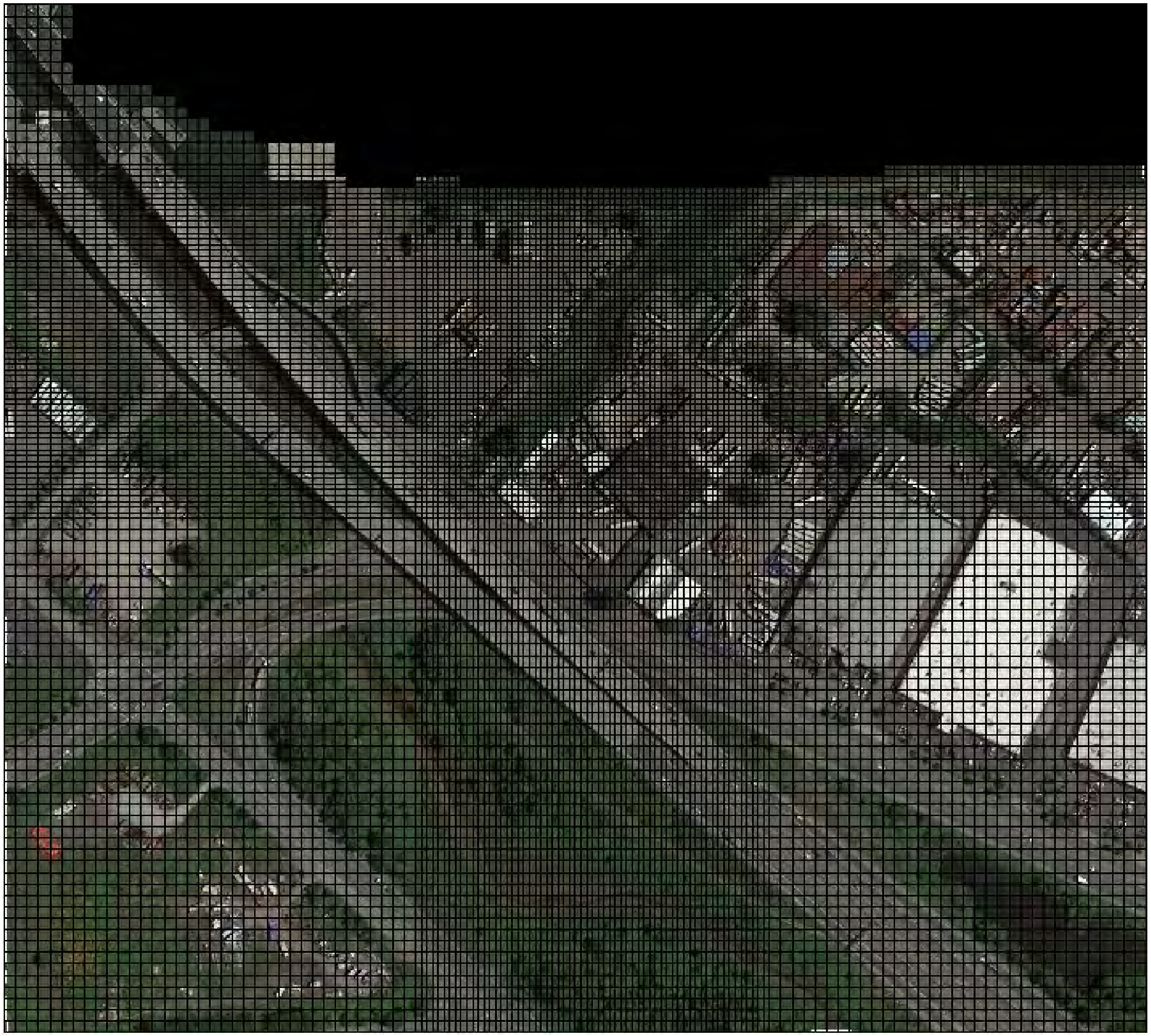

Figure 2. Groundwater model grid spacings

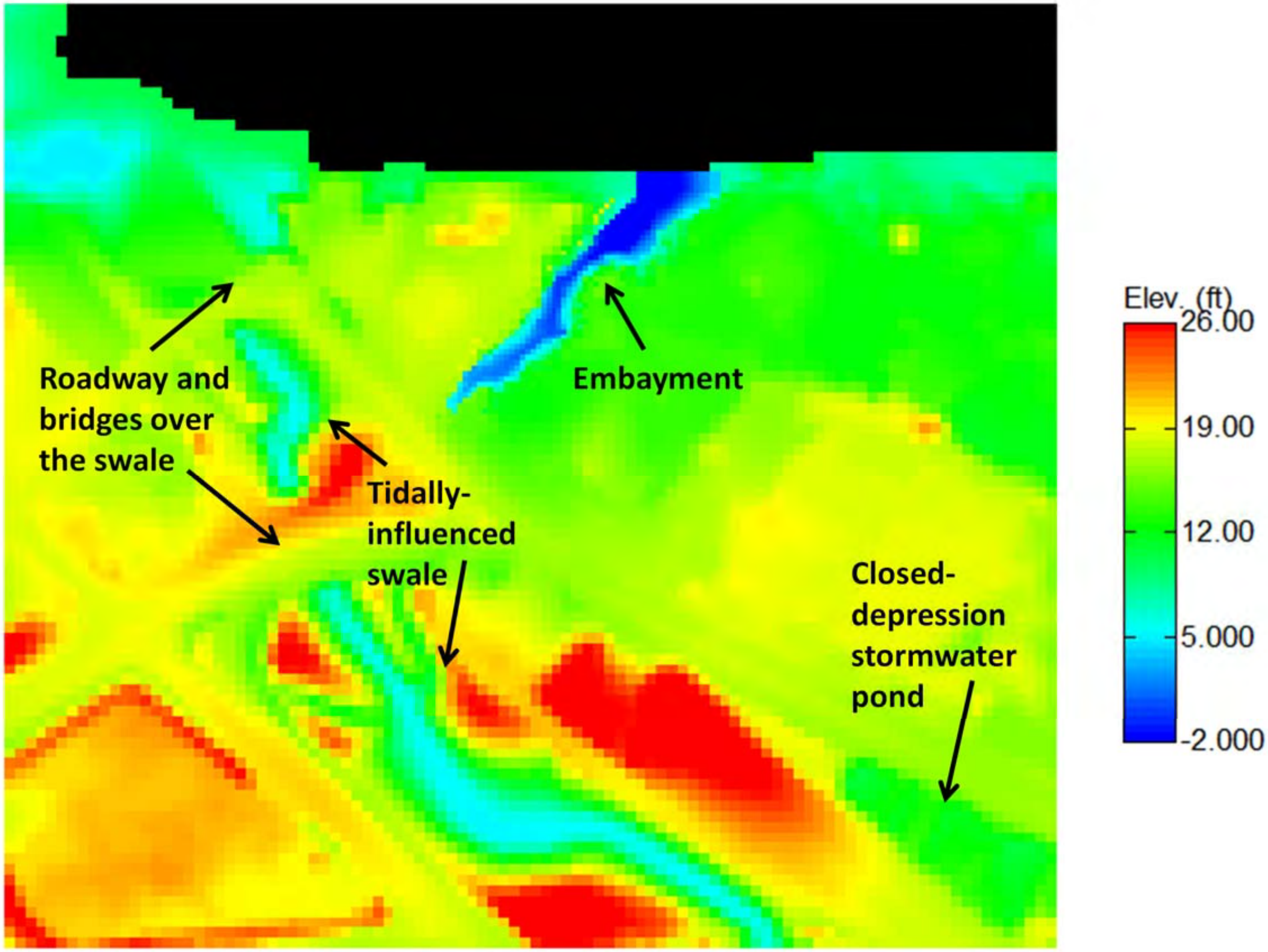

Figure 3. Surface topography and related features

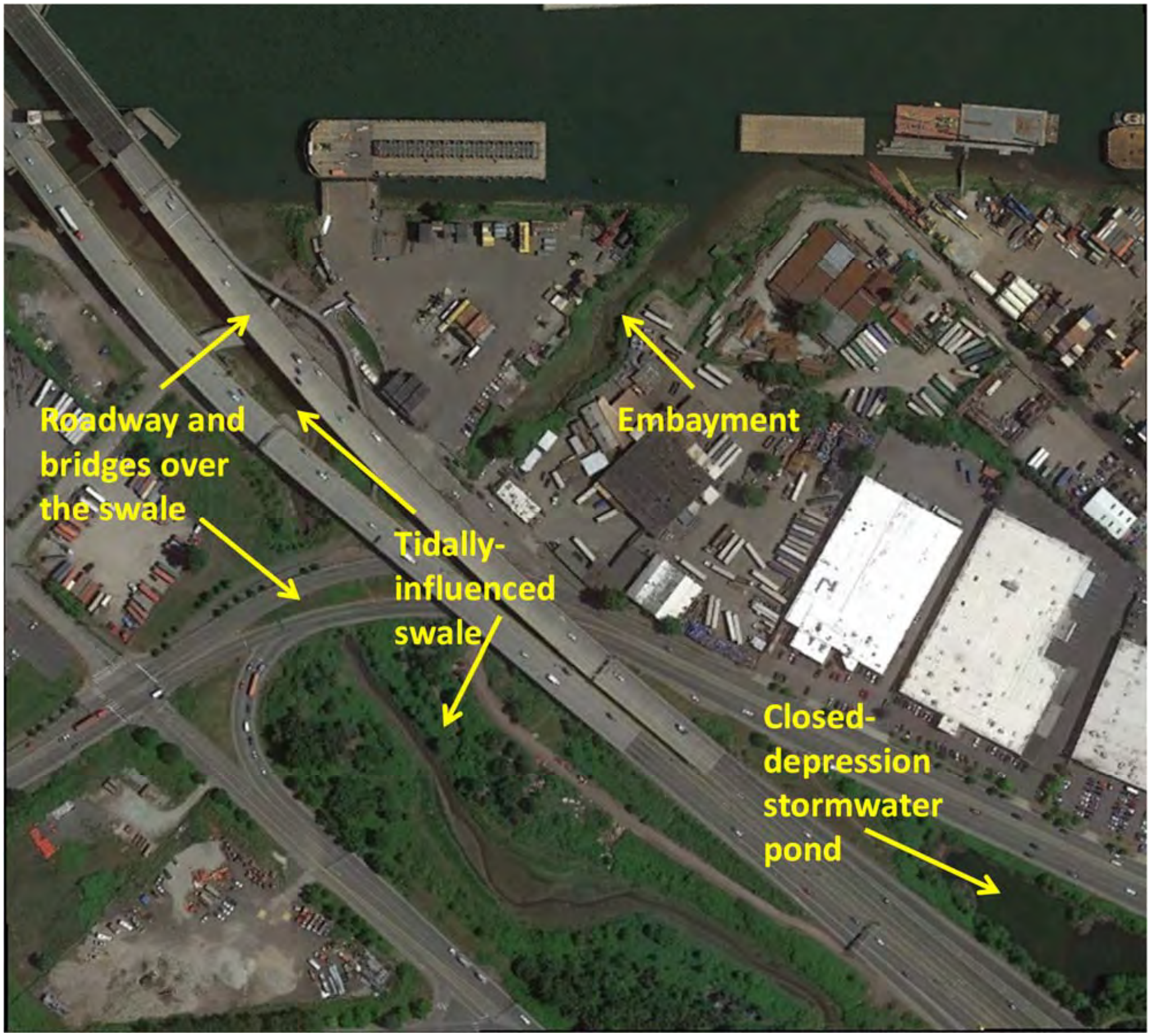

Figure 4. Roadways and bridges affecting surface topography

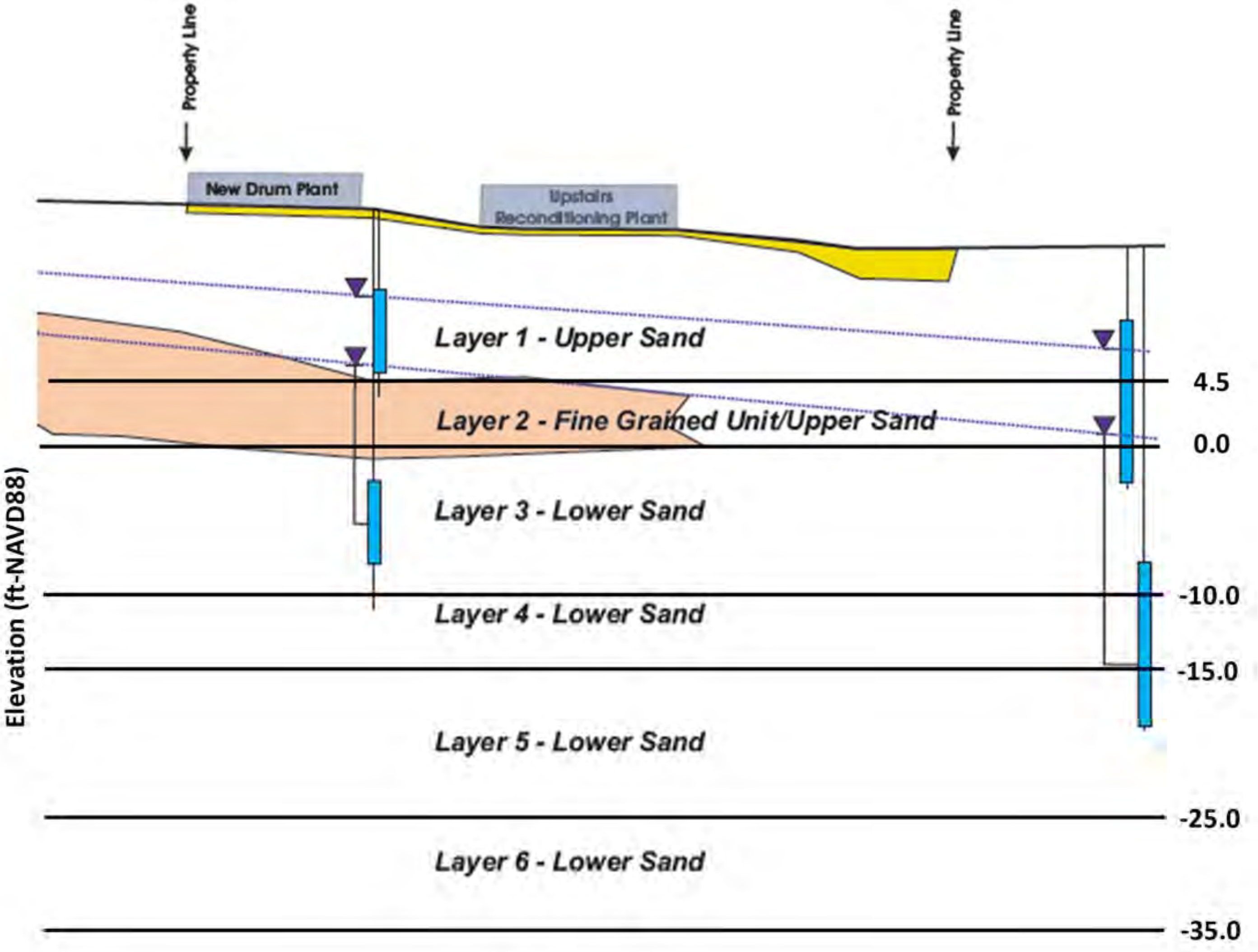

Figure 5. Example cross section showing model layers

Figure 6. Horizontal hydraulic conductivity zones in model Layer 1**.**

Figure 7. Horizontal hydraulic conductivity zones in model Layer2**.**

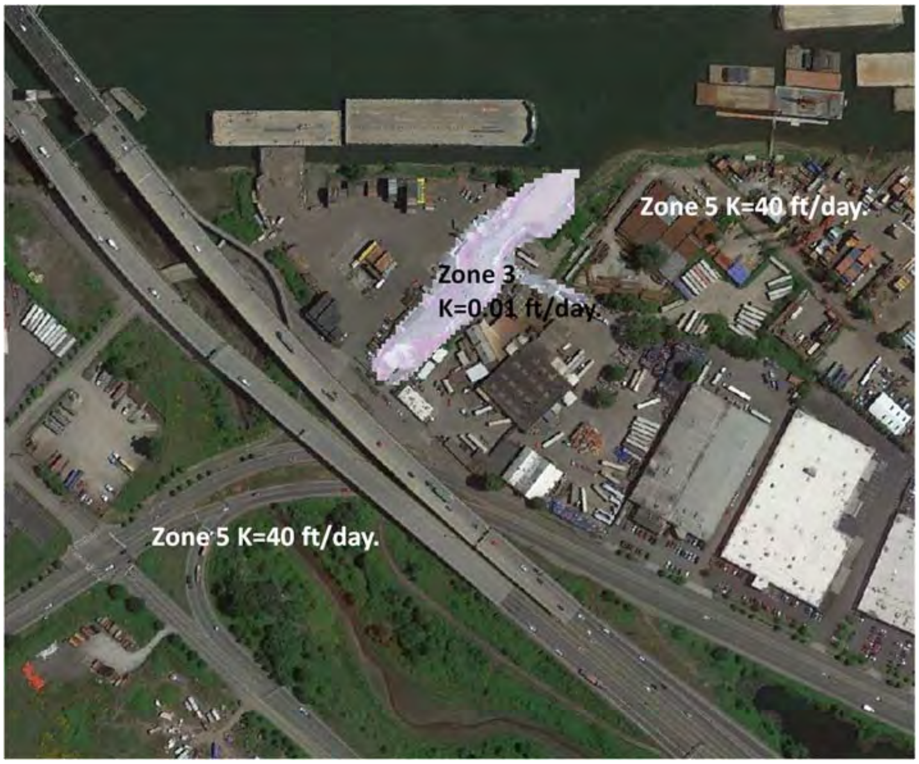

Figure 8. Horizontal hydraulic conductivity zones in model Layer3**.**

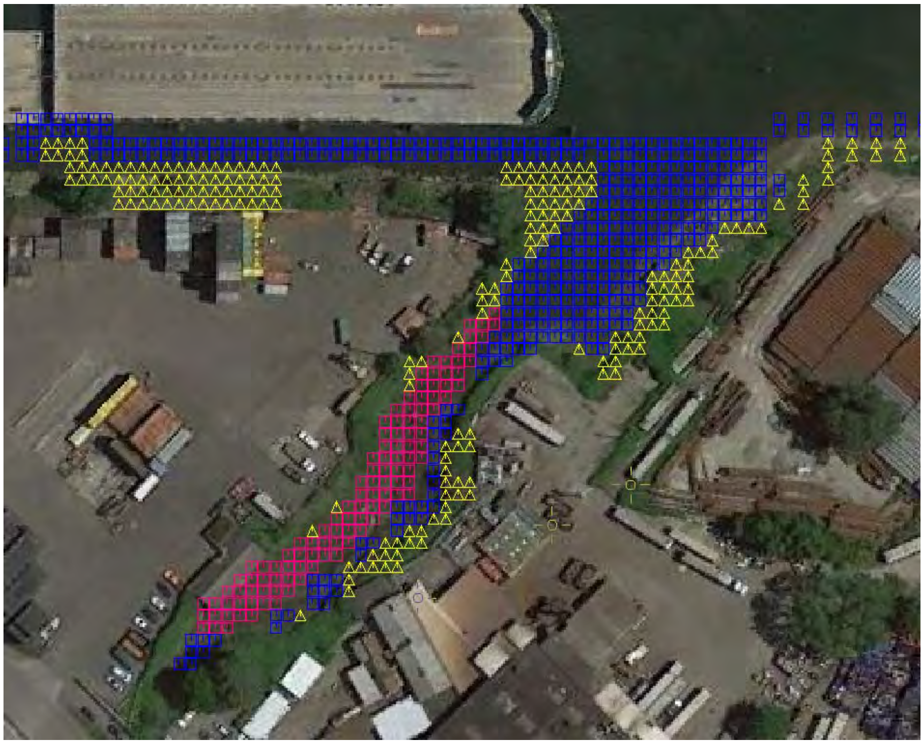

Figure 9. Location of cemented area in model Layer 1. Red symbols denote locations along the Embayment boundary with cemented conditions. Blue symbols denote areas without cemented conditions. Yellow symbols denote drains.

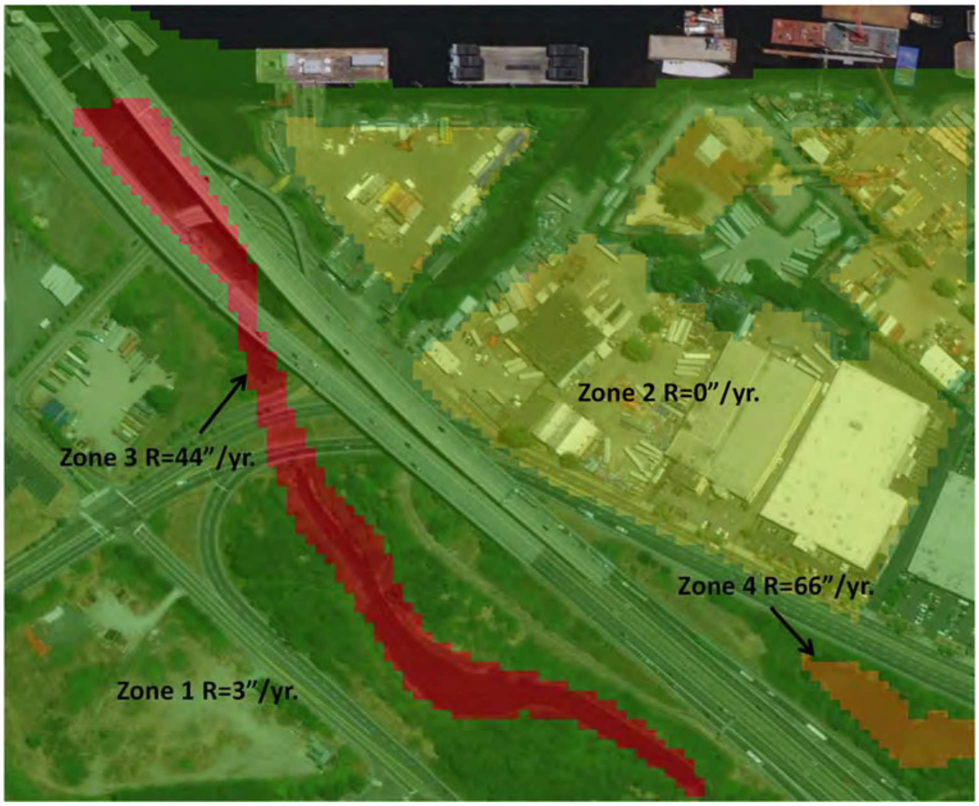

Figure 10. Recharge zones

Figure 11. Discharge boundaries.

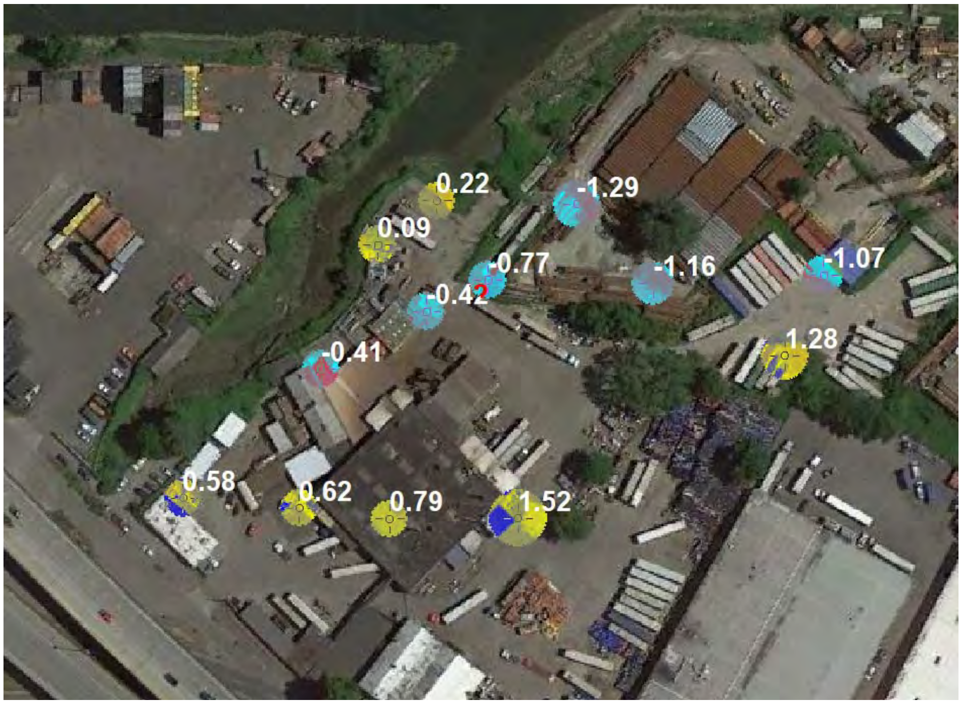

Figure 12. Water level residuals (ft) for the upper sand unit (model layers 1 and 2). Yellow denotes locations where model values are greater than observations; blue denotes locations where model values are less than observations.

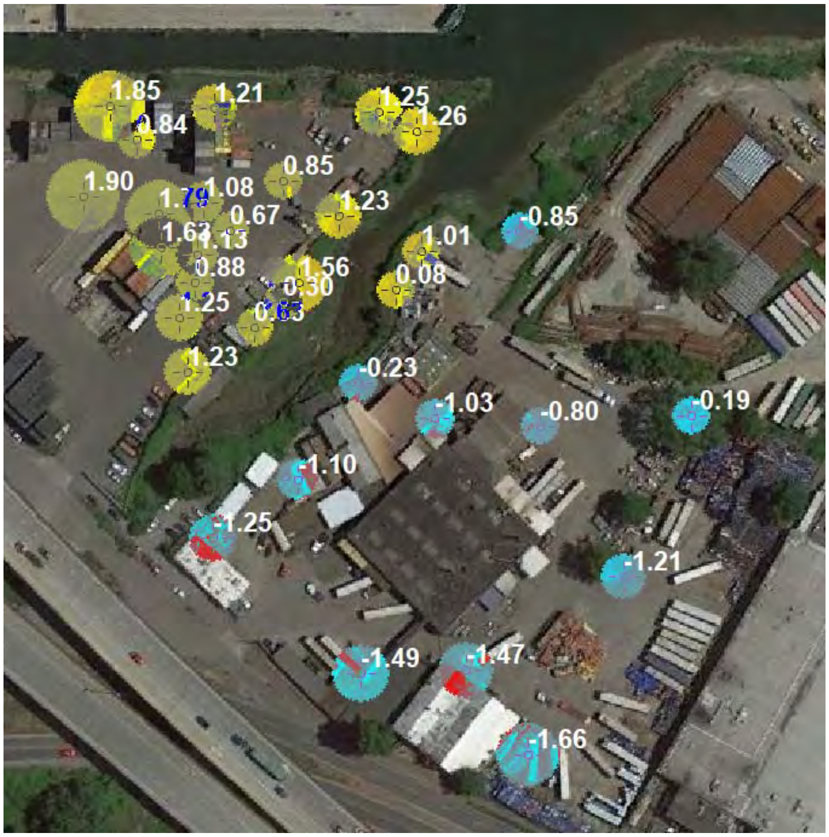

Figure 13. Water level residuals (ft) for the lower sand unit (model Layer 3)

Figure 14. Water level residuals (ft) for the lower sand unit (model Layer 4)

Figure 15. Model water level contours for the upper sand unit (model Layer 1)

Figure 16. Model water level contours for the lower sand unit (model Layer 4)

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MEMORANDUM

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From: Joel Massmann, Ph.D., P.E.

Date: January 12, 2022

Subject: ICS-NWC Interim Action
Groundwater modeling to evaluate effects of subsurface barriers
DRAFT

A. Overview

Keta Waters' scope of work for the ICS-NWC Interim Action involves a set of tasks associated with groundwater flow modeling at the ICS Site. The objective of the modeling activities is to simulate conceptual, interim-action remedies, including the effects of subsurface barriers. This memorandum describes the results of these simulations.

The three-dimensional, steady-state groundwater flow model described in Keta Waters (2021) was used to simulate groundwater flow and advective transport from the ICS site. The area included in the groundwater model is shown in Figure 1 and an example cross section showing the layering used to describe stratigraphy is summarized in Figure 2. Figure 3 shows the layer geometry beneath and adjacent to the embayment. The model is used to estimate flow paths and groundwater travel times from the ICS site to discharge locations along the Trotsky Inlet (the embayment) and along the Lower Duwamish Waterway (the waterway). These flow paths and travel times are calculated for two scenarios. The first scenario considers existing conditions and the second scenario considers the effects of a sheet pile wall constructed along the northwest side of the embayment.

B. Current conditions scenario

The current-conditions scenario is based on the steady-state groundwater flow model described in Keta Waters (2021). The embayment is treated as a river boundary where the groundwater discharge is determined based on the difference between the groundwater level and the elevation of the river. The river elevations are assigned from topography data. The conductance of the river boundaries used to represent the embayment is assigned a value of 0.4 ft^2/day, except for an area along the eastern edge of the embayment center. The presence of a hydraulic barrier in this area was noted in the Draft RI (DOF, 2020) based on water levels and tidal responses. The barrier is shown in Section I-I' included in a DOF technical memorandum dated June 9, 2021 (DOF, 2021). The conductance in this area was assigned a value of $4x10^{-6}$ ft^2/day. Drain boundaries are also used at locations along the banks of the embayment that are above the mean elevation of the waterway (4.75 ft NAVD). These drains allow discharge to seepage faces that may occur along the banks of the embayment.

Water level contours in the upper sand zone for the current-conditions scenario are shown on Figure 4. Figure 4 also shows the starting locations for particles used to depict groundwater flow pathways and to estimate groundwater travel times. Two sets of particles are included. The first set of particles originates on the Douglas property and the second set originates on the ICS property. The starting depth for the particles is assumed to be in the upper sand zone that is included in model layer 1 and in the fine-grained unit that is included in model layer 2. Travel times for the particles are calculated assuming a porosity of 0.25. The travel times represent advective flow for groundwater and do not consider retardation of dissolved constituents due to sorption or other geochemical processes.

Under current conditions, approximately 99% of the particles that originate at the locations shown in Figure 4 discharge to the embayment. The remaining 1% discharge to the waterway. The particle pathways are shown in Figure 5. The red and green lines in Figure 5 show pathways for particles as they travel in layers 1 and 2, respectively. The yellow lines denote locations where particles travel in layer 3. The median travel time for the particles that discharge into the embayment is 6.2 years. The median travel time for the relatively few particles that travel to the waterway is approximately 360 years.

C. Effects of sheet pile wall and removal of embayment hydraulic barrier

The effects of installing a sheet pile wall along the northwest side of the embayment and removing the hydraulic barrier within the embayment were simulated with the groundwater flow model. Figure 6 shows the location of the sheet pile wall simulated with the model. The wall extends to elevation -25 ft. NAVD, which is the bottom of layer 5 in the model. This is approximately 42 feet below the land surface and approximately 30 feet below the bottom of the embayment. The wall is assumed to be very low permeability and no leakage through the wall is considered.

With the sheet pile wall in place, approximately 39% of the particles discharge to the waterway and the remaining 61% discharge to the embayment. The particle pathways are shown in Figure 6. Many of the particles that travel to the waterway first travel downward to the lower sand (layer 3) and then travel horizontally through the lower sand to the waterway. Most of the particles that travel to the embayment travel directly from the source area into the embayment.

The sheet pile wall has a relatively small effect on travel times. The median travel time for those particles that discharge to the embayment increases from approximately 6.2 years to approximately 7.4 years. The median travel time for the particles that travel to the waterway is 196 years, as compared to 363 years under the current-conditions scenario. The travel times for the particles are summarized in Table 1. Again, these travel times represent advective flow for groundwater and do not consider retardation of dissolved constituents due to sorption or other geochemical processes.

It should be noted that with the wall in place, only particles from the ICS site go to the embayment. Nearly all particles that originate on the Douglas property go to the waterway when the wall is in place.[1]

The particle traces shown in Figure 6 and the travel times summarized in Table 1 consider all the particles on both the Douglas and ICS properties. Table 2 focuses on particles that originate on the ICS property. Table 2b illustrates that with the sheet pile wall in place, all particles that originate in layer 1 (the upper sand zone) discharge to the embayment with a median travel time of approximately 4.5 years. Table 2b shows that approximately 99.1% of the particles that originate in layer 2 (the fine-grained aquitard and the upper sand) discharge to the embayment with a median travel time of approximately 28 years. The single layer 2 particle that discharges to the waterway flows beneath the embayment along the embayment axis.

D. Groundwater discharge to the embayment.

Table 3 compare groundwater discharge rates for several different model scenarios. The first scenario is the base case with no sheet pile cutoff wall and with the presence of the hydraulic barrier. The second scenario considers no cutoff wall and no hydraulic barrier. Finally, the third scenario includes the cutoff wall but no hydraulic barrier.

The addition of the sheet pile wall and the removal of the hydraulic barrier from the embayment has a small effect on the amount of groundwater discharge that occurs to the embayment. Under existing conditions (i.e., no sheet pile wall but with the hydraulic barrier), the estimated total discharge to the embayment from all locations in the model is approximately 2,230 gallons per day (gpd). With no wall and no hydraulic barrier to the embayment, the estimated discharge increases to approximately 2,408 gpd. However, with a sheet pile cutoff wall and no hydraulic barrier, the discharge to the waterway is 2,239 gpd, which is essentially the same as the current conditions or baseline scenario.

Under the baseline scenario, the groundwater that discharges into the embayment occurs approximately equally from layers 1 (1,058 gpd) and 2 (1,004 gpd), with a relatively

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[1] Several of the particle starting locations on the Douglas property are inside of the sheet pile wall. These particles travel to embayment. All particles that originate outside the sheet pile wall on the Douglas property travel to the waterway.

small amount from layer 3 (168 gpd). If there is no hydraulic barrier present, then the flow from layer 1 increases to 1,328 gpd and the flow in layer 2 decreases to 915 gpd.

The estimated groundwater flow through the zone on the ICS property that was used for starting locations for particle tracking is approximately 270 gpd (see Figure 4 for the starting locations). Most of this flow (180 gpd) occurs in Layer 1 (the upper sand zone). The remaining 90 gpd occurs in layer 2 (the fine-grained aquitard and the upper sand).

As noted in Table 2, essentially all flow from the particle area in layers 1 and 2 discharges to the embayment under the current conditions scenario. This corresponds to approximately 270 gpd of discharge to the embayment from the area that contains the particle starting points.

E. Estimates of PCB travel times.

The travel times that are discussed in previous sections represent advective flow for groundwater and do not consider retardation of dissolved constituents due to sorption or other geochemical processes. Travel times for polychlorinated biphenyls (PCBs) will be much longer than groundwater travel times because of the effects of sorption. These effects can be approximated using retardation factors. PCB retardation factors give the ratio between the travel time for PCB and the travel time for groundwater.

The retardation factor is dependent upon the contaminant distribution coefficient, Kd. Kd is calculated as the product of the organic carbon partition coefficient, Koc, times the fraction of organic carbon in soils, foc (Kd=Koc x foc). Table 4 lists a range of foc and Kd values for PCB's that have been reported by GeoEngineers (2016) and DMD, Inc. (2019). The compounds included in Table 4 are listed from lowest to highest retardation factors. The highlighted row lists the mean site Kd from DMD (2019) and the resulting retardation factor (860,161). The retardation factors listed in Table 4 were calculated assuming a bulk soil density of 1.6 kg/L and a porosity of 0.25.

The retardation factor describes how slowly the PCB will migrate relative to groundwater. With a retardation factor of 860,000, a one-year groundwater travel time corresponds to an 860,000-year travel time for PCB. Figure 7 illustrates particle travel times for the particle traces that are shown in Figure 6 and listed in Table 2a. A range of retardation factors is considered. The curve with a retardation factor of 1 corresponds to the groundwater travel times for the particles. The median travel time (i.e., the travel time for which 50% of the particles are faster and 50% are slower) is approximately 7 years. The median travel time for PCB's assuming a retardation factor of 860,000 is approximately 5.9 million years. Even with the smallest retardation factor listed in Table 3 (12,000), the median travel time for PCB's is approximately 83,000 years.

References

DMD, Inc. Memorandum entitled "Geochemical Assessment of PCB's at the ICS/[former] Northwest Cooperage Site, Seattle, WA – ADDENDUM." From Raleigh Farlow to Matt Dalton (DOF). May 16, 2019.

DOF, Dalton Olmsted and Fuglevand, 2016. Remedial Investigation Report, Industrial Container Services, WA, LLC (former NW Cooperage Site), Seattle, WA. Public Review Draft, February 2020..

DOF, 2021a. Revisions to Draft RI Figures, ICS Remedial Investigation Report, February 2020. Technical memorandum to Vicki Sutton, Washington Dept. of Ecology, June 9, 2021 (includes revised Section I-I').

GeoEngineers, 2016. Ecology Review Draft, Remedial Investigation Report for 7100 1st Avenue South Seattle, LLC. December 30, 2016.

Keta Waters, 2021. Final Draft Description of Groundwater Flow Model Industrial Container Services, WA, LLC, Seattle, WA, prepared for Dalton, Olmsted & Fuglevand, Inc., Draft, December 30, 2021.

Table 1. Estimated groundwater travel times for particles originating on both the Douglas and ICS properties with starting locations shown in Figure 1.

	Current conditions		**Wall to -25 ft NAVD and removal of embayment hydraulic barrier**	
	Percentage of particles	Median travel time (yrs)	Percentage of particles	Median travel time (yrs)
Travel to embayment	99%	6.2	61%	7.4
Travel to waterway	1%	363	39%	196

Table 2. Estimated groundwater travel times for particles originating on the ICS property with starting locations shown in Figure 3.

a. Travel times for all particles in layers 1 and 2.

	Current conditions		**Wall to -25 ft NAVD and removal of embayment hydraulic barrier**	
	Percentage of particles	Median travel time (yrs)	Percentage of particles	Median travel time (yrs)
Travel to embayment	100%	7.8	99.6%	9.96
Travel to waterway	0%	n.a.	0.4%	94

b. Travel times particles originating in layer 1.

	Current conditions		**Wall to -25 ft NAVD and removal of embayment hydraulic barrier**	
	Percentage of particles	Median travel time (yrs)	Percentage of particles	Median travel time (yrs)
Travel to embayment	100%	4.49	100%	7.31
Travel to waterway	0%	n.a.	0%	n.a.

c. Travel times particles originating in layer 2.

	Current conditions		**Wall to -25 ft NAVD and removal of embayment hydraulic barrier**	
	Percentage of particles	Median travel time (yrs)	Percentage of particles	Median travel time (yrs)
Travel to embayment	100%	28.1	99.1%	27.8
Travel to waterway	0%	n.a.	0.9%	94

Table 3. Comparison of water balances for different model scenarios.

Component	**Water balance value (gallons/day)**		
Model scenario[1]	**1**	**2**	**3**
Inflow from recharge boundaries	31,397	31,397	31,397
Total outflow to discharge boundaries	31,409	31,408	31,420
Total discharge to Embayment	**2,230**	**2,408**	**2,239**
From layer 1:	1,058	1,328	1,233
From layer 2:	1,004	915	841
From layer 3:	168	165	164
Total discharge to Waterway	29,179	29,000	29,181
From layer 1:	8,912	8,847	8,904
From layer 2:	1,584	1,568	1,578
From layer 3:	1,663	1,654	1,663
From layer 4:	17,021	16,930	17,036

Scenario 1: With hydraulic barrier and no wall
Scenario 2: No hydraulic barrier and no wall
Scenario 3: No hydraulic barrier and with a wall

Table 4. Retardation factors calculated from Koc, Kd and foc estimates.

Compound	Source	Koc (L/kg)	foc	Kd (L/kg)	Retardation factor
Aroclor 1242	GeoEngineers	170,000	1.14%	1,938	12,404
Aroclor 1248	GeoEngineers	280,000	1.14%	3,192	20,430
Aroclor 1254	GeoEngineers	430,000	1.14%	4,902	31,374
Aroclor 1260	GeoEngineers	820,000	1.14%	9,348	59,828
Total PCBs	GeoEngineers	310,000	1.14%	3,534	22,619
Tetrachlorobiphenyls - Cl4 homologs	D.M.D., Inc.	755,300	2.0%	15,106	96,678
Pentachlorobiphenyls - Cl5 homologs	D.M.D., Inc.	1,555,250	2.0%	31,105	199,072
Hexachlorobiphenyls - Cl6 homologs	D.M.D., Inc.	4,789,150	2.0%	95,783	613,011
Heptachlorobiphenyls - Cl7 homologs	D.M.D., Inc.	11,884,500	2.0%	237,690	1,521,216
Octachlorobiphenyls - Cl8 homologs	D.M.D., Inc.	24,546,100	2.0%	490,922	3,141,901
Mean ICS-NWC site downgradient Cl-biphenyls	D.M.D., Inc.	6,720,000	2.0%	134,400	860,160

Figure 1. Area included in the groundwater model

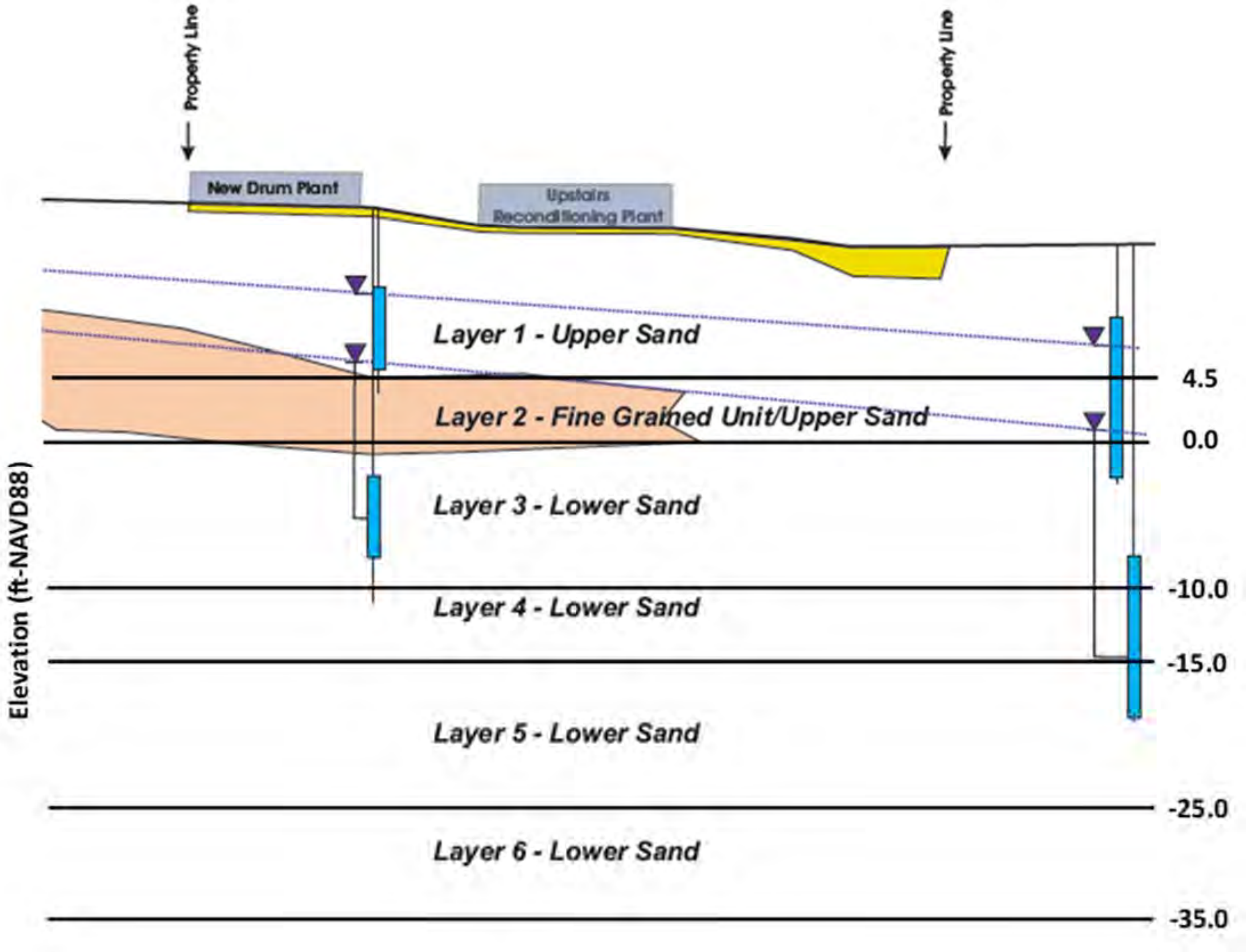

Figure 2. Example cross section showing model layers

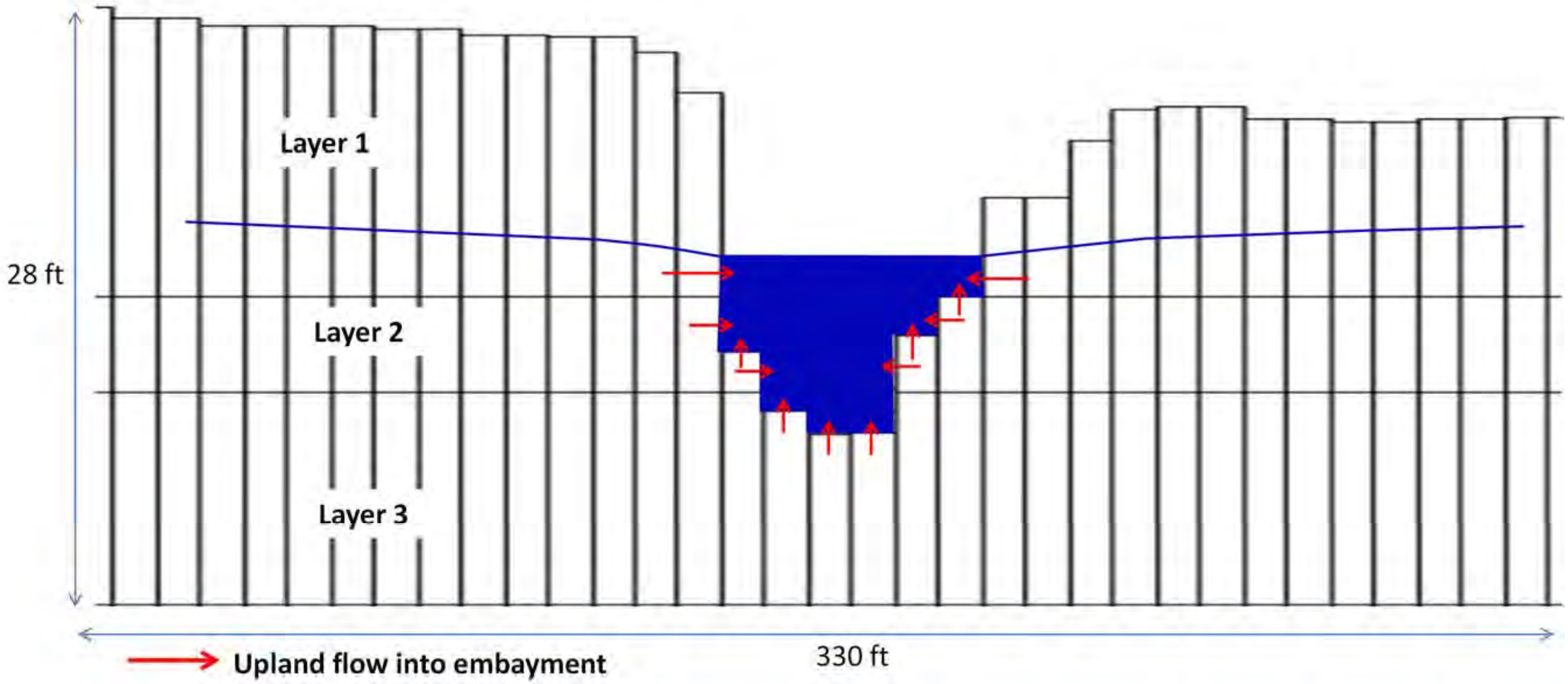

Figure 3. Example cross section showing layer geometry, model grid, and flow directions in the vicinity of the embayment

Figure 4. Modeled average water level contours in the upper sand zone for the current-conditions scenario and starting locations for particles used to depict groundwater flow pathways.

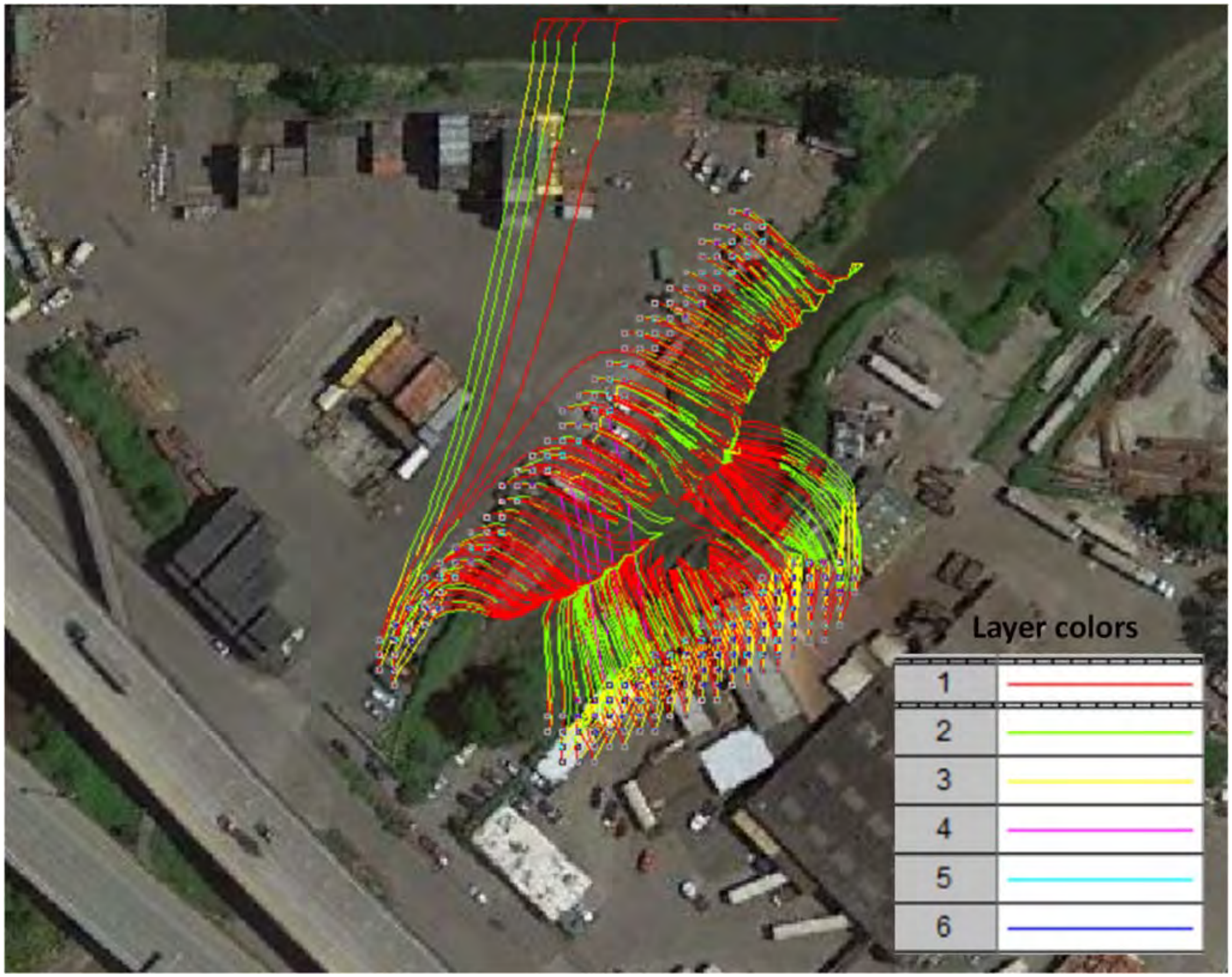

Figure 5. Pathways for particles under the current-conditions scenario.

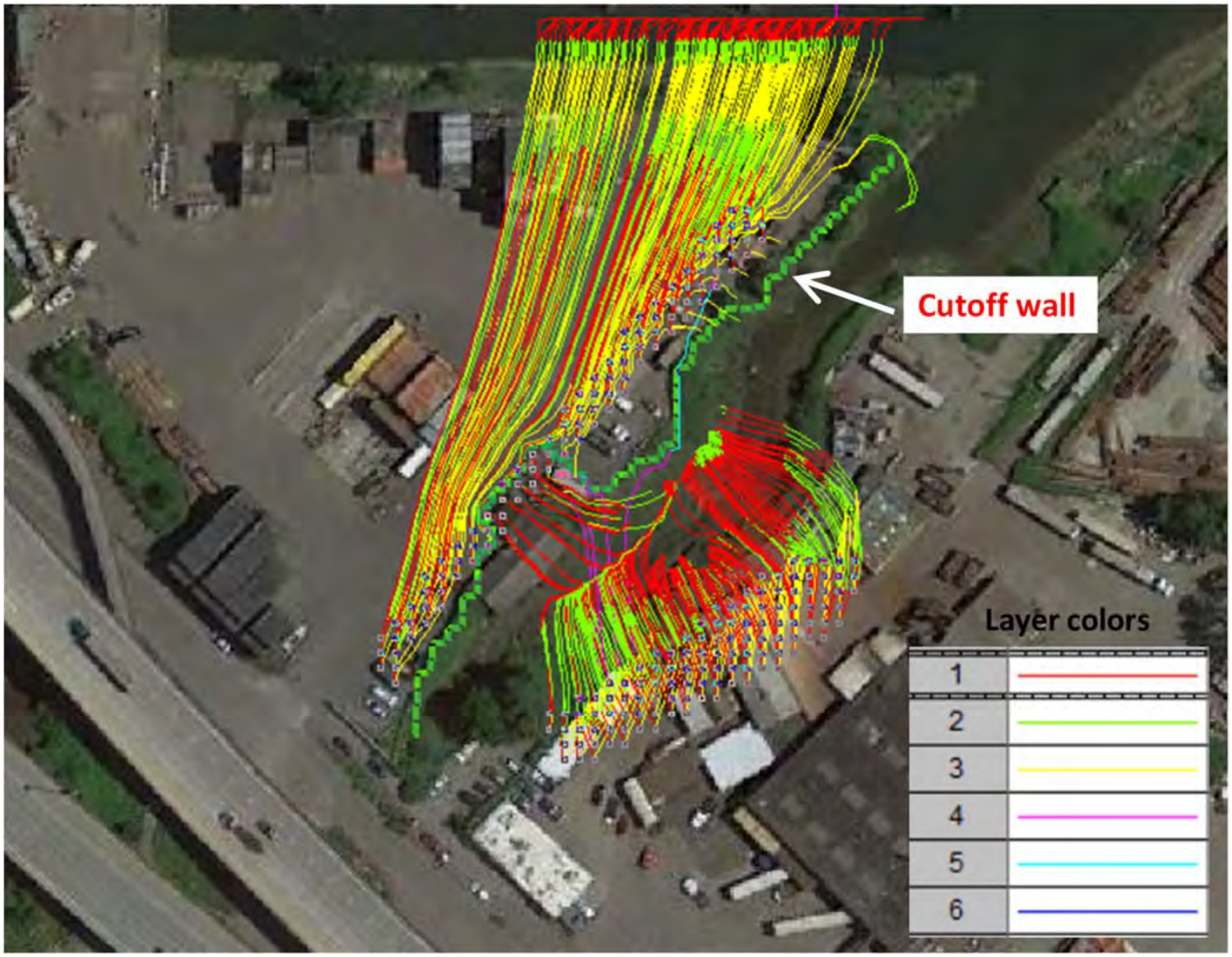

Figure 6. Location of the sheet pile wall, water level contours in the upper sand zone, and particle traces.

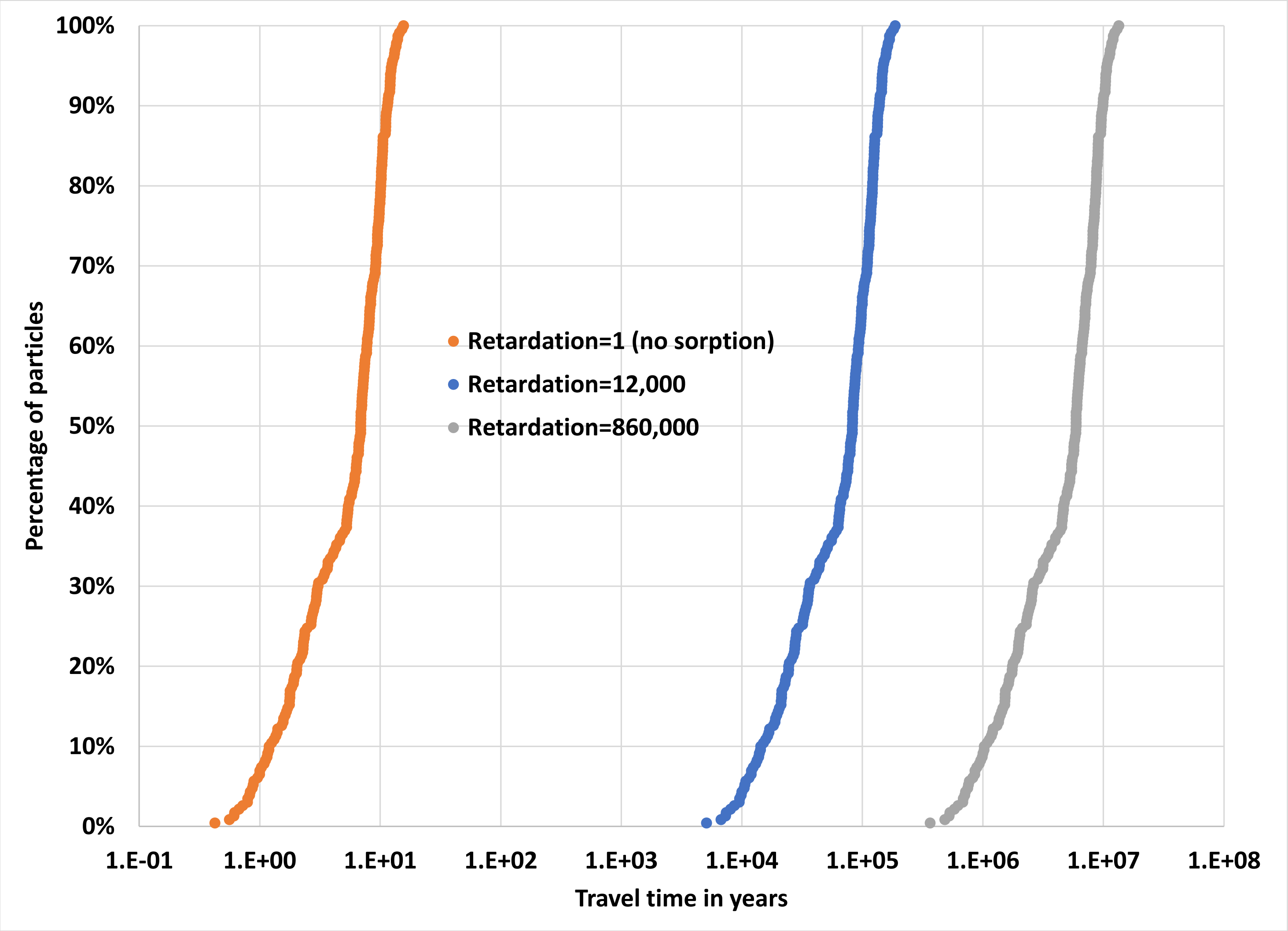

Figure 7. Particle travel times assuming a range of retardation factors.

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MEMORANDUM

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Date: January 12, 2022

Subject: ICS Interim Action
Sediment cap modeling
DRAFT

A. Overview

This memorandum presents results from simulations describing groundwater transport of PCB's through a proposed sediment cap on the ICS site. Transport through the proposed cap was modeled using the CapSim transport model (Shen et al., 2018). CapSim was specifically developed to simulate one-dimensional contaminant transport through sediment caps for the purposes of cap design. The model is built on a foundation of sediment and cap modeling dating back to 1991 (Thoma et al., 1993) and earlier versions were described in EPA guidance for capping (Palermo et al., 1998). The scientific background and logic structure for the current version of the model is described in Reible (2014) and Shen et al. (2018).

The cap system that was modeled is illustrated in Figure 1 and is comprised of three primary zones: 1) the sediment cap, 2) a sequester zone of cap material amended with sorptive additives, and 3) the underlying sediment. The CapSim model was used to simulate the simultaneous transport of three PCB constituents from the sediment into the cap system: Aroclor 1248, Aroclor 1254, and Aroclor 1260. Total PCB concentrations were derived by summing the concentrations of these three constituents.

Transport processes that were simulated include 1) advection and dispersion associated with groundwater flow through the cap, 2) molecular diffusion, and 3) sorption and desorption from sediment and cap materials. The sorption and desorption processes were simulated using equations that describe linear, reversible sorption, consistent with the modeling approach described in WAC 173-34-747(4) of the Model Toxics Control Act.

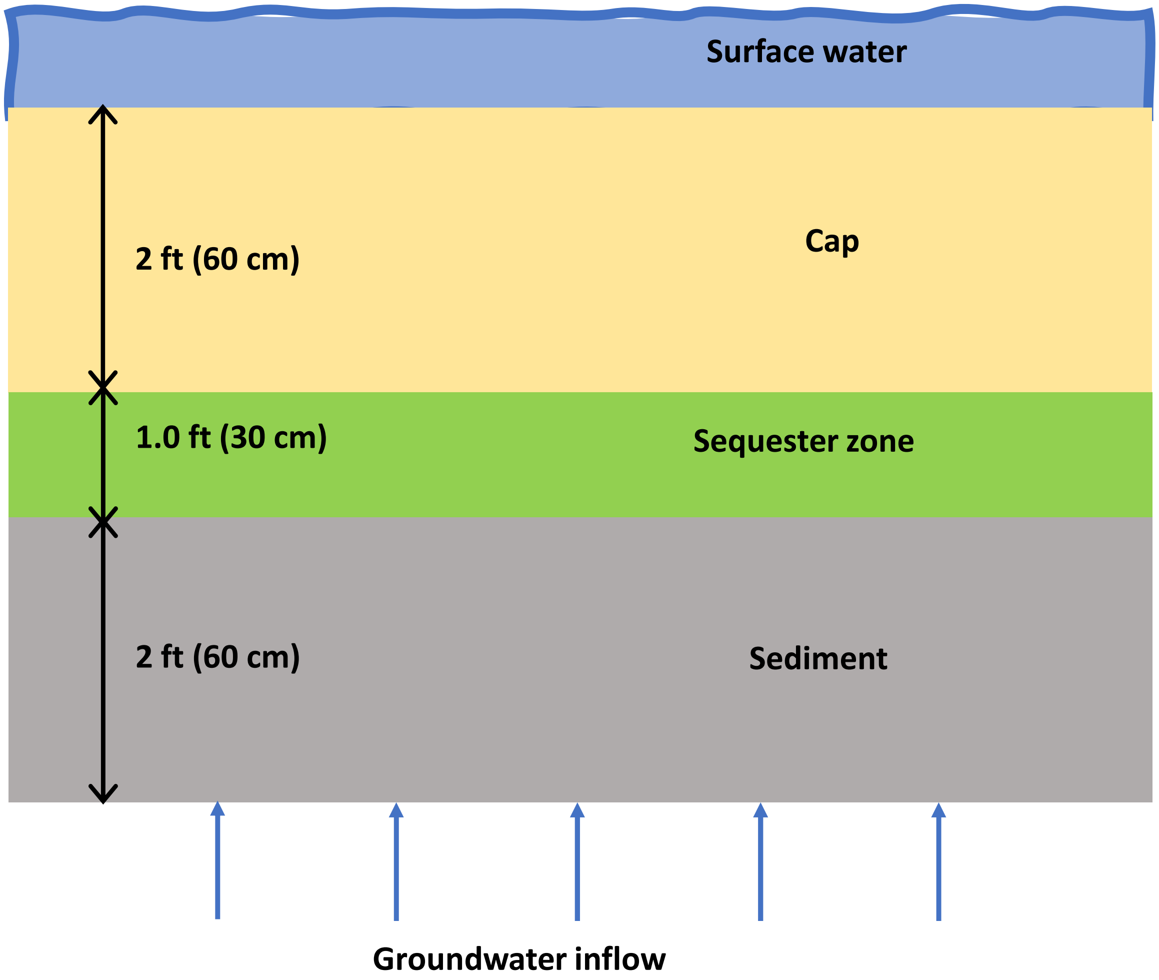

Figure 1. Configuration of the modeled engineered cap system

B. Transport properties

Properties assigned to the PCB constituents are listed in Table 1. These include molecular weight (MW), molecular diffusion coefficient (D_w), and contaminant distribution coefficient (K_d). The molecular weight and molecular diffusion coefficients listed in Table 1 are included in the CapSim database. The K_d values listed in Table 1 for the sediment are from Table 2 in the attached memorandum from DOF.[1] The K_d values for the sediment were calculated assuming the fraction of organic carbon (foc) in the sediment equals 3.4%, as described in the DOF memorandum.

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[1] Memorandum from Matt Dalton (DOF) to Joel Massmann (Keta Waters) dated April 3, 2020 with subject "Starting PCB Concentrations, Embayment CAP Modelling, ICS Site, Seattle, Washington."

A range of K_d values were used for the sequester zone, depending upon the amount of amendment that would be added to the cap materials. Three scenarios were considered, as listed in Table 1: f_{oc}=0.5%, f_{oc}=1.0%, and f_{oc}=1.5%.[2]

Table 1. Properties assigned to the PCB constituents

			K_d (L/kg)			
Name	**MW**	**D_w (cm^2/s)**	**Sediment**	**Sequester zone**		
			3.4% f_{oc}	0.5% f_{oc}	1.0% f_{oc}	1.5% f_{oc}
Aroclor 1248	292	5.40E-06	29,353	4,317	8,633	12,950
Aroclor 1254	326.4	5.20E-06	76,410	11,237	22,474	33,710
Aroclor 1260	360.9	5.00E-06	262,084	38,542	77,084	115,625

The sediment, cap, and sequester zone materials were assumed to have a porosity of 0.4. The dispersivity value was assumed to be 1 cm for each of these zones, based on the default values included in the CapSim database.

C. Groundwater inflow properties

Groundwater inflow into the cap from underlying sediments was estimated based on the results from the three-dimensional MODFLOW groundwater flow model developed for the site (Keta Waters, 2021; Keta Waters 2022). Flow through the cap is input to the CapSim model using estimates of specific discharge that are derived from the groundwater flow model.[3] The specific discharge was calculated using the version of the groundwater flow model that does not include the south shoreline hydraulic barrier.[4] The resulting estimated specific discharge is 43 cm/year (1.4 feet/year). The CapSim model was run assuming specific discharge values of 20 and 200 cm/year (0.66 and 6.6 ft/year) to assess a relatively wide range of specific discharge values.

The concentration of the PCB constituents in the groundwater inflow are listed in Table 2. These values were provided in the attached memorandum from DOF (M. Dalton, April 3, 2020). The groundwater concentrations were held constant over the duration of the simulation period.

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[2] The K_d values are linearly proportional to the f_{oc}. For example, the K_d for the sequester zone assuming an f_{oc} equal to 1.0% is equal to 0.29 (1%/3.4%) times the K_d for the sediment.

[3] Specific discharge is defined as flow per unit area and is given by the expression Q/A, where Q is the volumetric flow (L^3/t) and A is the area perpendicular to flow (L^2) (Fetter, 1988). In the context of the CapSim model, the specific discharge is the flow through the cap divided by the area of the cap.

[4] The specific discharge value was calculated from the groundwater flow model by taking the area of the embayment divided by the total flow into the embayment. The area in the vicinity of the PCB contamination that was used for this calculation was approximately 22,000 ft^2 (0.5 acres). The total discharge into this area was 85 ft^3/day. This includes both the horizontal and vertical. Dividing 85 ft3/day by 22,000 ft^2 gives the specific discharge of 0.0039 ft/day (85/22,000) or 1.4 ft/yr.

Table 2. PCB concentrations in groundwater inflow

Aroclor 1248	**Aroclor 1254**	**Aroclor 1260**	**Total**
(ug/L)	(ug/L)	(ug/L)	(ug/L)
0.78	0.16	0.035	0.98

D. Model simulation parameters

Parameters related to the model grid and time steps are listed in Table 3. The simulation time was set to 100 years with a time step of 0.1 years. The cap was divided into 220 cells or grid points. The cells ranged in size from 0.6 cm (0.02 ft) to 1.5 cm (0.05 ft). Both the grid size and the time steps were based on recommended values included in the CapSim software.

Table 3. Parameters related to the model grid and time steps.

Simulation time (yr):	100		
Time step (yr):	0.1		
Total number of grid points:	220		
	Cap	**Sequester zone**	**Sediment**
Layer grid size (cm):	0.6	1.5	0.6
Layer number of grids:	100	20	100

E. Model results

Results from the model simulations are summarized in Table 4. The results from six simulations are included. These results correspond to three different sequester zone configurations (0.5%, 1.0%, and 1.5% f_{oc} values) and two values for groundwater discharge through the cap (20 and 200 cm/yr [0.66 and 6.6 ft/yr]). Total dissolved and total sorbed concentrations are provided for a depth of 60 cm (2.0 feet). This location is at the bottom of the cap and corresponds to the interface between the sequester zone and the cap material. Total PCB concentrations were derived by summing the concentrations for the three constituents (Aroclors 1248, 1254, and 1260).

As expected, the highest estimated concentrations correspond to the simulation with the lowest amount of amendment in the sequester zone (f_{oc}=0.5%) and the highest groundwater discharge rate (200 cm/yr (6.6 ft/yr)). The total concentration of dissolved PCB in the porewater at this time (100 yrs.) and location is 1.8×10^{-8} ug/L and the total sorbed concentration is 7.9×10^{-5} ug/kg. If the groundwater discharge rate is equal to 20 cm/yr (0.66 ft/yr), the porewater at this time and location is 3.1×10^{-21} ug/L and the total sorbed concentration is 1.4×10^{-17} ug/kg. Increasing the amount of amendment in the sequester zone from an f_{oc} equal to 0.5% to an f_{oc} equal to 1.5% reduces the dissolved concentration to 1.8×10^{-16} ug/L and reduces the sorbed concentration to 2.3×10^{-12} ug/kg, assuming a groundwater inflow equal to 200 cm/yr (6.6 ft/yr).

Table 4. Summary of results from the model simulations at 100 years.

Sequester f_{oc}	Specific discharge	Dissolved PCB at 60 cm depth	Sorbed PCB at 60 cm depth
%	cm/yr	ug/L	ug/kg
0.5	20	3.146E-21	1.358E-17
0.5	200	1.832E-08	7.907E-05
1	20	4.676E-27	4.037E-23
1	200	2.609E-13	2.252E-09
1.5	20	1.462E-30	1.894E-26
1.5	200	1.84E-16	2.383E-12

References

Fetter, C.W., 1988, Applied Hydrogeology, 2nd Ed., Merrill Publishing Co., 592 pp.

Keta Waters, 2021. *Final Draft Description of Groundwater Flow Model, Industrial Container Services, WA, LLC, Seattle, WA.* Prepared for Dalton, Olmsted & Fuglevand, Inc., December 30, 2021.

Keta Waters, 2022. Memorandum from J. Massmann (Keta Waters) to M. Dalton (DOF) with subject “ICS-NWC Interim Action, Groundwater modeling to evaluate effects of subsurface barriers. January 8, 2022.

Palermo, M., et al., (1998). Guidance for in-situ subaqueous capping of contaminated sediments. EPA 9056B966004.

Reible, D.D., (2014). Sediment and Contaminant Processes, in Processes, Assessment and Remediation of Contaminated Sediments. Springer. p. 13-24.

Shen, X., Lampert, D., Ogle, S., & Reible, D. (2018). A software tool for simulating contaminant transport and remedial effectiveness in sediment environments. Environmental Modelling & Software, 109, 104-113.

Thoma, G.J., Danny D. Reible, Kalliat T. Valsaraj, and Louis J. Thibodeaux, (1993). Efficiency of Capping Contaminated Bed Sediments in Situ 2. Mathematics of Diffusion-Adsorption in the Capping Layer. Environ. Sci. Technol., 27(12): p. 2412-2419.

ATTACHMENT

Memorandum from Matt Dalton (DOF) to Joel Massmann (Keta Waters) dated April 3, 2020 (Revised 12-15/21) with subject "Starting PCB Concentrations, Embayment CAP Modelling, ICS Site, Seattle, Washington."

DOF DALTON
OLMSTED
FUGLEVAND

6034 N. Star Rd., Ferndale, Washington 98248
Telephone (cell) – (206) 498-6616

MEMORANDUM

TO: Dr. Joel Massmann P.E. – Keta Waters

FROM: Matt Dalton

DATE: April 3, 2020 (Revised 12-15-21)

SUBJECT: Starting PCB Concentrations
Embayment CAP Modelling
ICS Site, Seattle, Washington

REF. NO: SUM-008-03(FS)

CC: Raleigh Farlow - DMD
Dave Cooper – DOF
Rob Webb - DOF

This memorandum presents the recommended starting PCB groundwater concentration to model the embayment cap design. An engineered cap will be required because the cap will be placed over sediment containing contaminant residues.

To develop the starting model concentration, the "*Fixed parameter three-phase partitioning model*" was used that is described in WAC 173-340-747(4) of the Model Toxics Control Act. The model is described by the following equation (Equation 747-1):

$$\mathbf{C_S = C_W\,(UCF)DF[K_d+(0_w+0_aH_{cc})/P_b]}\quad \text{where:}$$

C_S = Soil concentration to be capped (mg/kg)
C_W = Model start groundwater concentration (ug/l)
UCF = Unit conservation factor (1 mg/l/1,000 ug)
DF = Dilution factor (1 – for saturated soil)
K*d* = Distribution coefficient (L/kg – constituent dependent)
0_W = Water filled porosity (saturated default value 0.43 ml water/ml soil)
0a = Air-filled soil porosity (0 ml air/ml soil for saturated soil)
H*cc* = Henry's Law constant (dimensionless – not needed for saturated soil)
P_b = Dry bulk density (1.5 kg/L – default value).

Site specific parameters are C_S and K*d* which are discussed below. Otherwise, default assumptions were used.

C_S, the assumed residual soil concentration to be capped, was based on sediment core concentrations in Tables F.4a of the draft RI (DOF 2020a) and A7.1 of the draft FS (DOF 2020b). PCBs were assumed to be of primary concern. Residual total PCB concentrations range between not detected (RL=0.0037 mg/kg) to 44.1 mg/kg based on remedial assumptions outlined in the draft FS. Residual PCB concentrations are summarized by location in Table 1 below.

Table 1 – Estimated PCB Residuals to be Capped

Sediment Core Location	Mid-Point Sample Depth (ft)	Total PCB (mg/kg-dry)	Proposed Excavation Depth (ft)
A	3.9	0.099	3
B	4.4	44.1 – 0.097(a)	5
C	3.3	55 - <0.0038(a)	3
D	3.8	0.067	4
F	4.5	<0.004	4
G	5.1	10	4
H	4.7	38.1 - 0.260(a)	4
I	4.2	0.395	4
J	4.9	0.337	4
K	5.5	1.6	4
L	3.5	2.3 - 0.023(a)	3
M	2.7	0.31 - <0.0037(a)	2

Note: Proposed cut depth spans two sample depths to a significant degree. The residue PCB concentration likely lies between the two concentrations.

Use of the highest PCB sample concentration from Core B in Table 1 provides a worse case analysis, as this sample has the highest residual PCB concentration. The total PCB concentration in this sample is a mixture of PCB Aroclors with differing geochemcial properties. Table 2 below summarizes pertinent information for this sample..

Table 2 – PCB Properties

Constituent	Embay-ment Location	Material Type	Concen-tration (mg/kg)	K*oc* (L/kg) (a)	f*oc* (%)	Sed. K*d* (L/kg) (c)
Aroclor 1248	Core B – 4.4’	Fine sandy Silt	23	863,337	3.4	29,353
Aroclor 1254			12	2,247,362	3.4	76,410
Aroclor 1260			9.1	7,708,355	3.4	262,084
Total			44.1			

Notes: (a) – Koc – organic carbon-water partitioning coefficient; foc – fraction organic carbon; K*d* – distribution coefficient.

K*d* is calculated using the following equation (Equation 747-2):

K*d* = K*oc* x f*oc* where:

K*d* = Distribution coefficient (L/kg)
K*oc* = Soil organic carbon-water partitioning coefficient (mg/g) – constituent dependent.
F*oc* = Soil fraction of organic carbon (sample dependent)

K*oc* values were derived for Aroclor 1248, 1254 and 1260. These values were provided by DMD Inc., based on current data and information concerning partitioning of these compounds to organic carbon in soil. K*oc*'s used in this analysis are summarized in Table 2 above. Derivation of the K*oc*'s is described in a memorandum prepared by DMD Inc. (2020) that is included as Attachment A to this memorandum. K*d*'s for the Aroclors were calculated using a sample specific f*oc* of 3.4% and are also included in Table 2 above.

Using equation 747-1 above, an equilibrium groundwater concentration was calculated for each Aroclor in Table 2. The results are summarized in Table 3 below.

Table 3 – Calculated PCB Equlibrium Concentrations

Aroclor	Equlibrium Conc. (ug/l)
1248	0.78
1254	0.16
1260	0.035
Total	**0.98**

REFERNECES

DMD Inc., 2020, Memorandum to Matt Dalton titled "Derivation of PCB/Aroclor Equilibrium Partition Coefficients for Use at the ICS/[former] Northwest Cooperage Site, Seattle, WA; March 29, 2020 (included as Attachment A).

DOF (Dalton Olmsted & Fuglevand, Inc.), 2020a, Remedial Investigation Report, Industrial Container Services, WA, LLC [Former NW Cooperage Site], Seattle, Washington; Public Review Draft: February 2020.

DOF, 2020b, Feasibility Study Report, Industrial Container Services, WA, LLC. (Former NW Cooperage Site), Seattle Washington; Agency Review Draft: March 8, 2020.

Attachment
DMD Inc. – Memorandum to Matt Datton dated March 29, 2020 titled "Derivation of PCB/Aroclor Equilibrium Partition Coefficients for Use at the ICS[former] Northwest Cooperage Site, Seattle, WA.

ATTACHMENT A
DMD Inc. – Technical Memorandum
March 29, 2020

ICS[former] Northwest Cooperage Site
Seattle, Washington

Dalton, Olmsted & Fuglevand, Inc.

D.M.D., Inc.
Environmental & Toxicological Services
13706 SW Caster Road, Vashon, WA 98070-7428 (206) 463-6223 email: dmdinc111@gmail.com

MEMORANDUM

TO: Matt Dalton (DOF)

FROM: Raleigh Farlow

DATE: March 29, 2020

SUBJECT: Derivation of PCB/Aroclor Equilibrium Partition Coefficients for Use at the ICS/[former] Northwest Cooperage Site, Seattle, WA

Per your request, an explanation and "walk through" of how Aroclor K_{oc}'s were developed from current and updated physicochemical data is presented here. The approach employed utilizes information presented and described in *Geochemical Assessment of PCB's at the ICS/[former] Northwest Cooperage Site, Seattle, WA – ADDENDUM*, dated May 16, 2019, from R. Farlow (DMD) to M. Dalton (DOF). The Geochemical Assessment (DMD 2019) relies on three technical documents available in the scientific literature, specifically:

- Di Toro, D.M., 1985. A particle interaction model of reversible organic chemical sorption. *Chemosphere* 14(10): 1503-1538. (Determination of the relationship between PCB K_{ow} and K_{oc}.)
- Frame, G.M., Cochran, J.W., and Boewadt, S.S., 1996. Complete PCB congener distributions for 17 Aroclor mixtures determined by 3 HRGC systems optimized for comprehensive, quantitative congener-specific analyses. *J. High Res. Chromatogr.* 19, 657-668. (Determination of PCB congener and homolog compositions of Aroclors.)
- IARC 2016. World Health Organization – International Agency for Research on Cancer Monograph 107, Polychlorinated Biphenyls and Polybrominated Biphenyls. (Comprehensive and up-to-date resource for environmental exposures, biological effects, and chemical/physical characteristics of PCB's. Presentation of log(K_{ow})'s for all 209 PCB congeners.)

A variety of historical documents and Agency guidances have presented physicochemical data and thermodynamic partition constants/factors for use in describing environmental behaviors, fates and distributions of PCB's. A review of current and modern technical literature was performed to determine and evaluate critical physicochemical data for use in understanding and characterizing PCB's behavior at the ICS/Northwest Cooperage site. Environmental PCB's data at the ICS/NWC site are reported and expressed in terms of Aroclors and individual PCB congeners concentrations in multiple matrix types (groundwaters, surface waters, soils, and estuarine sediments). Source area and contaminated media characterizations at the site have determined that commercial PCB mixtures as Aroclors (Aroclor 1248, Aroclor 1254 and Aroclor 1260) are readily recognized as the primary contaminants of concern.

Pertinent characteristics of PCB's and Aroclors are described under *Characteristics of PCB's* (DMD 2019, pg. 1-2) and Table 1 in DMD (2019). Aroclor compositions have been determined by Frame et al. (1996) and are summarized by PCB homolog content in Table 1. Mean log(K_{ow})'s for each homolog group are presented in the attached Table, entitled *PCB homologs partition factors*, and are derived from Table 1.3 of IARC 107 (2016). The IARC treatise presents log(K_{ow})'s for all 209 individual PCB congeners. Thus, the mean log(K_{ow}) for each homolog group is calculated by averaging the log(K_{ow})'s for all congeners within each respective group (found in Table 1.3 of IARC 107 (2016)). For example, in the case of monochlorobiphenyls, three congener log(K_{ow})'s (4.46, 4.69, and 4.69) were averaged to yield a mean log(K_{ow}) of 4.61, which is summarized in the attached Table *PCB homologs partition factors*. This process was performed for all ten homolog groups and presented in *PCB homologs partition factors*. The associated homolog group mean log(K_{oc})'s found in *PCB homologs partition factors* are derived from the relationship developed and described by Di Toro (1985) as the following (see pg. 6 in DMD 2019):

$$\log(K_{oc}) = 0.00028 + 0.983 \text{ x } \log(K_{ow})$$

Thus, in the case of pentachlorobiphenyls (PCBP):

$$\log(K_{oc})_{PCBP} = 0.00028 + 0.983 \text{ x } 6.40 = 6.29$$

Calculation of a mean K_{oc} for each Aroclor is performed by determining a weighted log(K_{oc}) by relative proportion of homolog group in each Aroclor (from Table 1). In the case of Aroclor 1254:

$$\log(K_{oc})_{\text{Aroclor 1254}} = 0.0024\text{x}5.00 + 0.0126\text{x}5.46 + 0.1025\text{x}5.88 + 0.5912\text{x}6.29 + 0.2676\text{x}6.68 + 0.0266\text{x}7.05 + 0.0004\text{x}7.39 + 0.0004\text{x}7.72 = 6.35$$

The mean K_{oc} for Aroclor 1254 is determined to be: $10^{6.35}$ or 10^(6.35) = 2,247,362

Consequently, mean K_{oc}'s for the three Aroclors of concern at this site are estimated to be the following:

Aroclor 1248 mean K_{oc} = 863,337
Aroclor 1254 mean K_{oc} = 2,247,362
Aroclor 1260 mean K_{oc} = 7,708,355

These Aroclor K_{oc}'s are greater than those recommended in previous guidances (using older and historical data) by factors of 9-35x. The effect of site modifiers on actual K_{oc}'s and Kd's are presented and described in DMD 2019. The use of the [greater] Aroclor K_{oc}'s developed using updated PCB's thermal equilibrium data and factors yields dissolved aqueous and solids' PCB concentrations consistent with those reported in site media.

Table 1.

Characteristics of PCB Homolog Groups and Weight Percent in Aroclors

PCB Homolog Group	Formula	# of Congeners	% Cl by wt.	log(Kow)	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260
1	$C_{12}H_9Cl$	3	18.79	4.46 - 4.69	0.75	0.07		0.02
2	$C_{12}H_8Cl_2$	12	31.77	4.65 - 5.30	15.04	1.55	0.24	0.08
3	$C_{12}H_7Cl_3$	24	41.30	5.02 - 5.89	44.91	21.27	1.26	0.21
4	$C_{12}H_6Cl_4$	42	48.65	5.53 - 6.48	20.16	32.77	10.25	0.35
5	$C_{12}H_5Cl_5$	46	54.30	5.71 - 6.95	18.85	42.92	59.12	8.74
6	$C_{12}H_4Cl_6$	42	58.93	6.22 - 7.42	0.31	1.64	26.76	43.35
7	$C_{12}H_3Cl_7$	24	62.77	6.69 - 7.71		0.02	2.66	38.54
8	$C_{12}H_2Cl_8$	12	65.98	7.20 - 8.00			0.04	8.27
9	$C_{12}HCl_9$	3	68.73	7.71 - 8.09			0.04	0.70
10	$C_{12}Cl_{10}$	1	71.10	8.18				

from IARC 2016

% Chlorine by Weight:	42	48	54	60
Average # of Chlorine Atoms per Molecule:	3	4	5	6

from Frame et al. 1996

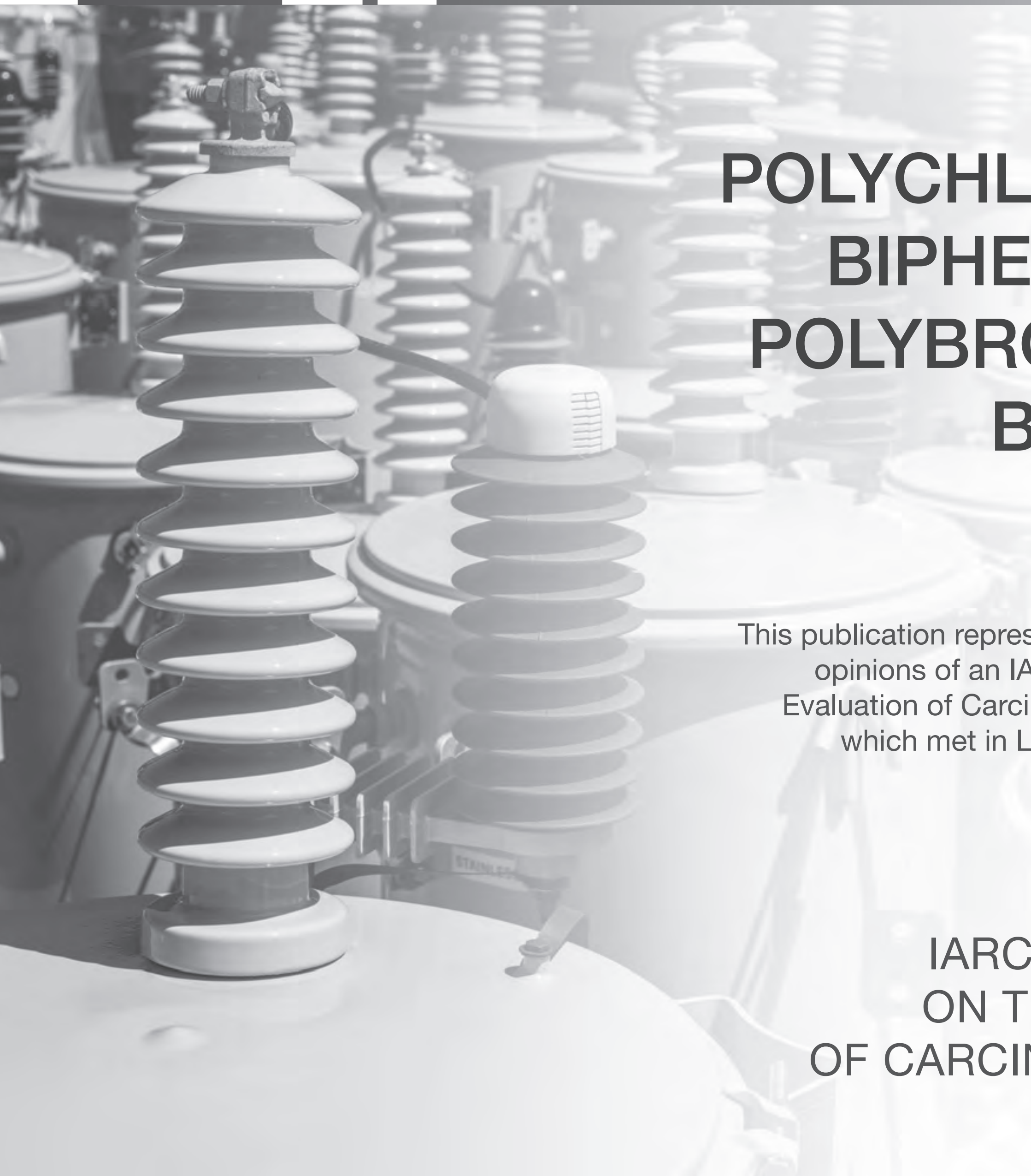
PCB homologs partition factors

Chlorinated biphenyl homologs		Mean log(Kow) *	Mean log(Koc) **	Kd (L/kg) @ 2% foc
Monochlorobiphenyls	Cl-1	4.61	4.54	686
Dichlorobiphenyls	Cl-2	5.09	5.00	2,019
Trichlorobiphenyls	Cl-3	5.55	5.46	5,715
Tetrachlorobiphenyls	Cl-4	5.98	5.88	15,137
Pentachlorobiphenyls	Cl-5	6.40	6.29	39,267
Hexachlorobiphenyls	Cl-6	6.80	6.68	95,726
Heptachlorobiphenyls	Cl-7	7.17	7.05	223,373
Octachlorobiphenyls	Cl-8	7.52	7.39	493,208
Nonachlorobiphenyls	Cl-9	7.85	7.72	1,042,389
Decachlorobiphenyl	Cl-10	8.18	8.04	2,198,012

* calculated mean from IARC 107 (2016)

** from Di Toro (1985)

IARC MONOGRAPHS



POLYCHLORINATED BIPHENYLS AND POLYBROMINATED BIPHENYLS

VOLUME 107

This publication represents the views and expert opinions of an IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, which met in Lyon, 12–19 February 2013

Lyon, France - 2016

IARC MONOGRAPHS
ON THE EVALUATION
OF CARCINOGENIC RISKS
TO HUMANS

International Agency for Research on Cancer
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Organization

Table 1.3 Relationship between BZ number, CAS number, IUPAC name,[a] congener descriptor, and log K_{ow} for individual PCBs

BZ No.	IUPAC name	CAS No.	Descriptor[b]	Log K_{ow}	Vapour pressure (atm at 25 °C)[c]
1	2-CB	2051-60-7	CP1	4.46	
2	3-CB	2051-61-8	CP0	4.69	
3	4-CB	2051-62-9	CP0	4.69	
4	2,2′-DiCB	13029-08-8		4.65	1.5 to 4.2×10^{-6}
5	2,3-DiCB	16605-91-7	CP1	4.97	
6	2,3′-DiCB	25569-80-6	CP1	5.06	
7	2,4-DiCB	33284-50-3	CP1	5.07	9.9×10^{-7} to 2.1×10^{-6}
8	2,4′-DiCB	34883-43-7	CP1	5.07	
9	2,5-DiCB	34883-39-1	CP1	5.06	2.0 to 2.3×10^{-6}
10	2,6-DiCB	33146-45-1		4.84	
11	3,3′-DiCB	2050-67-1	CP0, 2M	5.28	4.1 to 9.1×10^{-7}
12	3,4-DiCB	2974-92-7	CP0	5.22	1.3×10^{-8} to 7.8×10^{-7}
13	3,4′-DiCB	2974-90-5	CP0	5.29	
14	3,5-DiCB	34883-41-5	CP0, 2M	5.28	
15	4,4′-DiCB	2050-68-2	CP0, PP	5.30	5.0 to 7.4×10^{-7}
16	2,2′,3-TriCB	38444-78-9		5.16	
17	2,2′,4-TriCB	37680-66-3		5.25	
18	2,2′,5-TriCB	37680-65-2		5.24	3.5×10^{-7} to 1.2×10^{-6}
19	2,2′,6-TriCB	38444-73-4		5.02	
20	2,3,3′-TriCB	38444-84-7	CP1, 2M	5.57	
21	2,3,4-TriCB	55702-46-0	CP1	5.51	
22	2,3,4′-TriCB	38444-85-8	CP1	5.58	
23	2,3,5-TriCB	55720-44-0	CP1, 2M	5.57	
24	2,3,6-TriCB	55702-45-9		5.35	
25	2,3′,4-TriCB	55712-37-3	CP1	5.67	
26	2,3′,5-TriCB	38444-81-4	CP1, 2M	5.66	1.8 to 4.5×10^{-7}
27	2,3′,6-TriCB	38444-76-7		5.44	
28	2,4,4′-TriCB	7012-37-5	CP1, PP	5.67	1.5 to 3.3×10^{-7}
29	2,4,5-TriCB	15862-07-4	CP1	5.60	
30	2,4,6-TriCB	35693-92-6		5.44	9.3×10^{-7} to 1.5×10^{-6}
31	2,4′,5-TriCB	16606-02-3	CP1	5.67	
32	2,4′,6-TriCB	38444-77-8		5.44	
33	2,3′,4′-TriCB	38444-86-9	CP1	5.60	
34	2,3′,5′-TriCB	37680-68-5	CP1, 2M	5.66	
35	3,3′,4-TriCB	37680-69-6	CP0, 2M	5.82	
36	3,3′,5-TriCB	38444-87-0	CP0, 2M	5.88	
37	3,4,4′-TriCB	38444-90-5	CP0, PP	5.83	
38	3,4,5-TriCB	53555-66-1	CP0, 2M	5.76	
39	3,4′,5-TriCB	38444-88-1	CP0, 2M	5.89	
40	2,2′,3,3′-TetraCB	38444-93-8	4CL, 2M	5.66	4.5×10^{-8} to 1.1×10^{-7}
41	2,2′,3,4-TetraCB	52663-59-9	4CL	5.69	
42	2,2′,3,4′-TetraCB	36559-22-5	4CL	5.76	
43	2,2′,3,5-TetraCB	70362-46-8	4CL, 2M	5.75	
44	2,2′,3,5′-TetraCB	41464-39-5	4CL, 2M	5.75	

Table 1.3 (continued)

BZ No.	IUPAC name	CAS No.	Descriptor[b]	Log K_{ow}	Vapour pressure (atm at 25 °C)[c]
45	2,2′,3,6-TetraCB	70362-45-7	4CL	5.53	
46	2,2′,3,6′-TetraCB	41464-47-5	4CL	5.53	
47	2,2′,4,4′-TetraCB	2437-79-8	4CL, PP	5.85	
48	2,2′,4,5-TetraCB	70362-47-9	4CL	5.78	
49	2,2′,4,5′-TetraCB	41464-40-8	4CL	5.85	
50	2,2′,4,6-TetraCB	62796-65-0	4CL	5.63	
51	2,2′,4,6′-TetraCB	68194-04-7	4CL	5.63	
52	2,2′,5,5′-TetraCB	35693-99-3	4CL, 2M	5.84	1.8 to 8.9 × 10^{-7}
53	2,2′,5,6′-TetraCB	41464-41-9	4CL	5.62	1.1 to 4.0 × 10^{-7}
54	2,2′,6,6′-TetraCB	15968-05-5	4CL	5.21	1.2 × 10^{-6} to 6.5 × 10^{-7}
55	2,3,3′,4-TetraCB	74338-24-2	CP1, 4CL, 2M	6.11	
56	2,3,3′,4′-TetraCB	41464-43-1	CP1, 4CL, 2M	6.11	
57	2,3,3′,5-TetraCB	70424-67-8	CP1, 4CL, 2M	6.17	
58	2,3,3′,5′-TetraCB	41464-49-7	CP1, 4CL, 2M	6.17	
59	2,3,3′,6-TetraCB	74472-33-6	4CL, 2M	5.95	
60	2,3,4,4′-TetraCB	33025-41-1	CP1, 4CL, PP	6.11	
61	2,3,4,5-TetraCB	33284-53-6	CP1, 4CL, 2M	6.04	
62	2,3,4,6-TetraCB	54230-22-7	4CL	5.89	
63	2,3,4′,5-TetraCB	74472-34-7	CP1, 4CL, 2M	6.17	
64	2,3,4′,6-TetraCB	52663-58-8	4CL	5.95	
65	2,3,5,6-TetraCB	33284-54-7	4CL, 2M	5.86	
66	2,3′,4,4′-TetraCB	32598-10-0	CP1, 4CL, PP	6.20	
67	2,3′,4,5-TetraCB	73575-53-8	CP1, 4CL, 2M	6.20	
68	2,3′,4,5′-TetraCB	73575-52-7	CP1, 4CL, 2M	6.26	
69	2,3′,4,6-TetraCB	60233-24-1	4CL	6.04	
70	2,3′,4′,5-TetraCB	32598-11-1	CP1, 4CL, 2M	6.20	
71	2,3′,4′,6-TetraCB	41464-46-4	4CL	5.98	
72	2,3′,5,5′-TetraCB	41464-42-0	CP1, 4CL, 2M	6.26	
73	2,3′,5′,6-TetraCB	74338-23-1	4CL, 2M	6.04	
74	2,4,4′,5-TetraCB	32690-93-0	CP1, 4CL, PP	6.20	
75	2,4,4′,6-TetraCB	32598-12-2	4CL, PP	6.05	
76	2,3′,4′,5′-TetraCB	70362-48-0	CP1, 4CL, 2M	6.13	
77	3,3′,4,4′-TetraCB	32598-13-3	**CP0, 4CL, PP, 2M**	6.36	5.2 × 10^{-9} to 2.1 × 10^{-8}
78	3,3′,4,5-TetraCB	70362-49-1	CP0, 4CL, 2M	6.35	
79	3,3′,4,5′-TetraCB	41464-48-6	CP0, 4CL, 2M	6.42	
80	3,3′,5,5′-TetraCB	33284-52-5	CP0, 4CL, 2M	6.48	
81	3,4,4′,5-TetraCB	70362-50-4	**CP0, 4CL, PP, 2M**	6.36	
82	2,2′,3,3′,4-PentaCB	52663-62-4	4CL, 2M	6.20	
83	2,2′,3,3′,5-PentaCB	60145-20-2	4CL, 2M	6.26	
84	2,2′,3,3′,6-PentaCB	52663-60-2	4CL, 2M	6.04	
85	2,2′,3,4,4′-PentaCB	65510-45-4	4CL, PP	6.30	
86	2,2′,3,4,5-PentaCB	55312-69-1	4CL, 2M	6.23	
87	2,2′,3,4,5′-PentaCB	38380-02-8	4CL, 2M	6.29	
88	2,2′,3,4,6-PentaCB	55215-17-3	4CL	6.07	
89	2,2′,3,4,6′-PentaCB	73575-57-2	4CL	6.07	

Table 1.3 (continued)

BZ No.	IUPAC name	CAS No.	Descriptor[b]	Log K_{ow}	Vapour pressure (atm at 25 °C)[c]
90	2,2′,3,4′,5-PentaCB	68194-07-0	4CL, 2M	6.36	
91	2,2′,3,4′,6-PentaCB	68194-05-8	4CL	6.13	
92	2,2′,3,5,5′-PentaCB	52663-61-3	4CL, 2M	6.35	
93	2,2′,3,5,6-PentaCB	73575-56-1	4CL, 2M	6.04	
94	2,2′,3,5,6′-PentaCB	73575-55-0	4CL, 2M	6.13	
95	2,2′,3,5′,6-PentaCB	38379-99-6	4CL, 2M	6.13	
96	2,2′,3,6,6′-PentaCB	73575-54-9	4CL	5.71	
97	2,2′,3,4′,5′-PentaCB	41464-51-1	4CL, 2M	6.29	
98	2,2′,3,4′,6′-PentaCB	60233-25-2	4CL	6.13	
99	2,2′,4,4′,5-PentaCB	38380-01-7	4CL, PP	6.39	
100	2,2′,4,4′,6-PentaCB	39485-83-1	4CL, PP	6.23	
101	2,2′,4,5,5′-PentaCB	37680-73-2	4CL, 2M	6.38	1.4 to 3.5 × 10^{-8}
102	2,2′,4,5,6′-PentaCB	68194-06-9	4CL	6.16	
103	2,2′,4,5′,6-PentaCB	60145-21-3	4CL	6.22	
104	2,2′,4,6,6′-PentaCB	56558-16-8	4CL	5.81	4.3 × 10^{-8} to 1.7 × 10^{-7}
105	2,3,3′,4,4′-PentaCB	32598-14-4	**CP1, 4CL, PP, 2M**	6.65	8.6 × 10^{-9}
106	2,3,3′,4,5-PentaCB	70424-69-0	CP1, 4CL, 2M	6.64	
107	2,3,3′,4,5′-PentaCB	70424-68-9	CP1, 4CL, 2M	6.71	
108	2,3,3′,4,6-PentaCB	70362-41-3	4CL, 2M	6.72	
109	2,3,3′,4′,5-PentaCB	74472-35-8	CP1, 4CL, 2M	6.48	
110	2,3,3′,4′,6-PentaCB	38380-03-9	4CL, 2M	6.48	
111	2,3,3′,5,5′-PentaCB	39635-32-0	CP1, 4CL, 2M	6.76	
112	2,3,3′,5,6-PentaCB	74472-36-9	4CL, 2M	6.45	
113	2,3,3′,5′,6-PentaCB	68194-10-5	4CL, 2M	6.54	
114	2,3,4,4′,5-PentaCB	74472-37-0	**CP1, 4CL, PP, 2M**	6.65	
115	2,3,4,4′,6-PentaCB	74472-38-1	4CL, PP	6.49	
116	2,3,4,5,6-PentaCB	18259-05-7	4CL, 2M	6.33	
117	2,3,4′,5,6-PentaCB	68194-11-6	4CL, 2M	6.46	
118	2,3′,4,4′,5-PentaCB	31508-00-6	**CP1, 4CL, PP, 2M**	6.74	1.2 × 10^{-8}
119	2,3′,4,4′,6-PentaCB	56558-17-9	4CL, PP	6.58	
120	2,3′,4,5,5′-PentaCB	68194-12-7	CP1, 4CL, 2M	6.79	
121	2,3′,4,5′,6-PentaCB	56558-18-0	4CL, 2M	6.64	
122	2,3,3′,4′,5′-PentaCB	76842-07-4	CP1, 4CL, 2M	6.64	
123	2,3′,4,4′,5′-PentaCB	65510-44-3	**CP1, 4CL, PP, 2M**	6.74	
124	2,3′,4′,5,5′-PentaCB	70424-70-3	CP1, 4CL, 2M	6.73	
125	2,3′,4′,5′,6-PentaCB	74472-39-2	4CL, 2M	6.51	
126	3,3′,4,4′,5-PentaCB	57465-28-8	**CP0, 4CL, PP, 2M**	6.89	
127	3,3′,4,5,5′-PentaCB	39635-33-1	CP0, 4CL, 2M	6.95	
128	2,2′,3,3′,4,4′-HexaCB	38380-07-3	4CL, PP, 2M	6.74	1.0 to 3.6 × 10^{-9}
129	2,2′,3,3′,4,5-HexaCB	55215-18-4	4CL, 2M	6.73	
130	2,2′,3,3′,4,5′-HexaCB	52663-66-8	4CL, 2M	6.80	
131	2,2′,3,3′,4,6-HexaCB	61798-70-7	4CL, 2M	6.58	
132	2,2′,3,3′,4,6′-HexaCB	38380-05-1	4CL, 2M	6.58	
133	2,2′,3,3′,5,5′-HexaCB	35694-04-3	4CL, 2M	6.86	
134	2,2′,3,3′,5,6-HexaCB	52704-70-8	4CL, 2M	6.55	

Table 1.3 (continued)

BZ No.	IUPAC name	CAS No.	Descriptor[b]	Log K_{ow}	Vapour pressure (atm at 25 °C)[c]
135	2,2′,3,3′,5,6′-HexaCB	52744-13-5	4CL, 2M	6.64	
136	2,2′,3,3′,6,6′-HexaCB	38411-22-2	4CL, 2M	6.22	
137	2,2′3,4,4′,5-HexaCB	35694-06-5	4CL, PP, 2M	6.83	
138	2,2′,3,4,4′,5′-HexaCB	35065-28-2	4CL, PP, 2M	6.83	5.2×10^{-9}
139	2,2′,3,4,4′,6-HexaCB	56030-56-9	4CL, PP	6.67	
140	2,2′,3,4,4′,6′-HexaCB	59291-64-4	4CL, PP	6.67	
141	2,2′,3,4,5,5′-HexaCB	52712-04-6	4CL, 2M	6.82	
142	2,2′,3,4,5,6-HexaCB	41411-61-4	4CL, 2M	6.51	
143	2,2′,3,4,5,6′-HexaCB	68194-15-0	4CL, 2M	6.60	
144	2,2′,3,4,5′,6-HexaCB	68194-14-9	4CL, 2M	6.67	
145	2,2′,3,4,6,6′-HexaCB	74472-40-5	4CL	6.25	
146	2,2′,3,4′,5,5′-HexaCB	51908-16-8	4CL, 2M	6.89	
147	2,2′,3,4′,5,6-HexaCB	68194-13-8	4CL, 2M	6.64	
148	2,2′,3,4′,5,6′-HexaCB	74472-41-6	4CL, 2M	6.73	
149	2,2′,3,4′,5′,6-HexaCB	38380-04-0	4CL, 2M	6.67	
150	2,2′,3,4′,6,6′-HexaCB	68194-08-1	4CL	6.32	
151	2,2′,3,5,5′,6-HexaCB	52663-63-5	4CL, 2M	6.64	
152	2,2′,3,5,6,6′-HexaCB	68194-09-2	4CL, 2M	6.22	
153	2,2′,4,4′,5,5′-HexaCB	35065-27-1	4CL, PP, 2M	6.92	1.9×10^{-9} to 6.9×10^{-8}
154	2,2′,4,4′,5,6′-HexaCB	60145-22-4	4CL, PP	6.76	
155	2,2′,4,4′,6,6′-HexaCB	33979-03-2	4CL, PP	6.41	3.5×10^{-9} to 4.4×10^{-8}
156	2,3,3′,4,4′,5-HexaCB	38380-08-4	**CP1, 4CL, PP, 2M**	7.18	2.1×10^{-9}
157	2,3,3′,4,4′,5′-HexaCB	69782-90-7	**CP1, 4CL, PP, 2M**	7.18	
158	2,3,3′,4,4′,6-HexaCB	74472-42-7	4CL, PP, 2M	7.02	
159	2,3,3′,4,5,5′-HexaCB	39635-35-3	CP1, 4CL, 2M	7.24	
160	2,3,3′,4,5,6-HexaCB	41411-62-5	4CL, 2M	6.93	
161	2,3,3′,4,5′,6-HexaCB	74472-43-8	4CL, 2M	7.08	
162	2,3,3′,4′,5,5′-HexaCB	39635-34-2	CP1, 4CL, 2M	7.24	
163	2,3,3′,4′,5,6-HexaCB	74472-44-9	4CL, 2M	6.99	7.9×10^{-10}
164	2,3,3′,4′,5′,6-HexaCB	74472-45-0	4CL, 2M	7.02	
165	2,3,3′,5,5′,6-HexaCB	74472-46-1	4CL, 2M	7.05	
166	2,3,4,4′,5,6-HexaCB	41411-63-6	4CL, PP, 2M	6.93	
167	2,3′,4,4′,5,5′-HexaCB	52663-72-6	**CP1, 4CL, PP, 2M**	7.27	
168	2,3′,4,4′,5′,6-HexaCB	59291-65-5	4CL, PP, 2M	7.11	
169	3,3′,4,4′,5,5′-HexaCB	32774-16-6	**CP0, 4CL, PP, 2M**	7.42	7.9×10^{-10}
170	2,2′,3,3′,4,4′,5-HeptaCB	35065-30-6	4CL, PP, 2M	7.27	
171	2,2′,3,3′,4,4′,6-HeptaCB	52663-71-5	4CL, PP, 2M	7.11	
172	2,2′,3,3′,4,5,5′-HeptaCB	52663-74-8	4CL, 2M	7.33	
173	2,2′,3,3′,4,5,6-HeptaCB	68194-16-1	4CL, 2M	7.02	
174	2,2′,3,3′,4,5,6′-HeptaCB	38411-25-5	4CL, 2M	7.11	
175	2,2′,3,3′,4,5′,6-HeptaCB	40186-70-7	4CL, 2M	7.17	
176	2,2′,3,3′,4,6,6′-HeptaCB	52663-65-7	4CL, 2M	6.76	
177	2,2′,3,3′,4,5′,6′-HeptaCB	52663-70-4	4CL, 2M	7.08	
178	2,2′,3,3′,5,5′,6-HeptaCB	52663-67-9	4CL, 2M	7.14	
179	2,2′,3,3′,5,6,6′-HeptaCB	52663-64-6	4CL, 2M	6.73	

Table 1.3 (continued)

BZ No.	IUPAC name	CAS No.	Descriptor[b]	Log K_{ow}	Vapour pressure (atm at 25 °C)[c]
180	2,2′,3,4,4′,5,5′-HeptaCB	35065-29-3	4CL, PP, 2M	7.36	1.3×10^{-9}
181	2,2′,3,4,4′,5,6-HeptaCB	74472-47-2	4CL, PP, 2M	7.11	
182	2,2′,3,4,4′,5,6′-HeptaCB	60145-23-5	4CL, PP, 2M	7.20	
183	2,2′,3,4,4′,5′,6-HeptaCB	52663-69-1	4CL, PP, 2M	7.20	
184	2,2′,3,4,4′,6,6′-HeptaCB	74472-48-3	4CL, PP	6.85	
185	2,2′,3,4,5,5′,6-HeptaCB	52712-05-7	4CL, 2M	7.11	
186	2,2′,3,4,5,6,6′-HeptaCB	74472-49-4	4CL, 2M	6.69	
187	2,2′,3,4′,5,5′,6-HeptaCB	52663-68-0	4CL, 2M	7.17	
188	2,2′,3,4′,5,6,6′-HeptaCB	74487-85-7	4CL, 2M	6.82	
189	2,3,3′,4,4′,5,5′-HeptaCB	39635-31-9	**CP1, 4CL, PP, 2M**	7.71	
190	2,3,3′,4,4′,5,6-HeptaCB	41411-64-7	4CL, PP, 2M	7.46	
191	2,3,3′,4,4′,5′,6-HeptaCB	74472-50-7	4CL, PP, 2M	7.55	
192	2,3,3′,4,5,5′,6-HeptaCB	74472-51-8	4CL, 2M	7.52	
193	2,3,3′,4′,5,5′,6-HeptaCB	69782-91-8	4CL, 2M	7.52	
194	2,2′,3,3′,4,4′,5,5′-OctaCB	35694-08-7	4CL, PP, 2M	7.80	
195	2,2′,3,3′,4,4′,5,6-OctaCB	52663-78-2	4CL, PP, 2M	7.56	
196	2,2′,3,3′,4,4′,5,6′-OctaCB	42740-50-1	4CL, PP, 2M	7.65	
197	2,2′,3,3′,4,4′,6,6′-OctaCB	33091-17-7	4CL, PP, 2M	7.30	
198	2,2′,3,3′,4,5,5′,6-OctaCB	68194-17-2	4CL, 2M	7.62	
199	2,2′,3,3′,4,5,5′,6′-OctaCB	52663-75-9	4CL, 2M	7.62	
200	2,2′,3,3′,4,5,6,6′-OctaCB	52663-73-7	4CL, 2M	7.20	
201	2,2′,3,3′,4,5′,6,6′-OctaCB	40186-71-8	4CL, 2M	7.27	
202	2,2′,3,3′,5,5′,6,6′-OctaCB	2136-99-4	4CL, 2M	7.24	
203	2,2′,3,4,4′,5,5′,6-OctaCB	52663-76-0	4CL, PP, 2M	7.65	
204	2,2′,3,4,4′,5,6,6′-OctaCB	74472-52-9	4CL, PP, 2M	7.30	
205	2,3,3′,4,4′,5,5′,6-OctaCB	74472-53-0	4CL, PP, 2M	8.00	
206	2,2′,3,3′,4,4′,5,5′,6-NonaCB	40186-72-9	4CL, PP, 2M	8.09	
207	2,2′,3,3′,4,4′,5,6,6′-NonaCB	52663-79-3	4CL, PP, 2M	7.74	
208	2,2′,3,3′,4,5,5′,6,6′-NonaCB	52663-77-1	4CL, 2M	7.71	
209	2,2′,3,3′,4,4′,5,5′,6,6′-DecaCB	2051-24-3	4CL, PP, 2M	8.18	

[a] The nomenclature in this table adheres to the IUPAC rules and thus primed and unprimed numbers may be interchanged compared with Table 1.1. Please see text for more details.

[b] Congener descriptors (CP0, CP1, 4Cl, PP, 2M) have been given where relevant; they give rapid access to geometry and substituent positions. 68 coplanar congeners fall into one of two groups CP0 or CP1.

The first group of 20 congeners consists of those without chlorine substitution at any of the "*ortho*" positions on the biphenyl backbone and are referred to as CP0 or non-"*ortho*" congeners. The second group of 48 congeners includes those with chlorine substitution at only one of the "*ortho*" positions and are referred to as CP1 or mono-"*ortho*" congeners. 175 congeners have a total of four or more chlorine substituents, regardless of position (4Cl). 54 congeners have both "*para*" positions chlorinated (PP). 146 congeners have two or more of the "*meta*" positions chlorinated (2M). The twelve congeners that have all four of the congener descriptors are referred to as being "dioxin-like," and are indicated in bold type.

In ATSDR (2000), PCB-63 was mistakenly attributed the CAS number of a pentachlorobiphenyl; for Henry's law constants, vapour pressure and solubility of most individual congeners, the reader is referred to Dunnivant & Elzerman (1988) and references within.

[c] Vapour pressures have been indicated for a selection of individual congeners.

BZ, Ballschmiter and Zell; CAS, Chemical Abstracts Service; CB, chlorinated biphenyl; IUPAC, International Union of Pure and Applied Chemistry

From Dunnivant & Elzerman (1988), ATSDR (2000), Mills *et al.* (2007), and Lindell (2012)

APPENDIX B
DMD GEOCHEMICAL ASSESSMENT OF PCBS TECHNICAL MEMORANDA
January 15, 2018 (Revised February 24, 2021),
May 16, 2019 (Revised February 25, 2021), and
May 29, 2020

DMD Data Evaluation/Assessment Report
February 2019 Groundwater Data
Attachment to May 16, 2019 DMD Report

FEASIBILITY STUDY REPORT
ICS/NWC RI/FS
SEATTLE, WASHINGTON

Dalton, Olmsted & Fuglevand, Inc.

D.M.D., Inc.
Environmental & Toxicological Services
13706 SW Caster Road, Vashon, WA 98070-7428 (206) 463-6223 email: dmdinc111@gmail.com

MEMORANDUM

TO: Matt Dalton (DOF)

FROM: Raleigh Farlow

DATE: January 15, 2018 (revised February 24, 2021)

SUBJECT: Geochemical Assessment of PCBs at the ICS/[former] Northwest Cooperage Site, Seattle, WA

This assessment supports the Remedial Investigation and Feasibility Study (RI/FS) for the Industrial Container Services, WA, LLC site, formerly known as Northwest Cooperage, Inc., (ICS/NWC) located on a small tributary embayment to the Lower Duwamish Waterway. This memorandum was revised based on comments received from the Washington State Department of Ecology (Ecology) on February 1, 2021 and on additional research and analysis completed after the original draft memorandum was completed. This memorandum is the first of two memoranda that describe the fate and transport of PCBs at the site. The later memorandum [5/16/19, revised 2/25/21] includes analysis of PCB congener groundwater data collected in February 2019 and provides a more site-specific description of PCB partitioning to organic matter and possibility of colloid transport. The site consists of an upland area (6.3 acres) and adjacent embayment (0.8 acre). The Remedial Investigation identifies a number of Chemicals of Potential Concern (COPCs) impacting upland soils, site groundwater, and estuarine sediments. PCBs were identified as the COPCs of greatest concern due to greatest frequency of exceedance of the screening levels (SLs) and the geographic extent of contamination.

This evaluation provides a geochemical perspective of the site-specific characteristics for PCBs contamination in environmental media at the ICS/NWC site to provide an understanding of the chemical characteristics, distributions, fates, and migration mechanisms/pathways as the basis for development of an effective remedial management strategy. The remedial objectives in the upland area include mitigation of contaminant hotspots/sources as they affect possible receptors and associated releases to surface waters and sediments via groundwater and storm water discharges. Remedial objectives in the estuarine portion of the site include cleanup of embayment sediments, prevention of sediment recontamination consequent to storm and ground water discharges, and prevention of surface water contamination.

Summary of PCBs Contamination at the ICS/NWC Site

This evaluation is based on the available site-specific data presented in the ICS/NWC public review draft Remedial Investigation (RI) report (February 2020). PCB concentrations and distributions by site media are presented in the ICS/NWC (February 2020) RI report in the following figures:

- Figure 5-5a PCBs in Surface Sediment

- Figure 5-6a PCBs in Subsurface Sediment
- Figure 5-8a Total PCB Concentrations, Water Table Zone Above Aquitard
- Figure 5-8b Total PCB Concentrations (in groundwater), Upper Zone
- Figure 5-8c Total PCB Concentrations (in groundwater), Lower Zone
- Figure 6-2a Extent of Total PCBs in Soil Less than 5 Feet Deep)
- Figure 6-2b Extent of Total PCBs in Soil Five to Ten Feet Deep
- Figure 6-2c Extent of Total PCBs in Soil Ten to Fifteen Feet Deep
- Figure 6-2d Extent of Total PCBs in Soil Fifteen to Twenty Feet Deep
- Figure 6-3a PCBs (in subsurface soil) Along Section A-A'
- Figure 6-3b PCBs (in subsurface soil) Along Section B-B'
- Figure 6-3c PCBs (in subsurface soil) Along Section C-C'
- Figure 6-3d PCBs (in subsurface soil) Along Section D-D'
- Figure 6-3e PCBs (in subsurface soil) Along Section E-E'
- Figure 6-3f PCBs (in subsurface soil) Along Section F-F'
- Figure 6-3g PCBs (in subsurface soil) Along Section G-G'
- Figure 4-26a Estuarine Water Contents – Water Table/Upper Zone Groundwater
- Figure 4-26b Estuarine Water Contents – Lower Zone Groundwater
- Figure 6-4 DRO/RRO *vs.* PCBs in Soil

A summary of site [total] PCB concentrations (measured and reported as Aroclors) by media is as follows:

	Freq. of Detection	Range	Arithmetic Mean	Coefficient of Variation (CV)
Surface Sed. (µg/kg)	100 %	42 – 1,600,000	56,947	4.75
Subsurface Sed. (µg/kg)	62.5 %	3.7 U – 44,100	4413 (U=0) 4414 (U=DL)	2.26 (U=0) 2.26 (U=DL)
Groundwater (µg/L)	46.6 %	0.004 – 6.91 (U[DL]=0.01)	0.212 (U=0) 0.218 (U=DL)	3.64 (U=0) 3.52 (U=DL)
Soil (µg/kg)	61.1 %	5 U – 119,000	10,000 (U=0) 10,000 (U=DL)	2.60 (U=0) 2.59 (U=DL)
NAPL [SA-MW1] (µg/kg)	—	—	1,670,000 (0.167 %)	—

U – not detected. DL – reported detection limit. CV = (standard deviation [sd])/(arithmetic mean)

Areas exhibiting elevated concentrations of PCBs and PCB 'hotspots" are found in surficial and subsurface embayment sediments (Figures 5-5a and 5-6a), upland soils along the shoreline to the embayment, and soils (generally at less than 15' depth) along a former [filled] drainage ditch to the embayment located on the eastern boundary of the property (Figures 6-2a – 6-2d). PCBs in groundwater were generally detected (> 0.01 µg/L) in the immediate vicinity of soils exhibiting PCBs contamination (Figures 6-3a – 6-3g). PCBs contamination in soils and groundwater are relatively localized, in both depth and spatially. PCBs in estuarine sediments are found at sediment depths averaging 5 feet and, generally, throughout the embayment (Figures 5-5a and 5-6a). Greatest concentrations in sediments are found in surface sediments along the southwestern shoreline of the embayment, up to 0.16% (Figure 5-5a), associated with oil or non-aqueous phase liquid (NAPL). Figure 5-6a shows the greatest PCBs sediment concentrations in the embayment to be at the surface with an apparent plume into subsurface sediments associated with a TPH mineral oil profile. PCBs-contaminated NAPL collected from SA-MW1 exhibited chromatographic characteristics/profile consistent with that of mineral oils employed in dielectric applications.

Properties and Characteristics of PCBs

PCBs and PCB mixtures (Aroclors) are chlorinated aromatic hydrocarbons that are chemically and physically recalcitrant, which has made them useful in a variety of applications, including dielectric fluids in electrical equipment, heat transfer fluids and lubricants. PCBs and their mixtures exhibit specific gravities ranging from 1.2 to 1.6 (Monsanto Askarel MSDS) are extremely hydrophobic and their aqueous solubilities (S) are relatively low compared to most other environmental contaminants. PCBs in the environment have a strong affinity for soils, especially those with high organic carbon content, and are not readily solubilized into surface and groundwaters. Adsorption of PCBs by soils is highly correlated to the level of organic carbon content (TOC in soils) and is quantified by a soil sorption constant or partition coefficient (K_{oc} or log(K_{oc})). The degree of adsorption by soils, expressed in terms of the K_{oc} (soil-water partition coefficient), is directly related to the level of TOC in soils. The behavior of PCBs and PCB mixtures in the environment is also related to and quantified by their octanol-water partition coefficient (K_{ow} or log(K_{ow})), which is experimentally derived in the laboratory using pure water and related to a site-specific and determined K_{oc}. For comparison, Aroclor physicochemical coefficients and constants are similar to and within the range of those for tetracyclic and greater high molecular weight polycyclic aromatic hydrocarbons (HPAH (e.g. chrysene, benzopyrenes, indeno(1,2,3-cd)pyrene, benzo(g,h,i)perylene, etc.)). A summary of pertinent constants for PCB mixtures reported at the ICS/NWC site (as Aroclors; taken from a CRC treatise [PCBs and the Environment, Waid et al., 1986] and DMD, March 29, 2020) is as follows:

	S (µg/L)	K_{oc}	K_{ow}
Aroclor 1242	240-340 (2.46)	426,498 (5.63)	533,330 (5.73)
Aroclor 1248	54 (1.73)	863,337 (5.94)	1,102,659 (6.04)
Aroclor 1254	12-57 (1.54)	2,247,362 (6.35)	2,880,925 (6.46)
Aroclor 1260	2.7 (0.43)	7,708,355 (6.89)	10,133,970 (7.01)

Values in parentheses are log transformations of the associated constants. The Aroclor 1260 K_{oc} is about an order of magnitude greater than that presented in the MTCA cleanup regulations (October 2007).

Because PCBs are hydrophobic chemicals with no polar or active functional chemical groups, their behaviors can be simply described and understood by the application of the above physicochemical parameters and constants. These physicochemical parameters are critical for understanding and controlling the fates and distributions of PCBs and PCB mixtures in the environment. In simple terms, PCBs in a mixed aqueous-soils/sediments environment will preferentially associate with, or partition to, solid surfaces and hydrocarbon/oil phases. The physicochemical values presented above are generally applicable to fresh and laboratory reagent-grade waters and do not account for site-specific factors that affect both solubility and phase partition mechanisms. Site-specific modifiers for S and K_{oc} values include [total] dissolved solids (TDS and salinity), soils TOC content, and [co]dissolved organic constituents, such as dissolved organic carbon (DOC), humic materials, and petroleum hydrocarbons (Environ. Sci. Technol., 2012, 46(3), pp. 1496-1503; Geochimica et Cosmochimica Acta, 1976, 40(5), pp. 555-561; DNAPL Site Evaluation by R.M. Cohen, J.W. Mercer & J. Matthews, C.K. Smoley Publishers, 1993, pp. 4-26 – 4-28). Estuarine-impacted waters with elevated TDS exhibit decreased hydrophobic organic compound solubilities due to the “salting-out effect” associated with increased solution ionic strengths. Solubilities of dichloro- through hexachloro-biphenyls are shown to decrease 23-32% when comparing fresh/distilled water with estuarine waters (up to 33 ppth salinity) (Brownawell, B.J., 1986; PhD thesis, The Role of Colloidal Organic Matter in the Marine Geochemistry of PCBs; Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution, April 1986) and decrease 14% for tetrachlorobiphenyl due to the "salting out" effect (MC Rawling, Particle-Water Interactions of Hydrophobic Organic Micropollutants in Marine Systems, University of Plymouth Research Thesis, 1998). Similarly, K_{oc} values are increased with increasing TDS, resulting in decreased solution concentrations and increased mass adsorption (phase partitioning) of organic chemicals to solid/soil surfaces. Co-solvency or presence of organic co-solutes can affect these apparent values and increase hydrophobic chemical carrying capacity of ground and surface water systems. Co-solvency associated with surface and groundwater DOC, commonly referred to as the colloid-effect, are determined to be variable, and likely insignificant, in some estuarine systems (M-Y Chen et al., Marine Pollution Bulletin (Elsevier), pg 29-35, **62** 2011; AM Gunn et al., Investigation of Partitioning of Contaminants between Water and Sediment, National Rivers Authority R&D 016/6/N, July 1992; Rawling 1998). Hydrophobic contaminants have been shown to have little affinity for natural colloids and are likely in "true solution" for estuarine water column samples. The fraction of PCBs associated with colloid in filtered estuarine water column samples have been determined to be as much as 20% and generally less than 10% (Chen et al., 2011). Water column PCBs associated with colloid can generally be neglected due to low colloid concentrations where a two-phase distribution and dissolved PCBs are dominant (Brownawell 1986). A three-phase distribution is dominant, where colloidal association with PCBs is significant, in media exhibiting elevated levels of PCBs, such as soil/sediment PCBs of 10-30 mg/kg and interstitial porewater PCBs of 3-20 µg/L (3,000-20,000 ng/L)(Brownawell 1986).

The above values for these partition coefficients also indicate, for example, a preferential aqueous solubility and partitioning of Aroclor 1242 compared to Aroclor 1260 of 20-100x in the same environment where all controlling variables are equivalent. This is due to greater hydrophobicity of Aroclor 1260 associated with increased chlorine content and substitution in the biphenyl molecule (Aroclor 1242 contains 42% chlorine whereas Aroclor 1260 contains 60% chlorine by weight). The fates and distributions of PCBs at the ICS/NWC site are easily understood and dependent on these critical physicochemical parameters.[1]

Site-specific Observations and Characteristics Affecting PCB Fates and Distributions

Soils and Sediments

The ICS/NWC RI report (February 2020) identifies an association of PCBs with petroleum hydrocarbon oils (expressed as the sum of diesel oil-range and lube (motor) oil-range hydrocarbons, or TPH) and is evaluated for upland site soils in Figure 6-4, DRO/RRO *vs.* PCBs in Soil. This relationship indicates that 30% of the variability in soil PCBs levels is strictly controlled by TPH with the remaining (70%) variability due to variation in concentrations of PCBs in source materials and co-releases of other petroleum hydrocarbon mixtures (not containing PCBs). The slope of the line in the figure indicates the mean concentration of total PCBs in site NAPLs or oils is 9.9×10^{-4} or ~0.1% (~ 1 part per thousand (ppth) or 1000 ppm).

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[1] It should be noted that recent and current determinations of PCB K_{oc}s, presented above, are significantly greater than presented in historic literature. For example, Aroclor 1260 K_{oc} has been reported at 349,462 L/kg (CRC treatise [PCBs and the Environment, Waid et al., 1986]) and 822,422 L/kg (MTCA Cleanup Regulation [10/2007]).

The mean PCB concentration in oil for soil samples is 1.6 gm/kg (ppth) [1.6×10^{-3}] with a range of 2.1×10^{-5} to 6.6×10^{-3} and a coefficient of variation (CV) of 1.1. Available data indicate that PCBs contamination at the ICS/NWC site is principally associated with the release of petroleum-derived dielectric fluids based on TPH chromatographic analyses exhibiting mineral oil-type profiles. Other PCB-containing fluids, such as heat transfer fluids, hydraulic oils, and turbine coolants/lubricants, may also be present. Much of the variability in PCB concentrations in oil is expected to be related to the variability in primary source materials handled at and released from the facility (varying PCB formulations in oil), and presence/release of other contaminant hydrocarbons independent of PCB formulations (i.e. other hydrocarbon oils mixing with PCB-containing oils). Pure mineral oil dielectric fluids have a specific gravity of 0.9, whereas PCB-containing mineral oils exhibit specific gravities >1 (SD Meyers Transformer Specific Gravity Test Package by ASTM D 1298; Monsanto Askarel MSDS). PCBs are associated with TPH in site embayment (surficial and subsurface) sediments; with the following statistics for PCBs in oil associated with site estuarine sediments: mean concentration of PCBs in oil = 4.6×10^{-3} (4.6 ppth), range = $2.1 \times 10^{-5} – 2.7 \times 10^{-2}$ (2.7%), CV = 1.2. The greatest concentrations of PCBs in oil are found in nearshore surficial sediments in the southwestern portion of the embayment (5.3% at SED1 (SAIC 2007) and 2.7% at DSS-10 (DOF 2012)). *PCBs in site soils and sediments are clearly associated with non-aqueous phase petroleum liquids (NAPLs) and oils.*

Groundwater

The spatial distributions of PCBs in groundwater for both upper and lower zones presented in Figures 5-8b to 5-8c reflect the distributions of PCBs in upland soils presented in Figures 6-2a to 6-2d. This observation suggests that:

a) PCBs in groundwater is a result of groundwater contact with PCB-contaminated soils and oils, and

b) PCB-contaminated groundwater migration is either relatively slow and/or site conditions provide high attenuation for the migration of PCBs in groundwater.

PCBs in groundwater are generally associated with TPH in groundwater. An evaluation of PCBs *vs.* TPH in site groundwater indicates that approximately 20% of the variability in PCB concentrations is strictly dependent on the level of TPH in groundwater. This variability is similar to that observed for site soils (30%). (As indicated above, the factors controlling the remaining variability in PCB concentrations (in TPH or oil) include the variability in source-material PCB formulations and the amount of other contaminant hydrocarbon mixtures released that do not contain PCBs). The slope or mean concentration of PCBs in TPH for groundwaters is 6.7×10^{-4} or 0.67 ppth (670 ppm in oil). This concentration is comparable to the slope determined for PCBs in oil (TPH) for upland soils (9.9×10^{-4}). The range of concentrations for PCBs in oil/TPH for groundwaters is also comparable to that observed for upland soils – $(1.9 \times 10^{-5} – 9.0 \times 10^{-3})_{\text{groundwater}}$ *vs.* $(2.1 \times 10^{-5} – 6.6 \times 10^{-3})_{\text{soils}}$.

Further analysis of PCBs associated with TPH in site media (groundwater and soils) was performed on collocated soil, NAPL and groundwater samples. The location selected for this analysis using available data (multiple media contact in the same location) is at SA-MW1 for groundwater (tPCBs = 4.21 µg/L), NAPL (tPCBs = 1670 mg/kg) and soil (same as P29; tPCBs = 77 mg/kg). Specific Aroclors are presented as the percentage or proportion of the total PCBs found to evaluate any selective partitioning between media for Aroclors. (Note that any phase partitioning of PCBs between media, if occurring, is expected to show up to about 10x difference for Aroclor 1242/48 *vs.* Aroclor 1260 due to the differences in partition coefficients/factors, K_{oc}s. Aroclor 1242/48 would show a significant and proportional increase over Aroclor 1260 in groundwater relative to soils and NAPL if/when partitioning is an important mechanism for release of PCBs from soils/NAPL to groundwater.) The screening interval for the well is 4-24' and the sampling interval for the soil (SA-1-5 (P29)) was 5-6.5' below ground surface (bgs). The groundwater (GW) data represents a mean for three samples taken at different periods (11/15, 3/16 & 9/16).

	Aroclor percentage (%) of total PCBs			
	Aroclor 1242/48	Aroclor 1254	Aroclor 1260	total PCBs in oil (ppth)
SA-MW1 GW	65	24	11	2.9
SA-MW1 NAPL	60	28	12	1.7
SA-MW1 (P29) soil	66	23	11	1.2

The above data indicate the relative proportions of Aroclors in groundwater, NAPL and soil are essentially the same, suggesting that a phase partition mechanism for transfer of PCBs to water from soil/oil in source areas is negligible. If a phase partition mechanism was active, then the proportion of Aroclor 1242/48 to the total PCBs would be greater than the proportion exhibited in soil/oil. (This is due to the differences in the partition coefficients, K_{oc} [critical physicochemical constants discussed above], showing preferential partitioning or migration of Aroclor 1242/48 compared to Aroclor 1260 from soil/oil to water.) The above data indicate that PCBs in groundwater in the vicinity of source areas and materials is likely a result of simple solubilization of the oil and associated PCB constituents; a component of EPA's "facilitated transport" (EPA Region 4 Issue Paper for PCBs, 5/15/13). Another interesting observation is the near doubling of the PCB concentration in the oil (TPH) associated with the aqueous or groundwater phase compared to the NAPL and oil in soil. This difference in PCB concentrations associated with oils in water and soils is not consistent with the means (slopes) determined for PCBs in site-wide media, where the values were near equivalent (see previous discussion). Potential causes for the difference in PCB concentrations in TPH/oil observed at SA-MW1 could include – the concentration of PCBs associated with oil in soil and NAPL are not entirely representative of the media contributing to the groundwater contamination, and/or some preferential degradation of petroleum hydrocarbons *vs.* PCBs is occurring in groundwater. The later mechanism is entirely possible as PCBs are significantly more recalcitrant and stable to chemical and microbiological degradation than petroleum hydrocarbons. In summary, available ICS/NWC *site-specific data indicates that PCBs groundwater contamination in source areas is primarily a result of the mixing and solubilization of contaminated oils found in soils, resulting in enhanced or facilitated solubility of PCBs in groundwater in the vicinity of source areas. Differential phase partitioning across media in source areas is <u>not</u> evident.*

Migration or spread of PCB-contaminated groundwater at the site is relatively limited, and groundwater contamination appears to be mostly confined to identifiable source areas containing contaminated oil and soils. Figures 5-8a, 5-8b and 5-8c showing the distribution of PCBs in groundwater identify a [relatively contiguous] contaminated area in the upper and lower groundwater zones that is in direct contact with contaminated soils. This area comprises a northerly nearshore section of land (southern shoreline to the embayment) and former ditch/lagoon flanked by areas with groundwater exhibiting nondetectable (< 0.01 µg/L) PCBs contamination.[2] A separate and less-contaminated area (regarding groundwater contamination) is identified in the water table zone above the primary aquitard (Figure 5-8a). PCB-contaminated groundwater that likely impacts the estuarine environment (sediments and surface water) due to direct connectivity to estuarine waters is at HC-B1, MW-Eu, SA-MW2, and possibly SA-MW1.

Groundwater PCBs Attenuation

A comparison of groundwater PCB concentrations in source areas (SA) to downstream or downgradient (DG) (relative to groundwater flow direction) areas shows a steep reduction in groundwater PCB levels. The following analysis estimates groundwater PCB attenuation rates in the vicinity of the pipeline and former ditch located on the eastern boundary of the property. A groundwater mixing zone lies between the former ditch, which is a source area for PCB-contaminated groundwater, and the estuarine Duwamish Waterway. Groundwater migration and net flow in this zone is expected to be relatively low due to tidally influenced flow reversals. Groundwater station locations were selected in both the upper and lower zones, and in line with the estimated groundwater flow paths. Percentage estuarine influence is found in and taken from Figures 4-26a and 4-26b of the draft RI report (February 2020).

Upper Zone (10-17' depth)		
Source area – DOF-MW1	49% estuarine	0.646 µg/L tPCBs
Downgradient – P26	87% estuarine	0.020 µg/L tPCBs
	tPCBs attenuation = 32	
	~ 60' distance between locations	
Lower Zone (19-35' depth)		
Source area (SA) – P18-A	10% estuarine	0.59 µg/L tPCBs
SA – P21-A	< 5% estuarine	0.85 µg/L tPCBs
SA – P33-A	< 5% estuarine	0.30 µg/L tPCBs
Mean SA	5% estuarine	0.58 µg/L tPCBs
Downgradient (DG) – MW-IL	37% estuarine	0.006 µg/L tPCBs
DG – MW-FL	20% estuarine	< 0.01 µg/L tPCBs
DG – MW-GL	51% estuarine	< 0.01 µg/L tPCBs
Mean DG	36% estuarine	0.006 µg/L tPCBs
	tPCBs attenuation ≃ 100	
	60-120' distance between locations	

The estuarine influence in both upper zone samples may be the result of differential leakage along the unlined/unfilled ditch or from the drainage pipe (10.5' bgs) of estuarine water accumulated due to tidal backflow originating at the pipe discharge to the 2nd Ave. storm drain outlet in the embayment. Significant [lateral or horizontal] mixing of PCB-contaminated groundwater in the lower zone beneath the former ditch and pipeline is not apparent, based on the large differences in groundwater TDS (salinity and estuarine contributions) and PCB concentrations between the source area (the former ditch) and nearby downgradient wells (as

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[2] Additional and supplementary analyses employing PCB congeners were performed and reported in a subsequent assessment (DMD Addendum 5/19).

demonstrated above). Estuarine water contribution in the lower zone in the area of the former ditch is low, averaging less than 5%, whereas estuarine water contributions to downgradient wells (at the same depth) are significantly greater; averaging 36%.

Significant attenuation of PCBs contamination in site groundwater is observed in both upper and lower zones between contaminant source areas and downgradient wells. Groundwater PCB "apparent" attenuation factor rates from the pipeline and former ditch average 5-17x per 10 feet (0.5-1.7x/ft) in the downgradient flow direction. Possible mechanisms that control the observed attenuation in downgradient areas are low or restricted groundwater flow from source areas, groundwater advection/dispersion in downgradient mixing zones, and soil adsorption from the dissolved phase (application of K_{oc}) between source and downgradient areas. Either one or both of the first two mechanisms are important as demonstrated in the differences in percentage estuarine influence as an indicator of groundwater mixing. The third mechanism, soil adsorption and sequestration of PCBs from groundwater, is also likely significant, especially if soil organic carbon contents are elevated. Soil partition coefficients (K_{oc}) can be as great as $7.7\text{x}10^6$, in the case of Aroclor 1260, and can provide the mechanism for adsorption and soil sequestering of hydrophobic contaminants. This mechanism is the basis for commercial application of contaminated groundwater cleanup strategies employing injectable activated carbon suspensions (e.g., PlumeStop® by Regenesis). An evaluation of site TOC (total organic carbon) data for nonimpacted sediments (no measurable TPH and PCBs) indicates the range of site [fill] soil TOC to likely be in the range of 0.3-4.2%, with a mean of 2% and a CV of 0.51.[3] Adsorption of hydrophobic chemicals, such as PCBs, to TOC-containing soils is an important mechanism for the extraction and sequestration of chemicals from groundwater. This process is facilitated and enhanced by an increase in TDS in the mixing zone. The ICS/NWC site possesses characteristics that are demonstrated to "naturally" and effectively attenuate groundwater PCBs for the protection of estuarine surface water and sediments.

Summary

An evaluation of the fates and distributions of PCBs in contaminated media at the ICS/NWC site demonstrates that PCBs behavior is consistent with current published technical literature descriptions and understanding of extremely hydrophobic chemicals' contamination of environmental media. The ICS/NWC site exhibits site-specific characteristics that have minimized the wide-spread contamination of environmental media with PCBs from groundwater flow. PCBs-contaminated environmental media are relatively localized and, in conjunction with other factors, have been contained by fill soils exhibiting moderate levels of organic carbon (TOC) content. Groundwater migration of PCBs from highly contaminated source materials in some areas of the site has been relatively low as demonstrated by PCB groundwater attenuation rates on the order of 0.5-1.7x/ft.

Remedial Management Strategy

Based on the above findings, elements of an effective remedial strategy for the ICS/NWC site may include the following activities:

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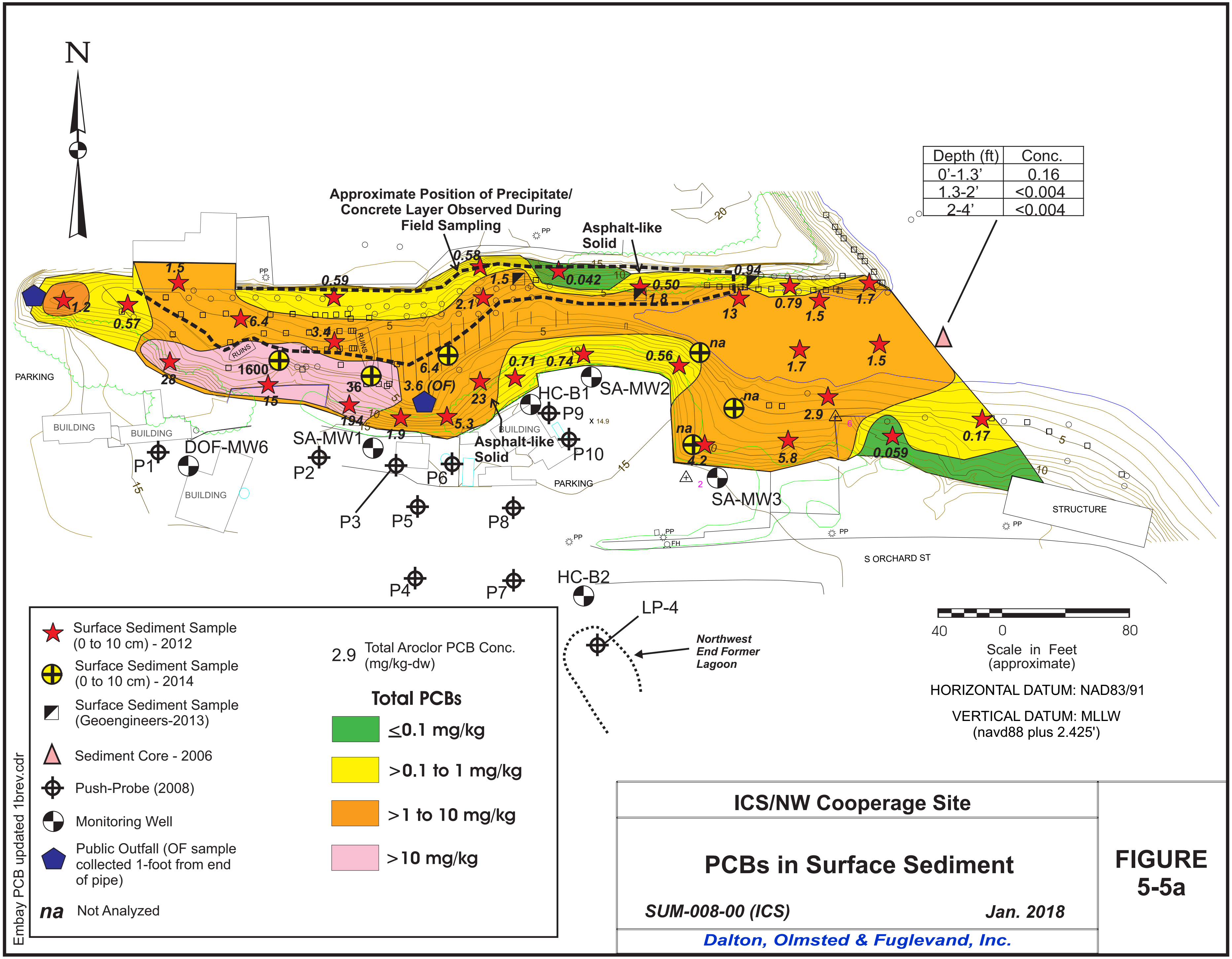
[3] Samples are within the group of subsurface sediments collected during 11/12 and presented in the draft RI report. TOC values were used for noncontaminated samples (n=18) exhibiting no detectable PCBs and low reported TPH.

- Removal of contaminated embayment sediments, as practical, and consider placement of an appropriate cap (augmented with organic carbon) to reduce migration of contaminated groundwater to surface waters and remediated sediments.
- Removal of contaminated source materials/soils from the nearshore area, as practical, to prevent estuarine contamination from groundwater seeps and soils erosion. If removal is impractical due to engineering constraints, the placement of an appropriate barrier may be necessary.
- Removal of contaminated source material/soils from along the pipeline and former ditch, as practical.
- Ensure that groundwater flowpaths from any residual contaminated source materials are sufficiently long to enhance attenuation by prolonging contact time with relatively noncontaminated and nonleachable soils (or amended soils) to extract/sequester contaminants from groundwater prior to discharge to surface waters. This may include redirection of groundwater flowpaths to enhance advection/dispersion and increase efficiencies of contaminant sequestration prior to discharge to surface waters.
- Ensure conditions are optimal for sequestration of contaminants from groundwater, such as sufficient levels of TOC in soils or amended soils. Injection of activated carbon suspensions into soils and groundwater could be employed as a contingency measure to enhance sequestration by adsorption and prevent PCBs migration via groundwater.

Appropriate engineering solutions can be designed and applied during site remediation in order to address the site-specific issues identified above. An effective remedial strategy should be within the range of established remedial construction practices.



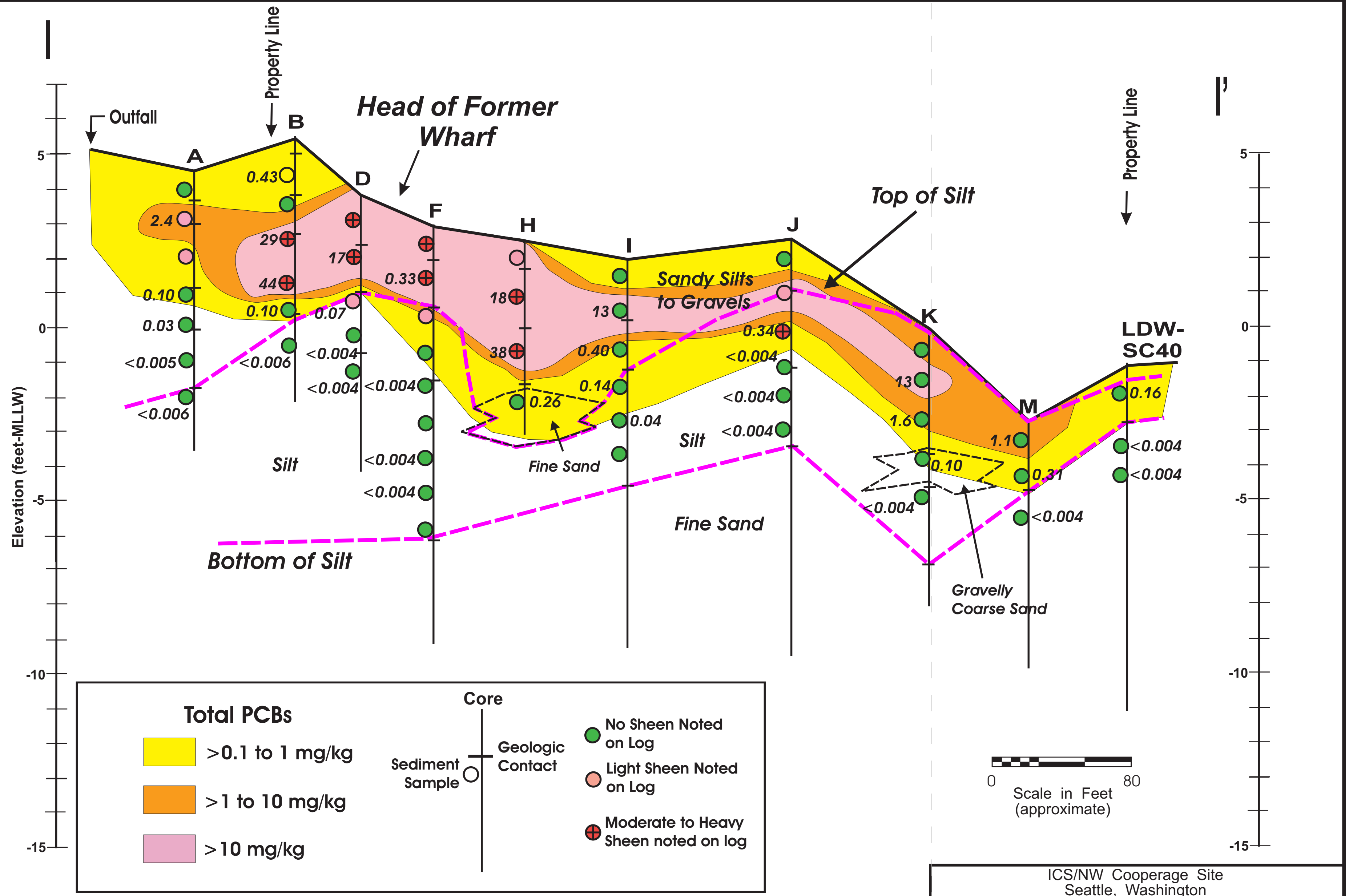
ICS/NW Cooperage Site

PCBs in Surface Sediment

SUM-008-00 (ICS) ***Jan. 2018***

Dalton, Olmsted & Fuglevand, Inc.

FIGURE 5-5a



ICS/NW Cooperage Site
Seattle, Washington

PCBs in Subsurface Sediment

SUM-008-00 **FIGURE 5-6a** Mar. 2018
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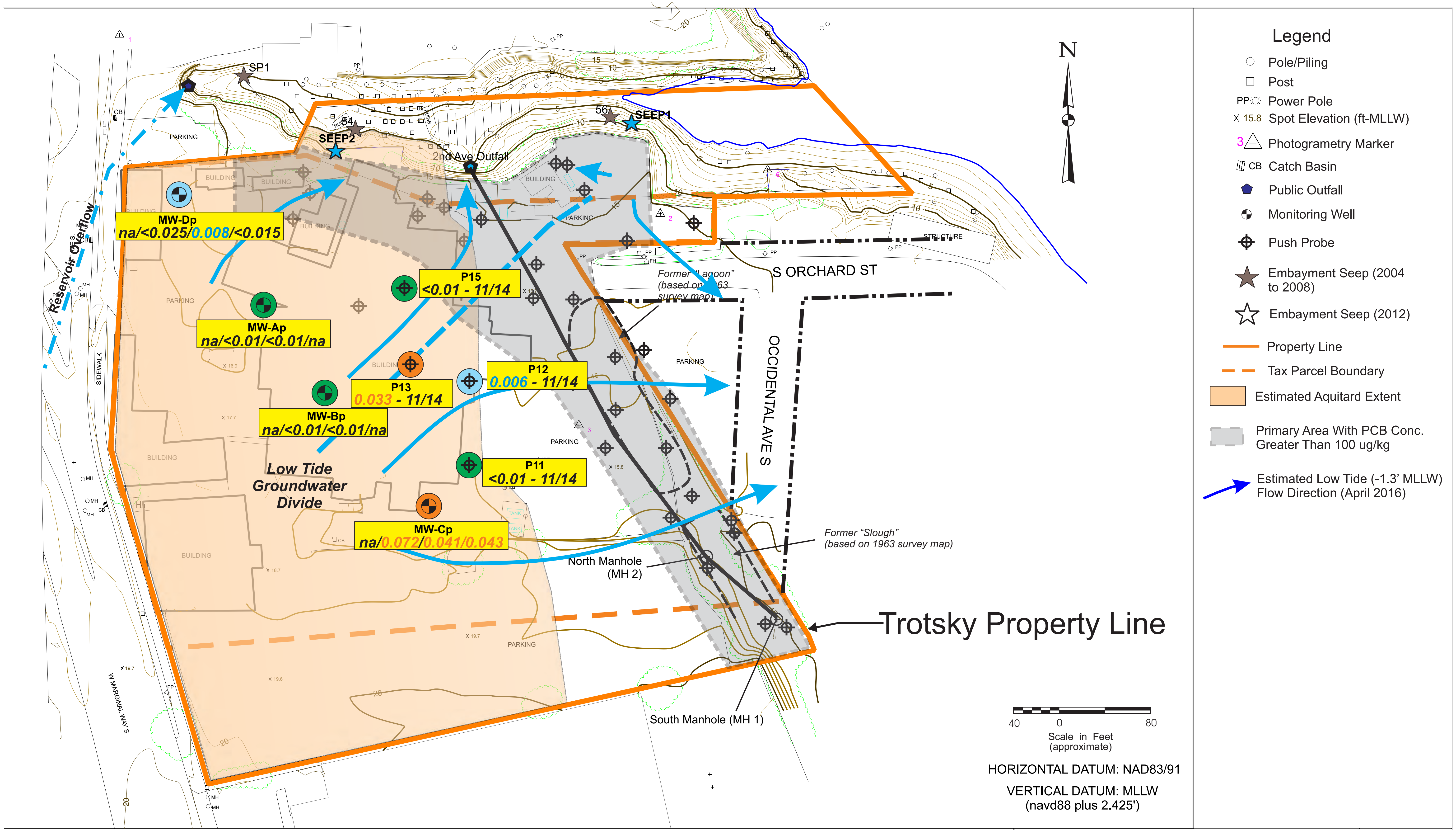
Ref: Section I-I' Conc rev rpt.cdr



● Concentration ≤ Screening Level (SL= 7.0E-06*; PQL=0.01 ug/l)

● Concentration > Screening Level (SL= 7.0/E-06*; PQL=0.01 ug/l)

● Detection at or below PQL

2.0/5.3/6.0/2.0 Concentration - ug/l (11-2012/11-2015/3-2016/9-2016)

na - Not Available; * SL Based on PQL

Ref: TPCBs GW Plot R1-R3rev.cdr

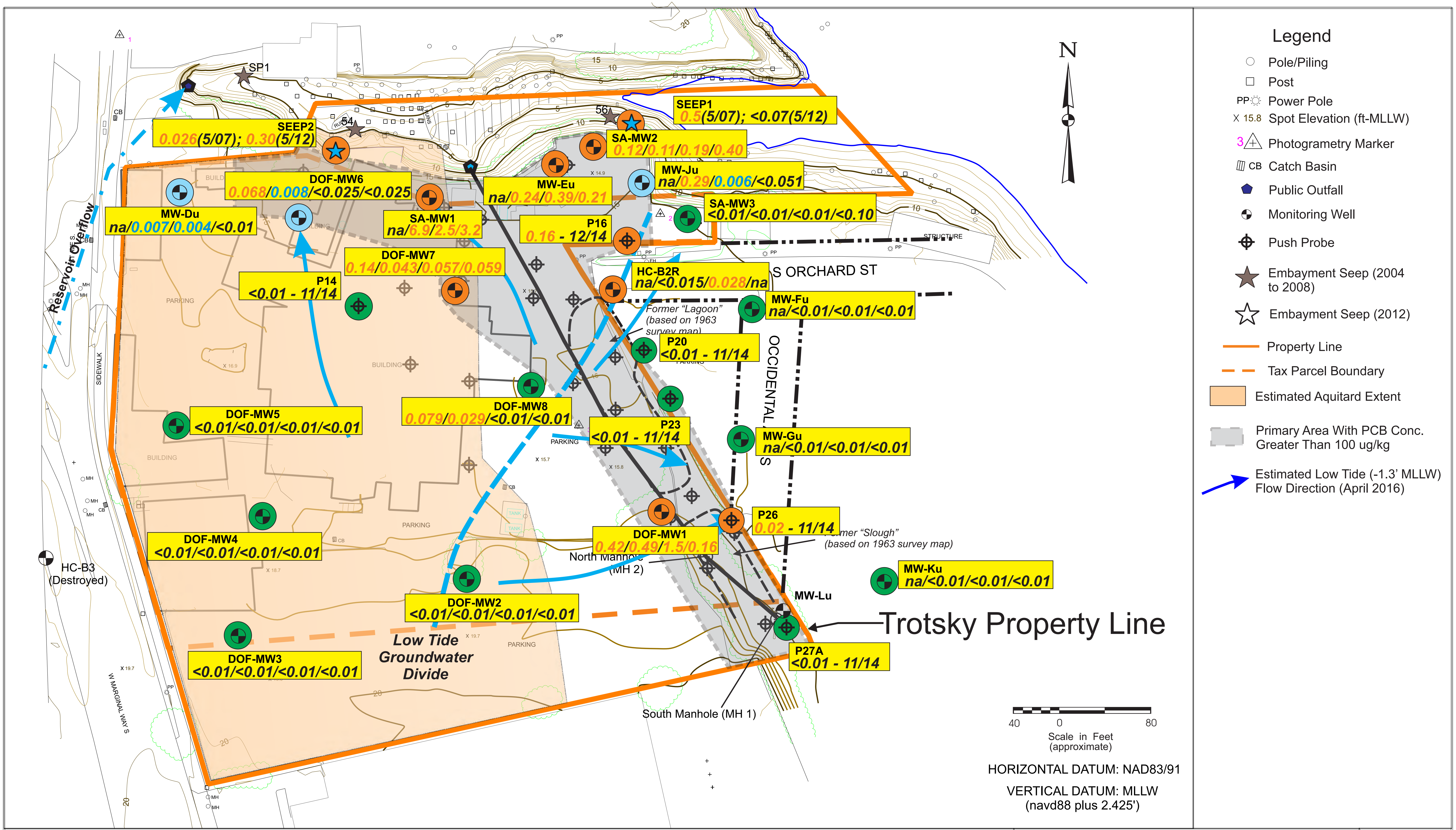
ICS/NW Cooperage Site

Total PCB Concentrations
Water Table Zone Above Aquitard

SUM-008-00 (ICS) ***Mar. 2018***

Dalton, Olmsted & Fuglevand, Inc.

FIGURE 5-8a



🟢 Concentration ≤ Screening Level (SL= 7.0E-06*; PQL=0.01 ug/l)

🟠 Concentration > Screening Level (SL= 7.0/E-06*; PQL=0.01 ug/l)

○ Detection at or below PQL

2.0/5.3/6.0/2.0 Concentration - ug/l (11-2012/11-2015/3-2016/9-2016)

na - Not Available; * SL Based on PQL

Ref: TPCBs GW Plot R1-R3rev.cdr

ICS/NW Cooperage Site

Total PCB Concentrations Upper Zone

SUM-008-00 (ICS) *Mar. 2018*

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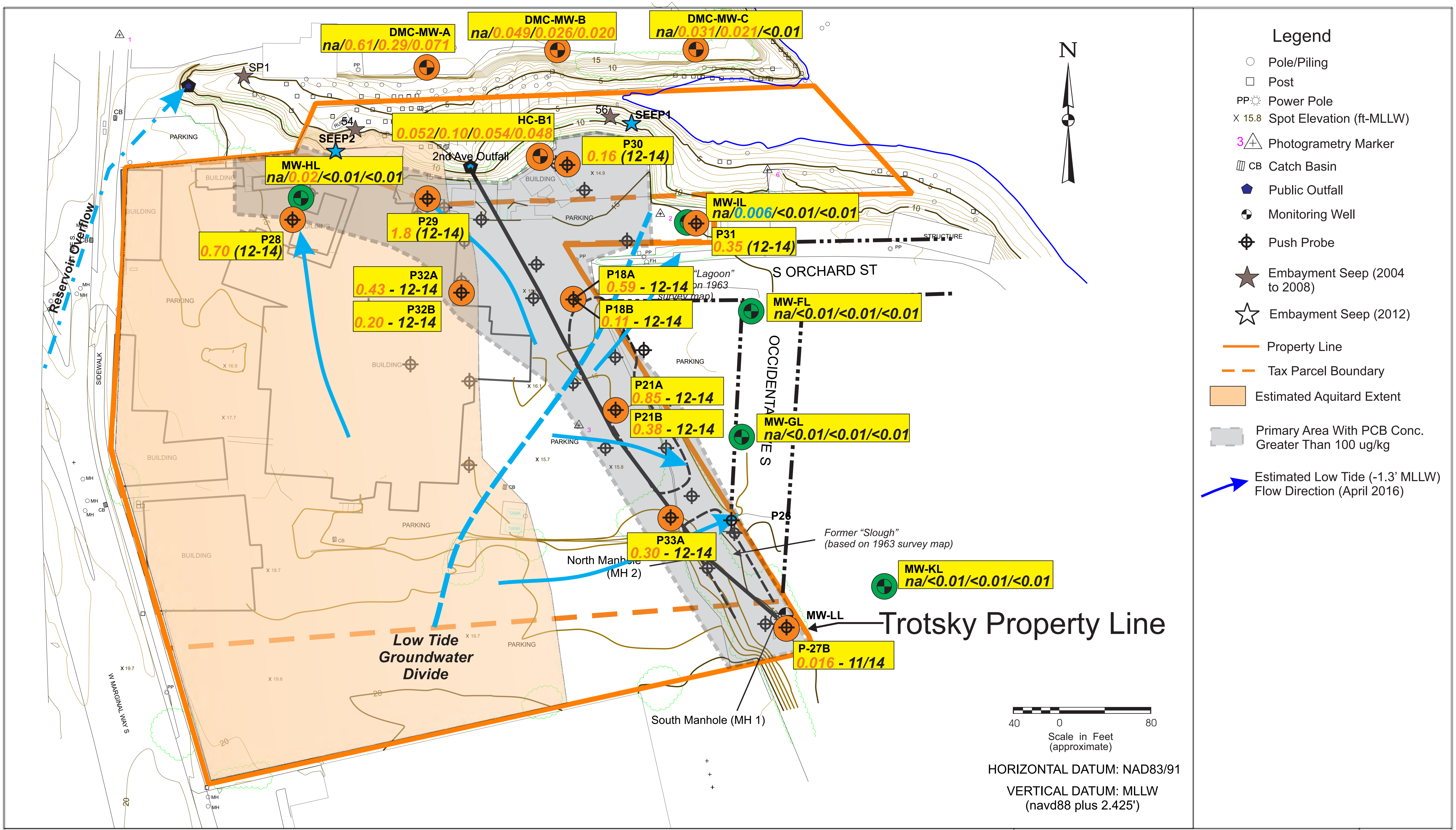
FIGURE 5-8b



- 🟢 Concentration ≤ Screening Level (SL= 7.0E-06*; PQL=0.01 ug/l)
- 🟠 Concentration > Screening Level (SL= 7.0/E-06*; PQL=0.01 ug/l)
- 🔵 Detection at or below PQL

2.0/5.3/6.0/2.0 Concentration - ug/l (11-2012/11-2015/3-2016/9-2016)

na - Not Available; * SL Based on PQL

Ref: TPCBs GW Plot R1-R3rev.cdr

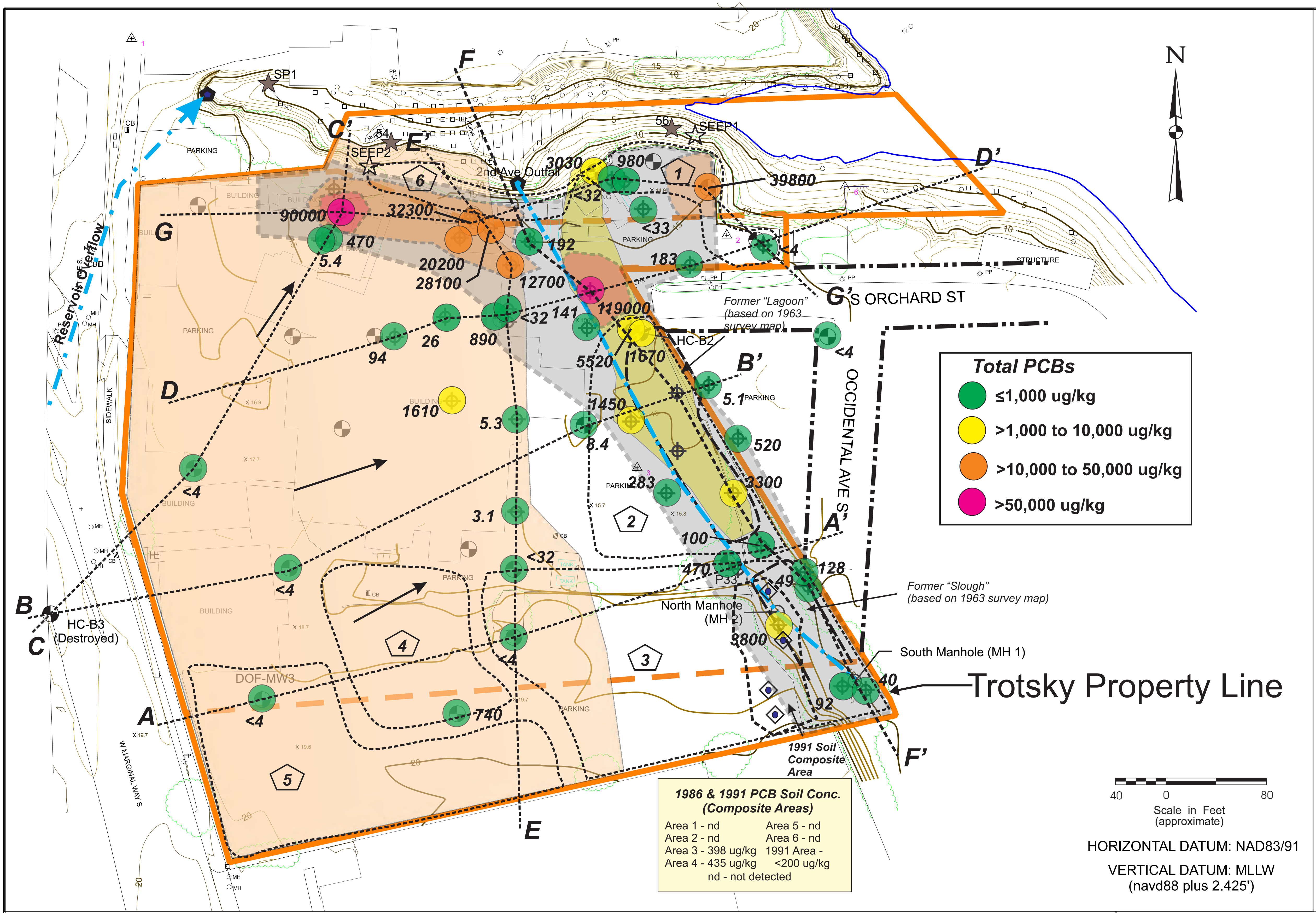
ICS/NW Cooperage Site

Total PCB Concentrations
Lower Zone

SUM-008-00 (ICS) *Mar. 2018*

Dalton, Olmsted & Fuglevand, Inc.

FIGURE 5-8c



Total PCBs

- 🟢 ≤1,000 ug/kg
- 🟡 >1,000 to 10,000 ug/kg
- 🟠 >10,000 to 50,000 ug/kg
- 🔴 >50,000 ug/kg

1986 & 1991 PCB Soil Conc. (Composite Areas)

Area 1 - nd	Area 5 - nd
Area 2 - nd	Area 6 - nd
Area 3 - 398 ug/kg	1991 Area - <200 ug/kg
Area 4 - 435 ug/kg	

nd - not detected

HORIZONTAL DATUM: NAD83/91

VERTICAL DATUM: MLLW
(navd88 plus 2.425')

Legend

○	Pole/Piling
□	Post
PP ☼	Power Pole
X 15.8	Spot Elevation (ft-MLLW)
3 △	Photogrammetry Marker
▥ CB	Catch Basin
⬟	Public Outfall
◐	Monitoring Well
⊕	Push Probe
X	Surface Sediment Sample SAIC - 1991
⊕	Surface Sediment Sample SAIC - 2007
⊞	LDW-RI Surface Sample Locations RI Report
△	Sediment Core - RI Report (2006)
★	Embayment Seep (2004 to 2008)
☆	Embayment Seep (2012)
◈	Composite Soil Sample (1991)
⊕	Man-hole
●	Composite Soil Sample (1986)
┈	1986 Soil Spl. Composite Area
━	Property Line
╍	Tax Parcel Boundary
▨	Estimated Aquitard Extent
⬠ 5	1986 Composite Area Sample
A - - - A'	PCB Section Trend
→	Estimated Aquitard Slope

SL = Screening Level

Notes: Soil Contact SL = 1,000 ug/kg

▨ Primary Area With PCB Conc. Greater Than 100 ug/kg

Ref: Upland Phase2a TPCB.cdr

ICS/NW Cooperage Site

Extent of Total PCBs in Soil Less than Five Feet Deep

SUM-008-00 (ICS) *March 2018*

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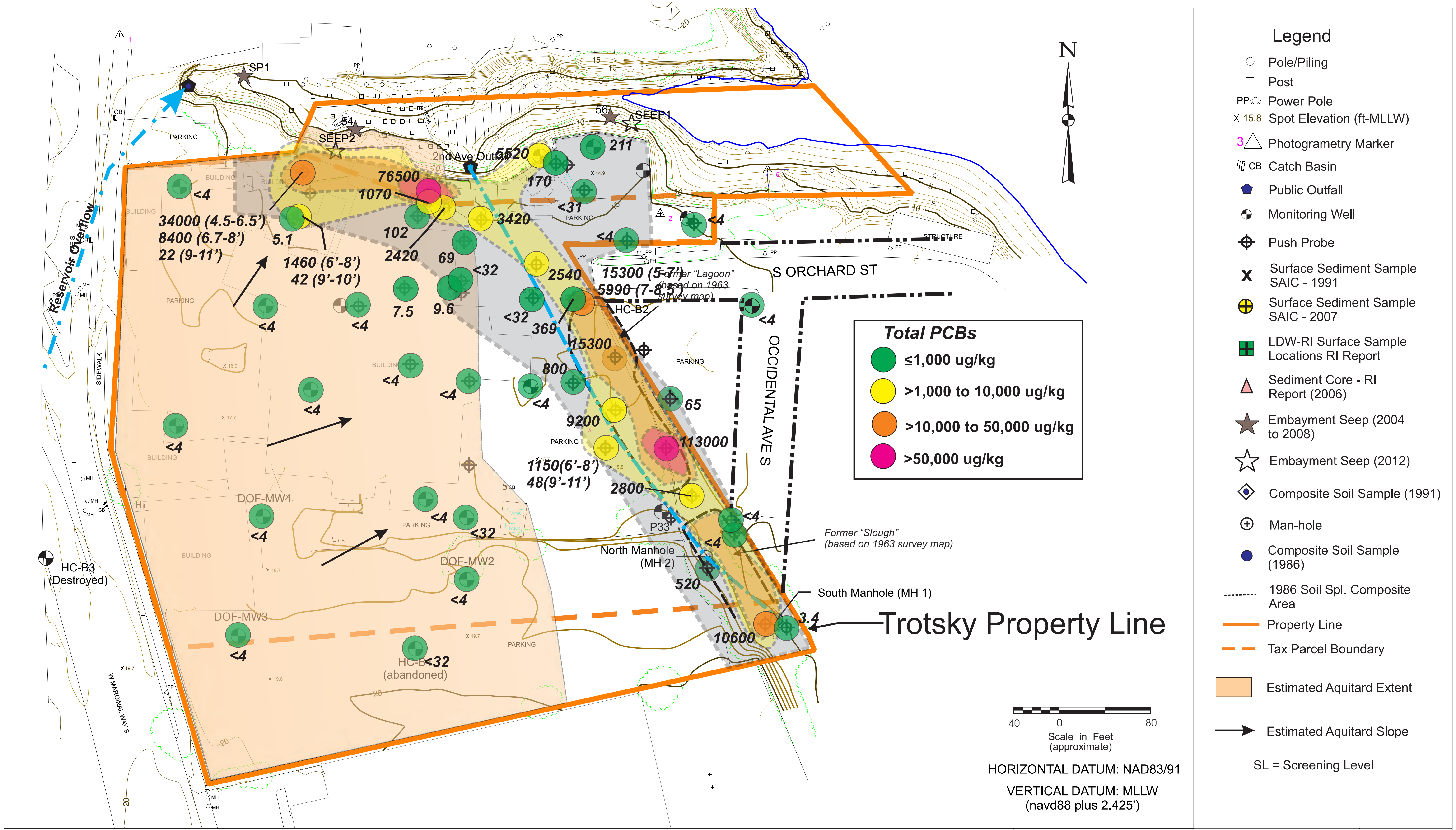
FIGURE 6-2a



Notes: Soil Contact SL = 1,000 ug/kg

▨ Primary Area With PCB Conc. Greater Than 100 ug/kg

ICS/NW Cooperage Site

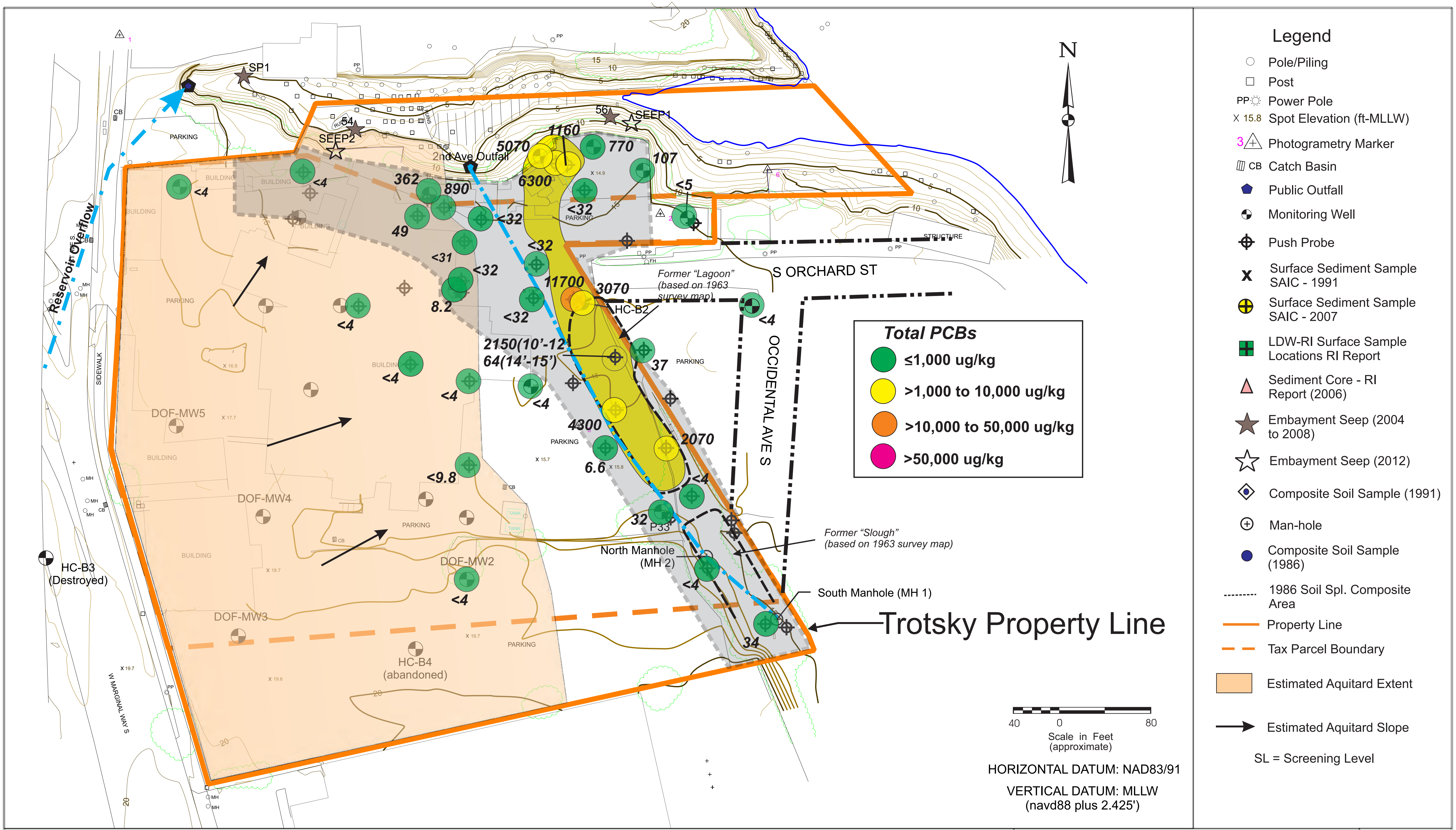
Extent of Total PCBs in Soil
Five to Ten Feet Deep

SUM-008-00 (ICS) ***March 2018***

Dalton, Olmsted & Fuglevand, Inc.

FIGURE 6-2b

Ref: Upland Phase2a TPCB.cdr



Notes: Soil Contact SL = 1,000 ug/kg

▨ Primary Area With PCB Conc. Greater Than 100 ug/kg

ICS/NW Cooperage Site

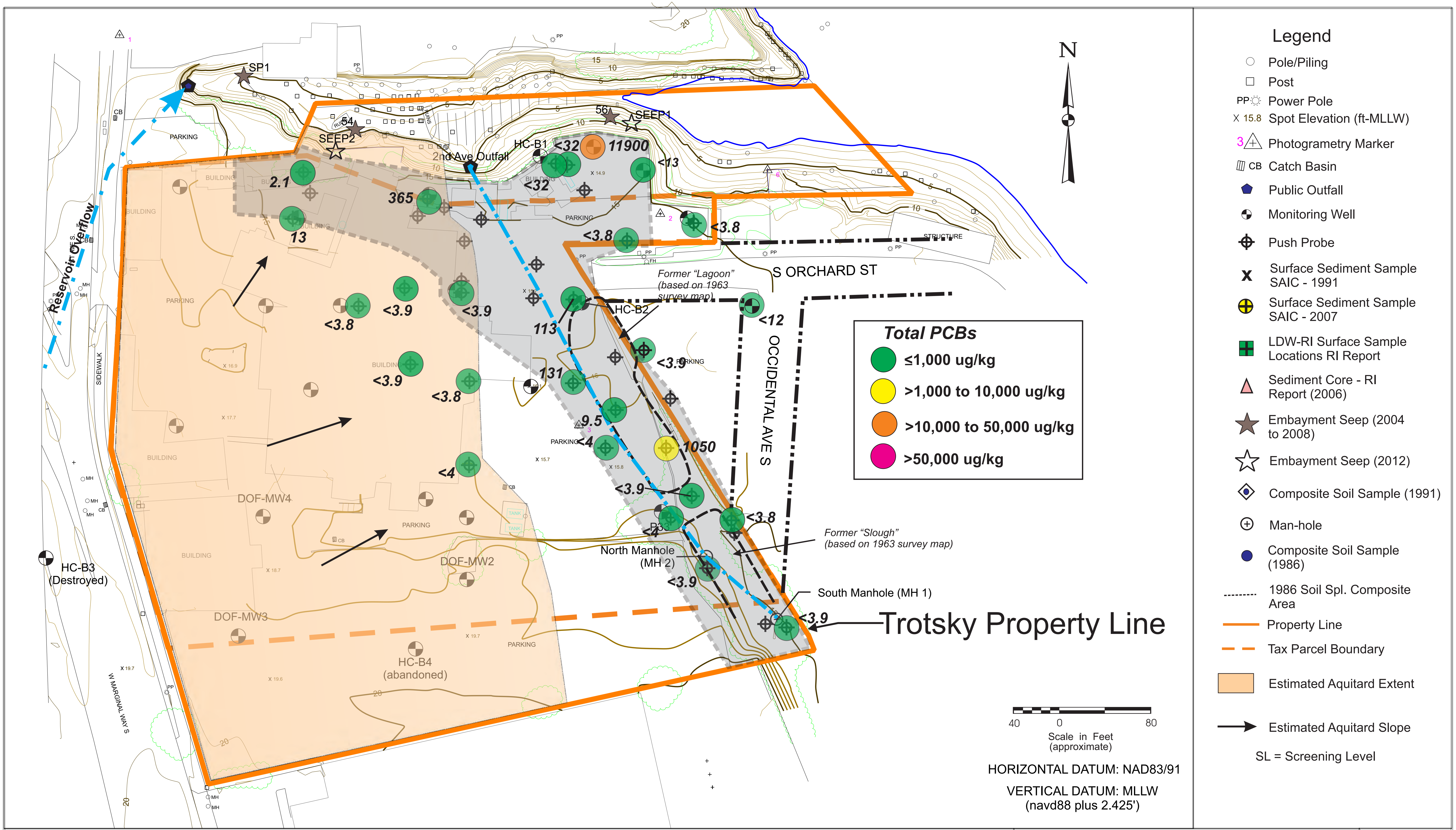
Extent of Total PCBs in Soil Ten to Fifteen Feet Deep

SUM-008-00 (ICS) *March 2018*

Dalton, Olmsted & Fuglevand, Inc.

FIGURE 6-2c

Ref: Upland Phase2a TPCB.cdr



Primary Area With PCB Conc. Greater Than 100 ug/kg

Ref: Upland Phase2a TPCB.cdr

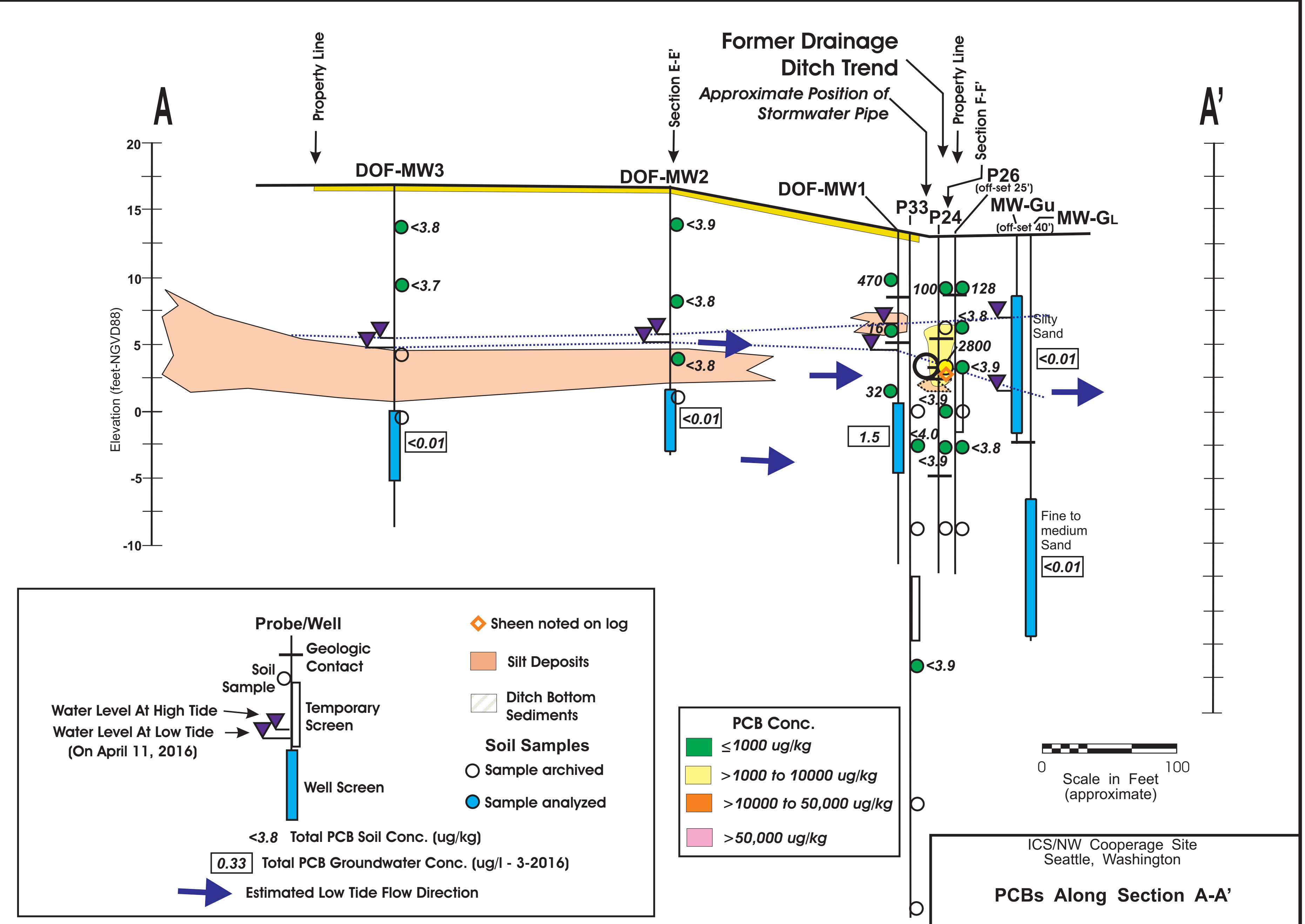
ICS/NW Cooperage Site

Extent of Total PCBs in Soil Fifteen to Twenty Feet Deep

SUM-008-00 (ICS) *March 2018*

Dalton, Olmsted & Fuglevand, Inc.

FIGURE 6-2d



ICS/NW Cooperage Site
Seattle, Washington

PCBs Along Section A-A'

SUM-008-00 **FIGURE 6-3a** April 2018

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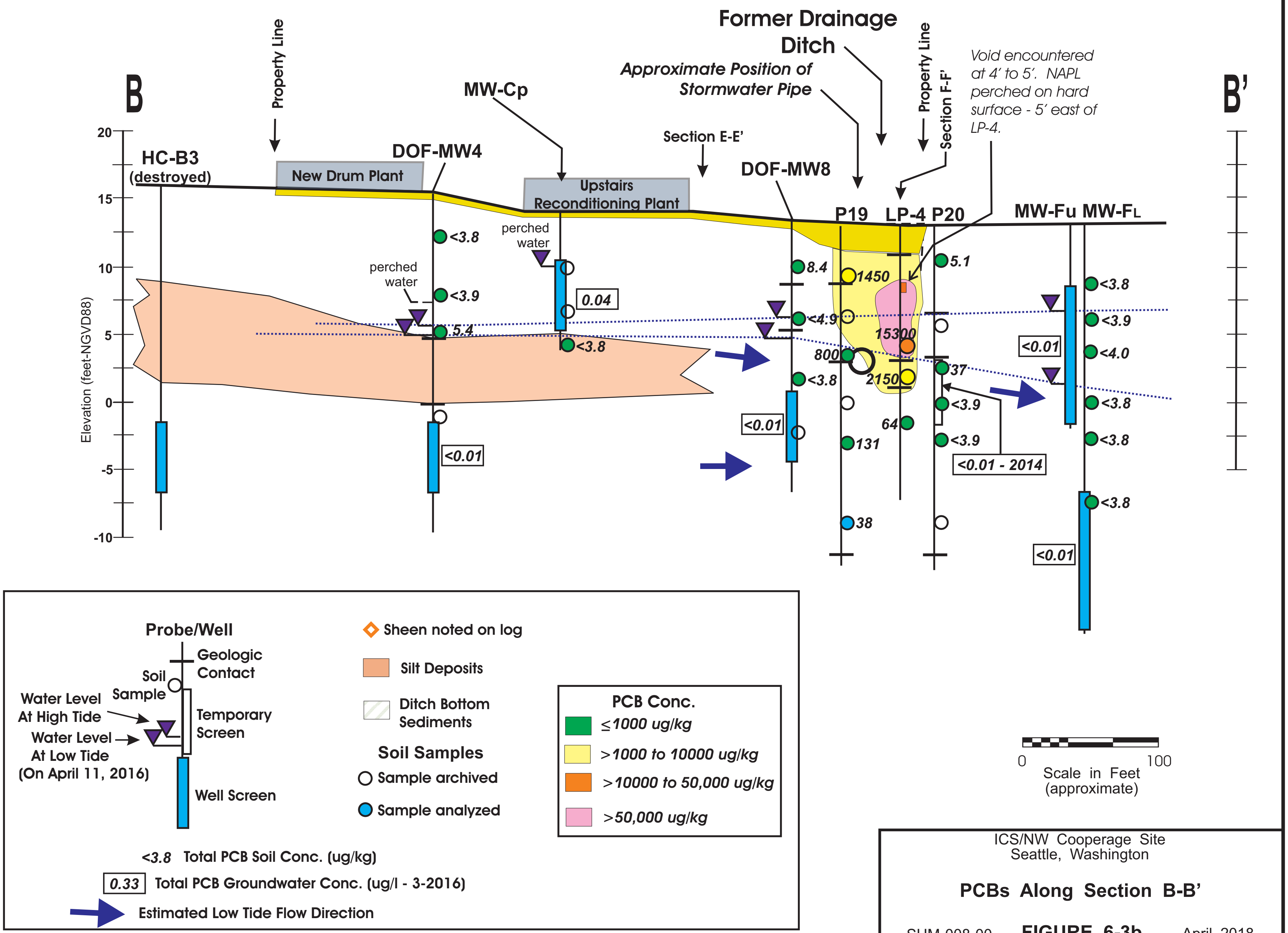
Ref: Section A-A' PCB 7-2016.cdr

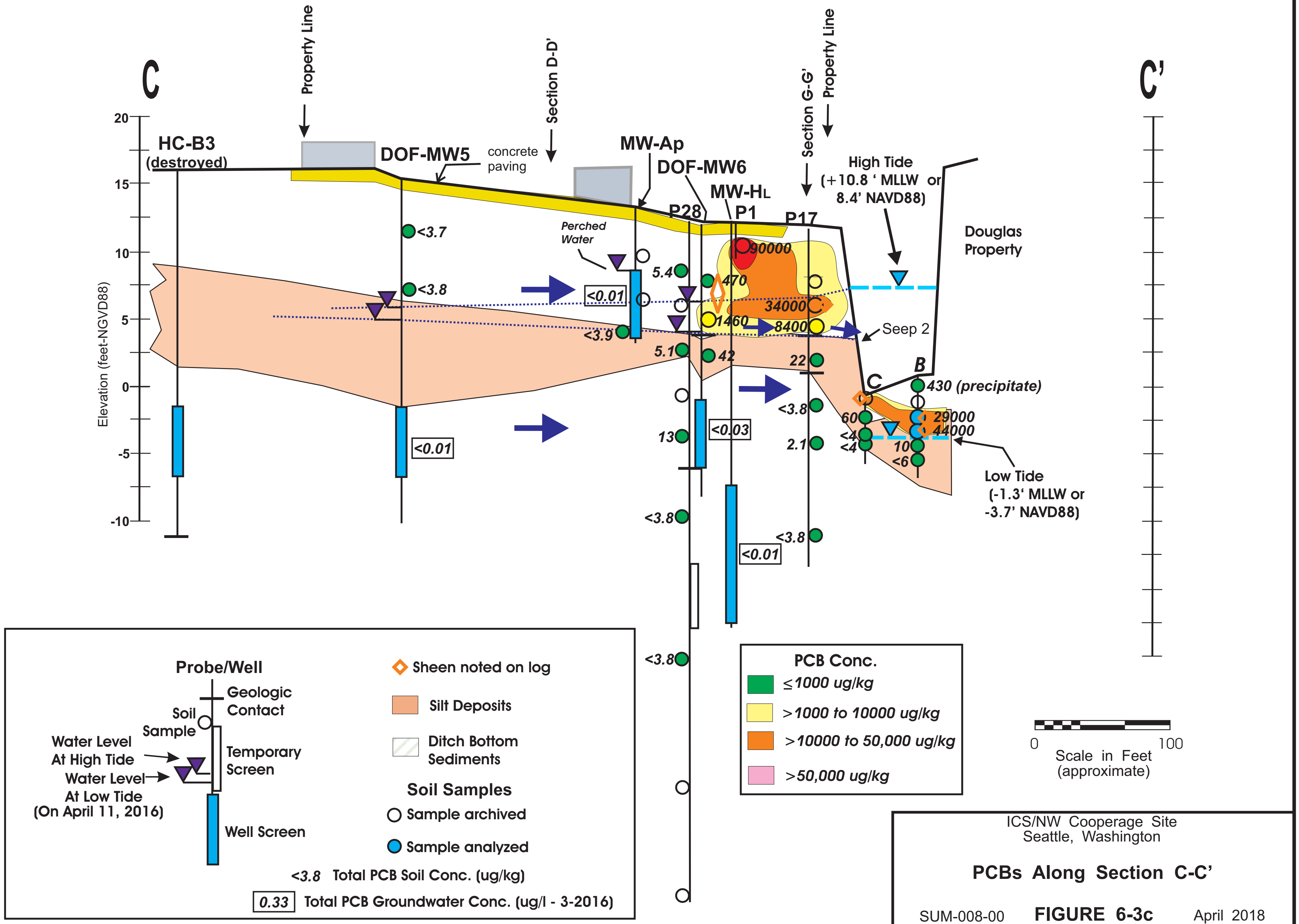


Ref: Section B-B'7-2016.cdr

ICS/NW Cooperage Site
Seattle, Washington

PCBs Along Section B-B'

SUM-008-00 **FIGURE 6-3b** April 2018
Dalton, Olmsted & Fuglevand, Inc.

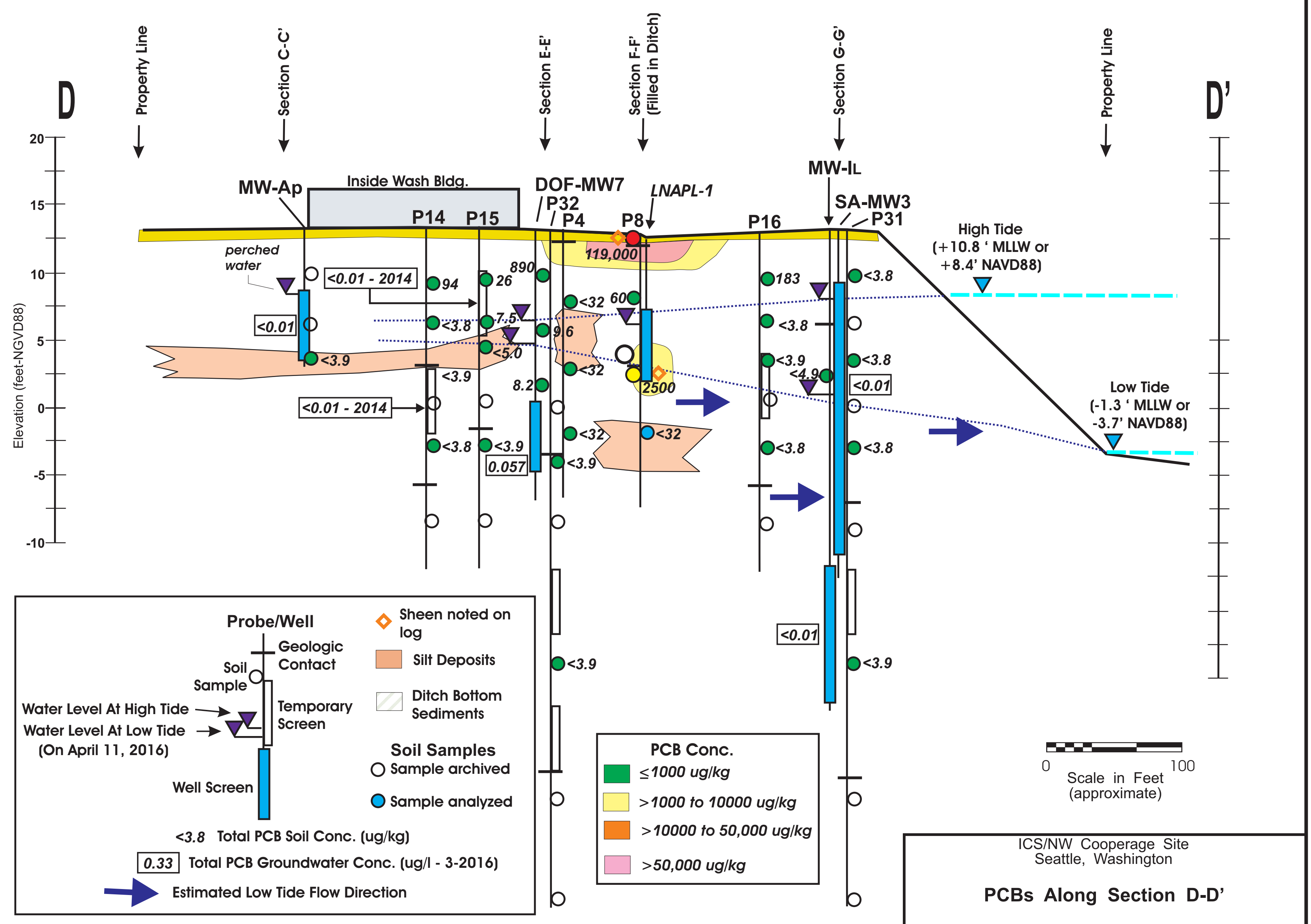


Ref: Section C-C'PCB 7-2016.cdr

ICS/NW Cooperage Site
Seattle, Washington

PCBs Along Section C-C'

SUM-008-00 **FIGURE 6-3c** April 2018
Dalton, Olmsted & Fuglevand, Inc.

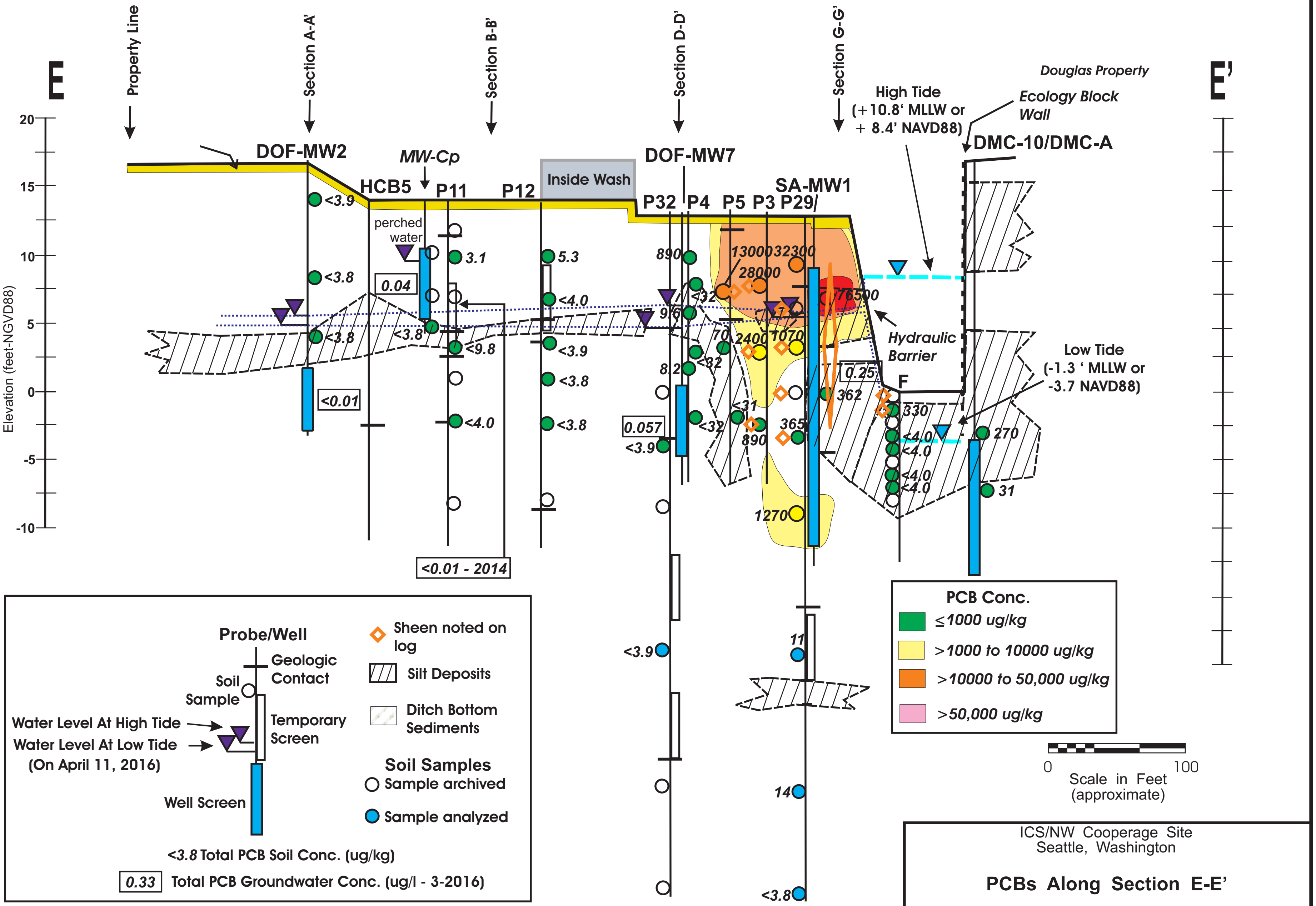


ICS/NW Cooperage Site
Seattle, Washington

PCBs Along Section D-D'

SUM-008-00 **FIGURE 6-3d** April 2018
Dalton, Olmsted & Fuglevand, Inc.

Ref: Section D-D' PCB 7-2016.cdr



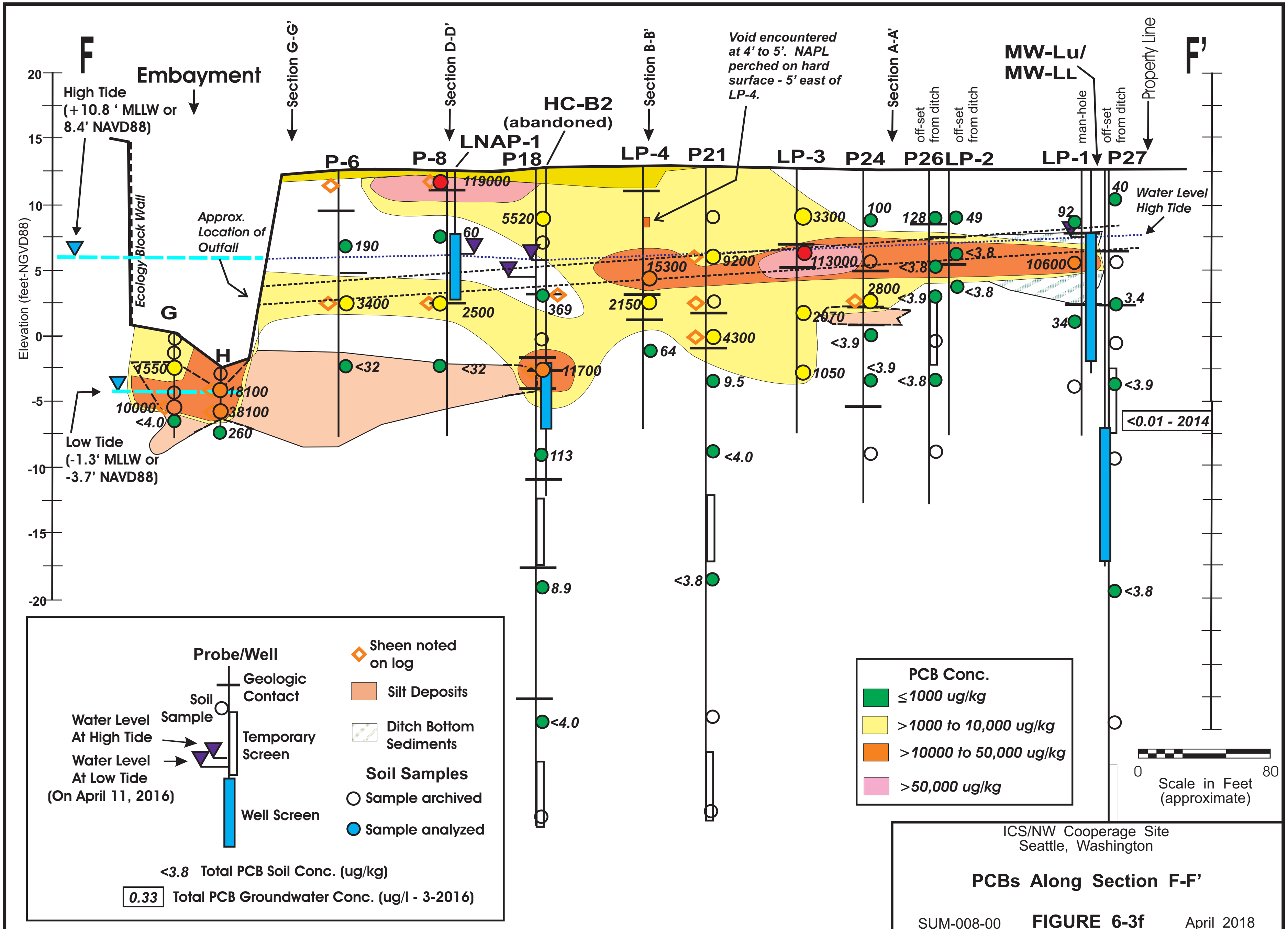
ICS/NW Cooperage Site
Seattle, Washington

PCBs Along Section E-E'

SUM-008-00 **FIGURE 6-3e** April 2018

Dalton, Olmsted & Fuglevand, Inc.

Ref: Section E-E' PCB7-2016.cdr



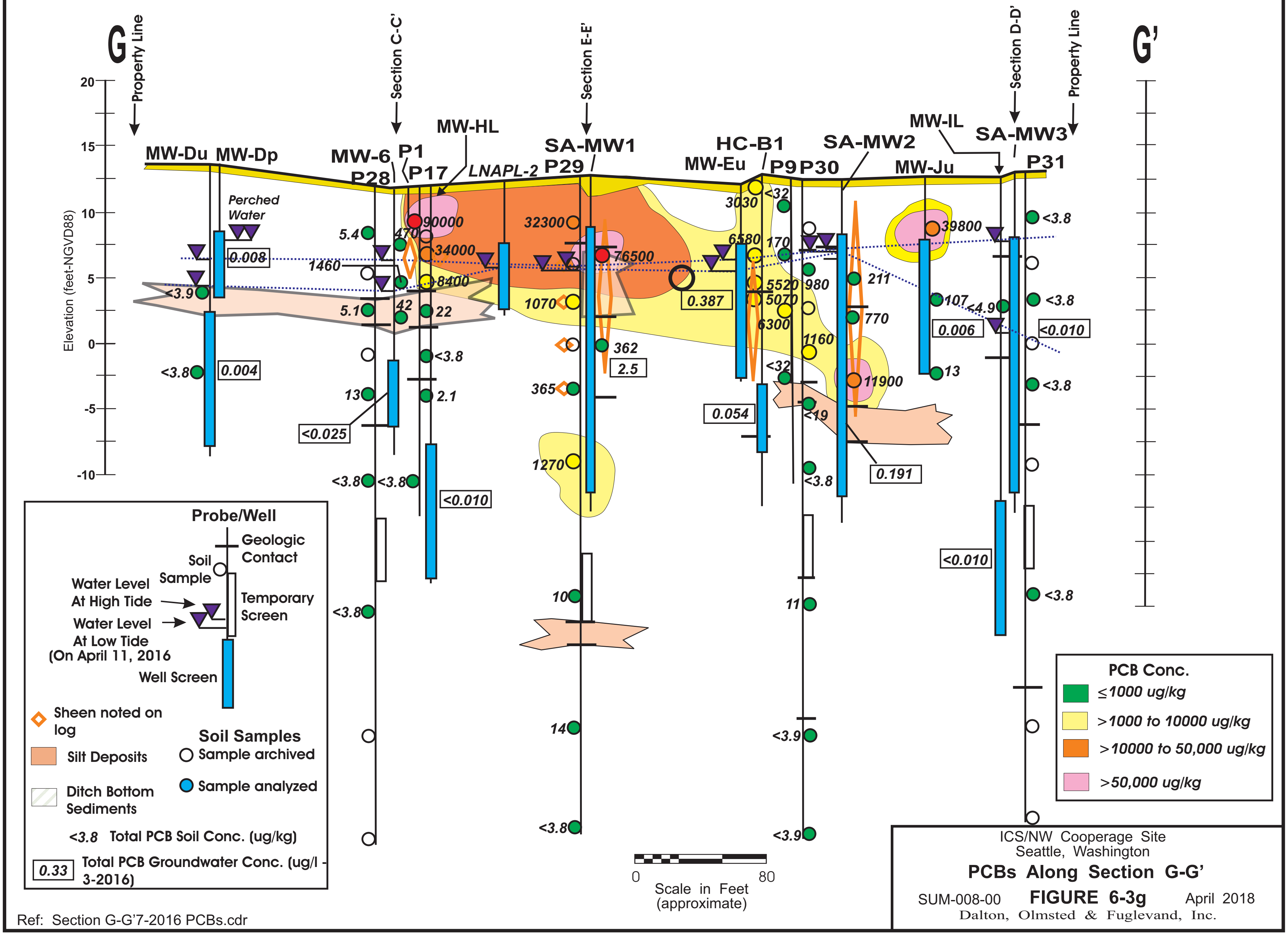
Ref: Section F-F'a PCBs.cdr

ICS/NW Cooperage Site
Seattle, Washington

PCBs Along Section F-F'

SUM-008-00 **FIGURE 6-3f** April 2018

Dalton, Olmsted & Fuglevand, Inc.



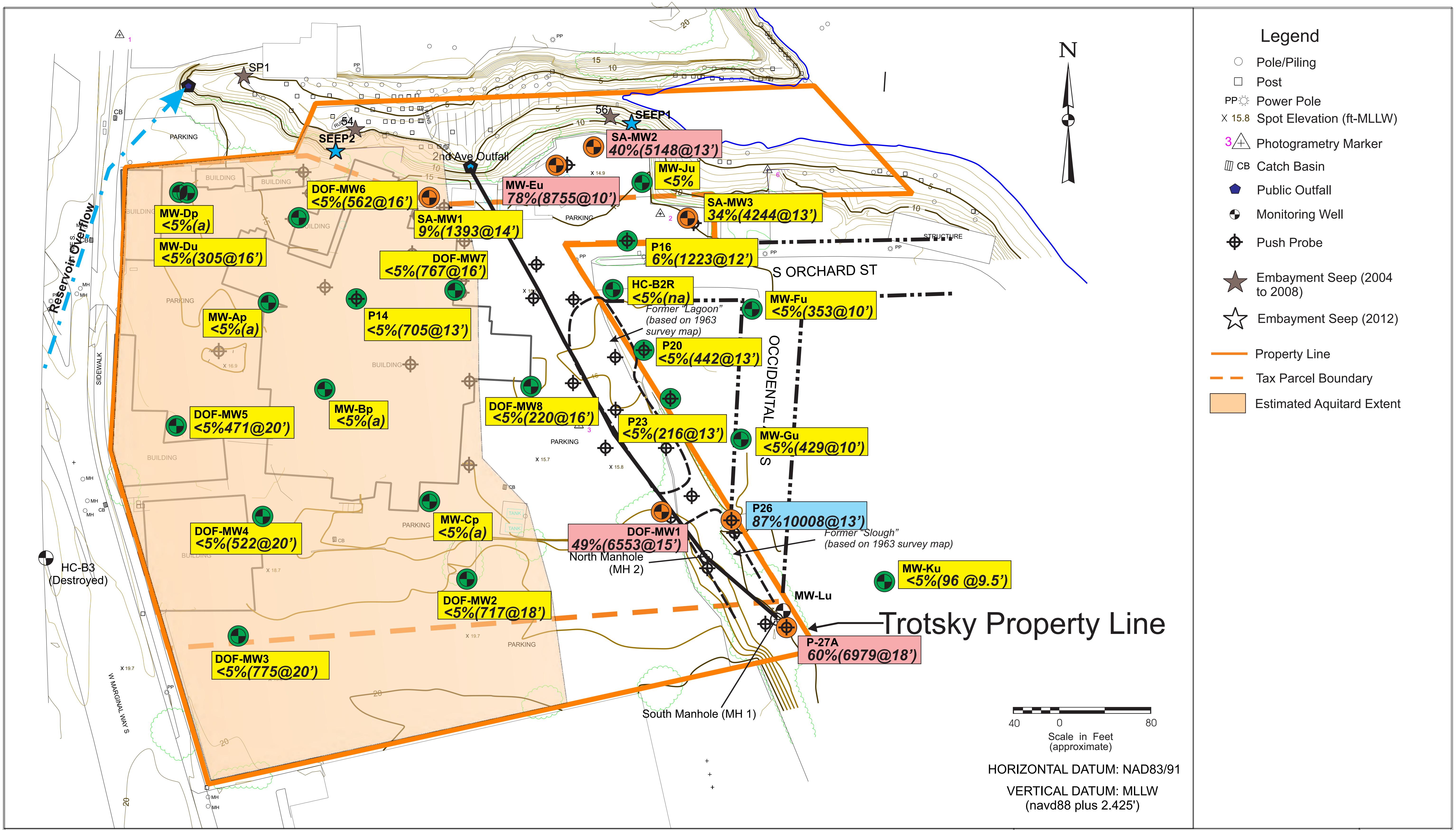
ICS/NW Cooperage Site
Seattle, Washington

PCBs Along Section G-G'

SUM-008-00 **FIGURE 6-3g** April 2018

Dalton, Olmsted & Fuglevand, Inc.

Ref: Section G-G'7-2016 PCBs.cdr



Notes: (a) Estuarine Water Content Estimated to be Less Than 5% Based on Electrical Conductivity Measurements (<1,000 uS/cm)

<5%(220@16') - % Estuarine Water (Dissolved Solids in mg/l@ Mid-point Spl. Depth in feet)

Ref: Mixing Ratios rev.cdr

- 🟢 Estuarine Water Content Less Than 5%
- 🟠 Estuarine Water Content Equal to or Greater Than 5%
- 🟨 Dissolved Solids <5,000 mg/l
- 🟥 Dissolved Solids 5,000 to 10,000 mg/l
- 🟦 Dissolved Solids > 10,000 mg/l

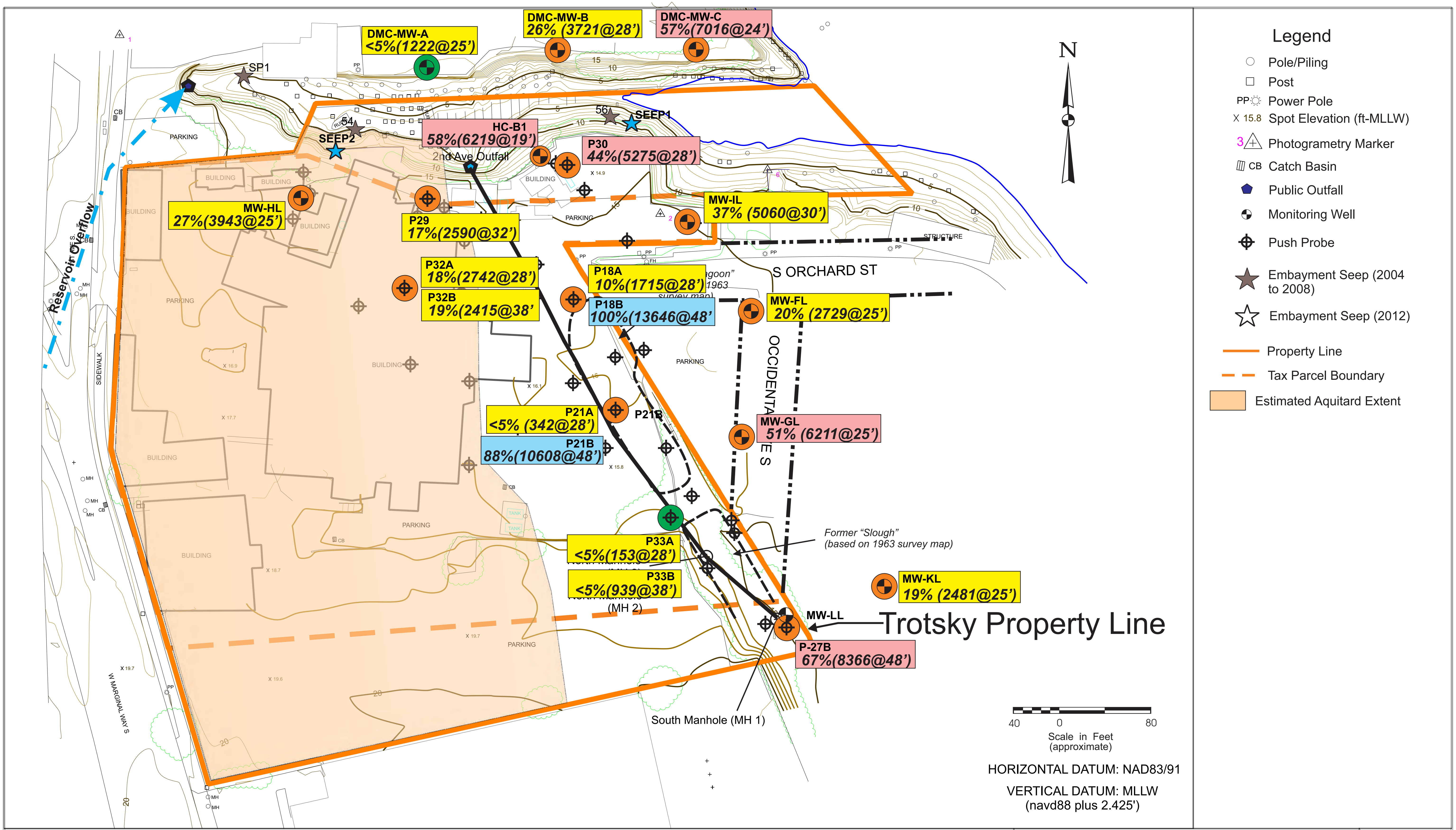
ICS/NW Cooperage Site

Estuarine Water Contents
Water Table/Upper Zone Groundwater

SUM-008-00 (ICS) ***Mar. 2018***

Dalton, Olmsted & Fuglevand, Inc.

FIGURE 4-26a



Notes:

<5%(220@16') - % Estuarine Water (Dissolved Solids in mg/l@ Mid-point Spl. Depth in feet)

- ● Estuarine Water Content Less Than 5%
- ● Estuarine Water Content Equal to or Greater Than 5%
- 🟨 Dissolved Solids <5,000 mg/l
- 🟥 Dissolved Solids 5,000 to 10,000 mg/l
- 🟦 Dissolved Solids > 10,000 mg/l

Ref: Mixing Ratios rev.cdr

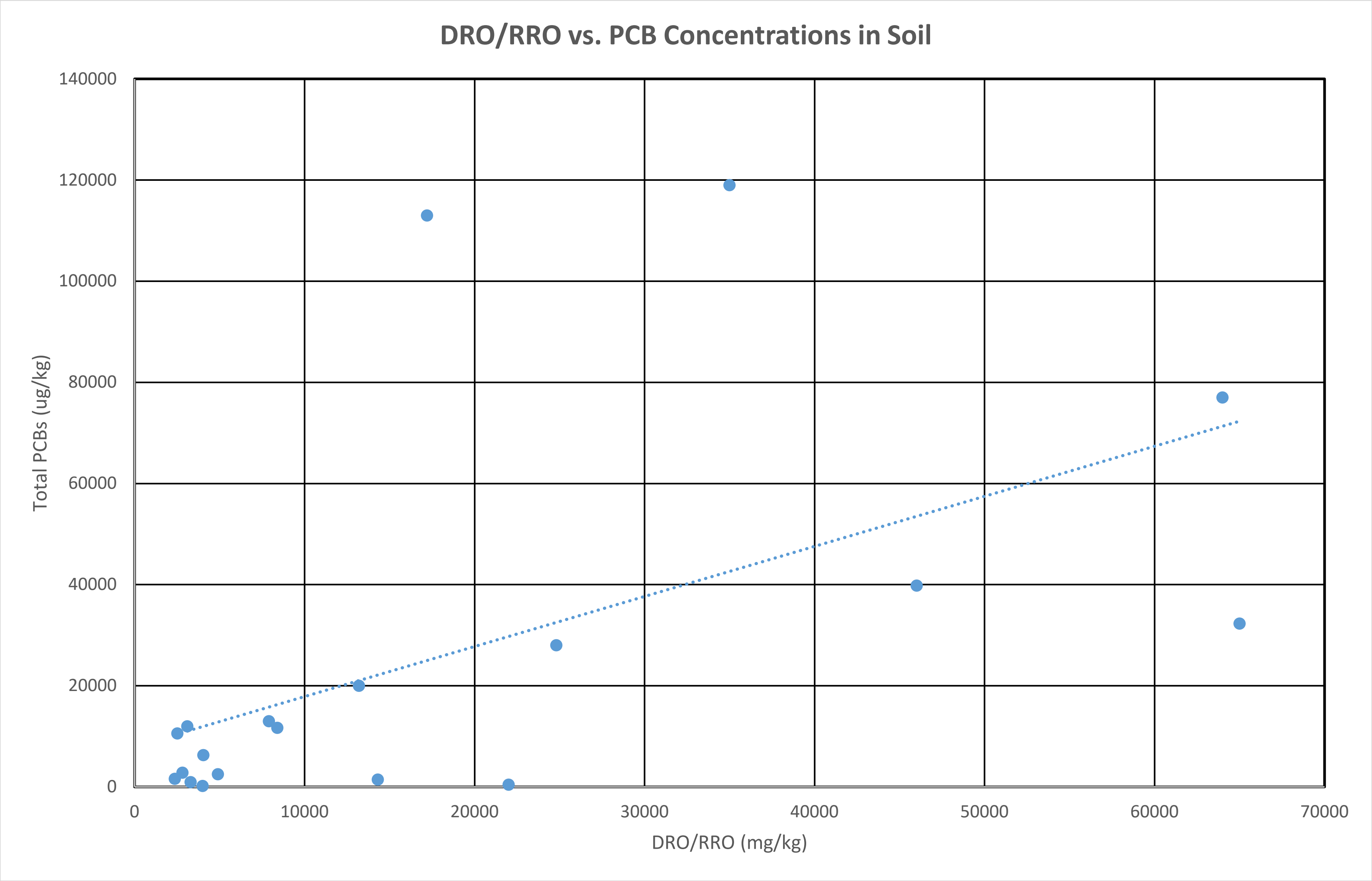
ICS/NW Cooperage Site

Estuarine Water Contents
Lower Zone Groundwater

SUM-008-00 (ICS) *Mar. 2018*

Dalton, Olmsted & Fuglevand, Inc.

FIGURE 4-26b



(TPH vs PCB in Soil.xlsx-Sheet1)

FIGURE 6-4 - DRO/RRO vs. PCBs in Soil

D.M.D., Inc.
Environmental & Toxicological Services
13706 SW Caster Road, Vashon, WA 98070-7428 (206) 463-6223 email: dmdinc111@gmail.com

MEMORANDUM

TO: Matt Dalton (DOF)

FROM: Raleigh Farlow

DATE: May 16, 2019 (revised February 25, 2021)

SUBJECT: Geochemical Assessment of PCBs at the ICS/[former] Northwest Cooperage Site, Seattle, WA - ADDENDUM

This evaluation is an addendum to a previous assessment dated January 15, 2018 (revised 02/24/21) (*Geochemical Assessment of PCBs at the ICS/[former] Northwest Cooperage Site, Seattle, WA*, from R. Farlow (DMD) to M. Dalton (DOF)[1]). This memorandum was revised based on comments from the Department of Ecology (Ecology) received on February 1, 2021 and additional research and analysis to respond to the comments. This addendum includes a third memorandum dated March 29, 2020 as an attachment that was originally submitted to Ecology as an attachment to a Keta Waters cap modeling report dated April 10, 2020. This addendum addresses additional or supplemental data that were generated from the collection of groundwater samples per the *Work Plan to Complete Additional Groundwater Sampling Along Embayment Shoreline ICS RI/FS*, dated November 12, 2018, from M. Dalton (DOF) to V. Sutton (Dept. of Ecology). The objectives of the work/sampling and analysis plan (WP/SAP) were to further characterize the significance of potential impact of COPCs on surface waters and to provide data for the evaluation of groundwater remedies in the Feasibility Study (FS). Data collected and generated [by the project laboratories] under the requirements of the WP/SAP were evaluated and reported in *Data Evaluation/Assessment for 14 Groundwaters Collected from Monitoring Wells during a Supplemental Characterization Event Performed during February 2019 from the ICS / [former] NW Cooperage and Douglas Management Property Sites, Seattle, WA*, dated May 8, 2019, from R. Farlow (DMD) to M. Dalton (DOF); data validation report (DVR) attached. All sample results and associated data quality were reported to be in compliance with method and WP/SAP requirements. Data completeness was determined to be 100%. Since the February 2019 work was completed, Ecology published draft final guidance for the sampling and analysis of PCBs (both as Aroclors and congeners)(Ecology Technical Memo, January 11, 2021). This work was completed in general accordance with this new guidance with the exception that groundwater samples were not filtered.

Per the 2018 WP/SAP, groundwater sampling and analyses were performed on samples collected using ultra-trace technique to minimize inadvertent contamination of site samples by field equipment/handling and for the reliable reporting of trace levels of PCBs and specifically congeners down to concentrations of parts-per-quadrillion (pg/L or 10^{-3} ng/L or 10^{-6} µg/L [0.000001 µg/L]).

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[1] Included [originally] as Appendix N to the DOF draft RI report, September 2018.

Characteristics of PCBs

As a refresher to the reader, PCBs are mixtures of chlorinated and polychlorinated biphenyls with the chemical formula $C_{12}H_{10-x}Cl_x$, where $1 \leq x \leq 10$. Table 1, attached, presents some of the chemical and physical characteristics of PCB mixtures. The total number of individual chlorinated biphenyl compounds (or congeners) possible with x = 1-10 is 209. Homolog groups are defined as a group of compounds (or congeners) with the same number of chlorines or the same "x", in the above chemical formula. For this review, a homolog group of 3, for example, is equivalent to all chlorinated biphenyl congeners with formula $C_{12}H_7Cl_3$ where x = 3; and homolog group 6 is, similarly, equivalent to all chlorinated biphenyls with formula $C_{12}H_4Cl_6$ where x = 6. Commercial PCB mixtures in greatest use in the U.S. were manufactured by Monsanto Chemical Company under the name Aroclors. The Aroclors consist of a series of mixtures identified by their average chlorine content. For the 1200-series of Aroclors, the 3rd and 4th digits are the average percentage of chlorine present in the mixture; thus, Aroclor 1242 consists of an average of 3 chlorine atoms per molecule and contains 42% chlorine by weight, Aroclor 1254 consists of an average of 5 chlorine atoms per molecule and contains 54% chlorine by weight, and Aroclor 1260 consists of an average of 6 chlorine atoms per molecule and contains 60% chlorine by weight. As the number of chlorines increases on the biphenyl molecule (as "x" increases), the hydrophobicity and K_{ow} (octanol-water partition coefficient, and similarly K_{oc}) increases. In other words, as "x" increases, the chemical affinity for solids or partitioning capacity to adsorb to carbon-containing particulate matter (or soils) increases.

This assessment includes the evaluation of site PCB data collected from 2015 to 2019. All PCB data, prior to the recent (2019) sample collection and reporting of PCB congeners and homologs, are reported as Aroclors. Aroclors have been characterized as to their chlorinated biphenyl homolog compositions (Frame et al., 1996), which allows the conversion of Aroclor data to homolog group concentrations. Table 1 presents PCB homolog compositions for Aroclors reported at the site. Chromatograms of site Aroclor data have been inspected and found to exhibit minimal, if any, modification in peak patterns relative to authentic Aroclor standards. This allows the merging and comparison of the two different types of data sets – Aroclors *vs.* congener/homolog (Method 8082 reported data *vs.* Method 1668 reported data). PCB homolog data is the basis for this geochemical assessment because of the abundance of site data, and the chemical and physical characteristics are near equivalent for all chemicals within a homologous group.

Study Area

Groundwater samples were collected from selected wells on the Douglas Management Property and the ICS/NW Cooperage sites (see attached Figure Aa – Selected Well Locations). Data from the February 2019 monitoring event (see Table of results in attached DVR) supplemented previously collected data (since 2015; see DOF Public Review Draft RI report, February 2020) and allowed a refinement of the assessment performed in the 2018 Site Geochemical Assessment report.

2019 Monitoring Event Lower Reporting Limits for PCB Congeners

The lower reporting limits achieved for the PCB congener analyses were significantly less than the WP/SAP goal of 0.0001 µg/L (100 pg/L or parts-per-quadrillion [ppq]). Lower reporting limits for individual PCB congeners were 20 ppq for the LOQ (PQL) and 0.5 ppq for the LOD.

These LODs were found to be necessary for a geochemical analysis to distinguish analytical laboratory method/procedural blank concentrations from 1) upgradient/background[2] well (DOF-MW3 and DOF-MW5) samples, 2) from ICS/NW Cooperage downgradient well (MW-Fu, MW-Gu and SA-MW3) samples, and 3) Douglas Property samples. With a few exceptions, almost all of the PCB congener concentrations for monochloro- dichloro-, trichloro- and tetrachlorobiphenyls (homolog groups 1 to 4) in upgradient/background and downgradient well samples were determined to be significantly affected/biased by analytical method/procedural blank levels and were thus qualified with the "J_B" descriptor code[3]. Figure B, attached, graphically presents the concentrations of homolog groups for the analytical method/procedural blank and upgradient/background well samples. The homolog profile in Figure B demonstrates the predominant homologs concentrations peak/maximize with the dichlorobiphenyls (homolog group 2) and slope downward through decachlorobiphenyl (homolog group 10). The variability for PCB congener concentrations between the two upgradient/background wells (DOF-MW3 and DOF-MW5) is remarkably low (see results Table in DVR). A comparison of analytical method/procedural blank to site groundwater samples, with the exception of the upgradient/background well samples, have characteristically different homolog and congener profiles with predominant PCBs peaking at pentachloro- through heptachlorobiphenyls. Figure C presents the PCB homolog profiles for five groups of samples analyzed in the 2019 monitoring event. The profiles with the greatest similarities are the ICS/NW Cooperage (DOF-MW6 and MW-Eu exhibiting total PCBs > 10 ng/L) and the Douglas Property well samples with a correlation coefficient of R = 0.985. The next similar pair is the analytical method/procedural blank and the upgradient/background wells with R = 0.886. The ICS/NW Cooperage downgradient well samples exhibit a relatively unique profile compared to the other groups showing relative enhancements in the proportion of the higher homologs, such as hexa-, hepta- and octachlorobiphenyls. Figure B and the 2019 DVR both indicate that the PCB congener profiles and concentrations for analytical method/procedural blank and upgradient/background well samples are similar and barely distinguishable – we are in the proverbial "grass" or noise at these levels of PCBs. There may be some "real" concentration differences between the analytical method/procedural blank and the upgradient wells for penta-, hexa-, hepta- and octachlorobiphenyls, but the concentration differences are small, less than 15 parts-per-quadrillion (ppq; pg/L), and the groundwater data is significantly affected by the laboratory method/procedural blank (laboratory background). ICS/NW Cooperage site and Douglas Property shoreline groundwaters exhibit similar PCB homolog profiles, which resemble

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[2] Background refers to both field and laboratory background for assessment of downgradient PCB concentrations in groundwater. In this context, for the assessment of low-level (sub-ppt or ppq) PCBs in groundwater at this site, wells DOF-MW3 and DOF-MW5 are considered background control wells. Given the screen depths (below the silt layer) and upgradient locations, these two wells are considered background for evaluating the field handling, collection, and analyses for low-level PCBs throughout the site. "Laboratory background" contributes 73% of the total PCBs to the measured values for samples from these wells. It is appropriate to call out these wells as upgradient/background, especially since it is determined that the ability to distinguish upgradient PCB levels from background levels remains uncertain. It should also be noted that the PCB concentrations detected in these two upgradient/background wells are near the PQL for total PCBs based on review of the analytical method blanks for available [congener] samples analyzed in April 2017 and March/April 2019. For these data sets, a total PCBs PQL of approximately 220 pg/L (0.00022 ug/L) is determined. This PQL does not include consideration of inadvertent field background introduced during sample collection.

[3] No "censoring" of sample results were performed as described in Ecology Technical Memo 2021 for this geochemical analysis.

relatively unmodified Aroclor homolog profiles. This likely indicates well screens are within or in close proximity to source materials. ICS/NW Cooperage downgradient well sample homolog profiles are characteristically and significantly different from the other groups and exhibit higher homolog enhancements (for Cl_6, Cl_7 and Cl_8 homolog groups) relative to other site homolog profiles.

Groundwater Contaminant Migration

The site remedial investigation has established site groundwater flow directions and contaminant migration pathways. Predominant groundwater flow on both the Douglas Property and ICS/NW Cooperage sites is towards the river (Lower Duwamish Waterway) and is tidally modulated showing some cyclic flow reversals. Some shallow discharge of contaminated groundwater on the ICS/NW Cooperage site flows northward via seeps to the embayment. ICS/NW Cooperage contaminant source areas, containing contaminated soils and sediments, are identified in a) the former lagoon along the eastern property line, b) upland soils along the southern shoreline of the embayment, and c) embayment sediments. These source areas are associated with surface releases of contaminants during historic facility operations and current discharges of contaminated oil to the embayment in the vicinity of SA-MW1. Principal source(s) of PCB contamination to embayment sediments contain significant mobile oil contamination (high levels of TPH or non-aqueous phase liquid (NAPL)) identified in the SA-MW1 upland source area. Nearshore embayment sediment contamination is contiguous with upland TPH/oil and PCBs-contaminated soils. The PCB Aroclor profiles found in upland soils along the embayment are similar to those observed in embayment sediments suggesting the events responsible for contamination in both media to be similar, if not concurrent. A change in Aroclor profiles associated with partitioning mechanisms during [nonfacilitated] groundwater transport is not observed. While some transport of contaminated upland groundwater is likely contributing (and was considered) to embayment sediment contamination, the overwhelming mechanism responsible for the greatest nearshore contamination to the embayment appears to be associated with the transfer and accumulation of PCBs-contaminated oil and NAPL via surface events, such as historic facility releases, seeps and/or soil sloughing/erosion. Figures 5-5a and 5-6a in the 01/2018 (revised 02/24/21) assessment shows the greatest PCBs sediment concentrations in the embayment to originate nearshore at the surface with an apparent plume into subsurface sediments associated with a TPH mineral oil profile. Deeper contamination on the Douglas Property site is primarily associated with the covering with fill material of [previously] contaminated estuarine sediments.

Upgradient/background upper zone groundwater that is noncontaminated from site source areas is in the area of wells DOF-MW3 and DOF-MW5, which were sampled in the 2019 monitoring event to establish contaminant site background reference levels. These background levels of PCBs include contributions from analytical method/procedural blanks, field sample collection and handling, and upgradient environmental background[4]. This background level is important to establish as PCBs are ubiquitous to the environment (IARC 2016). Downgradient (from contaminant source areas) wells sampled in 2019 were MW-Fu, MW-Gu, SA-MW3 (screened in the upper portion of the aquifer), and MW-IL (screened in a deeper portion of the aquifer).

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[4] It is noted that application of the Ecology January 2021 PCB guidance would result in total PCBs reported at less than the PQL in upgradient/background samples by using a censor factor of 5 and individual congener PQLs of 20 pg/L.

Major ion (anions and hardness) analyses indicate minimal estuarine/saline water in the shallower three wells and approximately 25% estuarine influence in deeper well MW-IL. All tidally influenced wells were sampled during approximate low ebb (outgoing) tide.

An analysis of groundwater PCBs concentration as a function of distance from the former lagoon was performed to evaluate and estimate attenuation processes or mechanisms affecting groundwater transport of PCBs from contaminated media in source areas to downgradient wells that could ultimately impact surface water quality. Contaminant transfer from source material along migration pathways is an important consideration for potential impact to downgradient wells and subsequent surface water discharges. The pathway evaluated here is from relatively high contaminant source areas to groundwaters that are likely to impact estuarine surface waters. This evaluation includes the following representative wells – source area well DOF-MW1 (sample results from 2015, 2016 and 2017), source area perimeter well HC-B2R (sample results from 2016)[5], and downgradient wells MW-Fu, MW-Gu and SA-MW3 (sample results from 2019). These wells are screened in the upper portion of the aquifer at overlapping depths bgs and downgradient of significant source areas. A plot of total PCB concentrations *vs.* distance from the lagoon source area is presented in Figure D and reveals a decreasing exponential function of concentration with distance. This relationship is described as follows:

$$\text{total PCBs (ng/L)} = e^{(-0.0652 \times (\text{distance [ft]}) + 6.7906)}$$

with a correlation coefficient of $R = 0.998$. As expected, the principal mechanism responsible for this relationship is an adsorption partition process of hydrophobic constituents in an aqueous system, and not a simple advection/dispersion mechanism. An advection/dispersion mechanism in an aqueous system yields a linear (dilution) function with distance as generally seen with highly water soluble constituents. PCBs are highly hydrophobic chemicals with K_{ow}s in the range of 40,740 ($\log K_{ow} = 4.61$) for monochlorobiphenyls to 151,360,000 ($\log K_{ow} = 8.18$) for decachlorobiphenyl. For comparison purposes, the K_{ow} for benzene, which is relatively soluble and mobile in groundwater systems, is 134 ($\log K_{ow} = 2.13$) (Howard 1990). For the PCB mixtures identified in site groundwaters collected and analyzed in the period 2015-2019, the chlorinated homolog centroids[6] (by sample) range from 3.4 to 6.5 (which means there is an average of 3.4 chlorines on the biphenyl molecule for a single sample and an average of 6.5 chlorines on the biphenyl molecule for another sample), with correspondingly mean K_{ow}s of 525,000 ($\log K_{ow} = 5.72$) and 9,770,000 ($\log K_{ow} = 6.99$), respectively. Thus, the more chlorine substitution on the biphenyl molecule yields a greater K_{ow} or "hydrophobicity" for greater association/adsorption to organic-containing particulate matter and soils. The mean number of chlorines on the biphenyl molecule for all groundwater samples collected during 2015 through 2019 is 5. PCB congener and homolog K_{ow}s are referenced in IARC 2016 and summarized in Table 1, attached (also presented with K_{oc}s in DMD 2020, attached).

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[5] PCB results for HC-B2R are reported as nondetects for most Aroclors, an elevated nondetect of 50 ng/L for Aroclor 1254 due to some chromatographic interferences, and a reliable value for Aroclor 1260 at 28 ng/L. An inspection of the laboratory raw data reveals the presence of Aroclor 1254. In order to minimize bias in reporting total PCBs, one-half of the elevated nondetect for Aroclor 1254 (25 ng/L) was summed with the Aroclor 1260 result (28 ng/L) to yield a total PCBs concentration estimated at 53 ng/L for this geochemical evaluation.

[6] Centroid is a weighted mean or center of mass.

PCBs Association with Solids

PCBs exhibit a strong association with groundwater suspended solids (total suspended solids; TSS) because of their hydrophobicity (elevated K_{ow}s and consequent K_{oc}s). The 2018 WP/SAP describes good correlations between groundwater turbidities and total PCB concentrations for both the Douglas Property shoreline and ICS/NW Cooperage wells (R = 0.92-0.93). For the 2019 monitoring data, a linear regression between total PCBs and TSS also reveals a relatively strong relationship (R = 0.89) with approximately 0.85 ng PCBs per milligram suspended solids. Outlier well samples are identified as MW-Eu and DOF-MW6 (in a source area), which show 11 ng and 27 ng PCBs/mg solids, respectively, and the downgradient wells (MW-Fu, MW-Gu and SA-MW3) exhibiting an especially low level of PCBs at a mean of 0.007 ng PCBs/mg solids. A groundwater sample from well DMC-MW13 exhibits a relatively high level of PCBs relative to the mean relationship due to a low TSS value (3 mg/L) at 4.3 ng PCBs per mg of solids. The higher levels of PCB concentrations per mg of TSS in samples near source materials is likely associated with co-solvency in the presence of multiple contaminants (and oils) as well as higher levels of organic carbon on solids (TSS). Co-solvency is likely associated with the "facilitation or facilitated transport" identified by EPA Region 4 (EPA 2013) and Brownawell (1986) rather than colloid transport in the filterable fraction. Elevated levels of PCBs in the filterable fraction are associated with contaminated materials exhibiting sediment/soils TOC of 4-6%, PCBs of 20-30 mg/kg, and interstitial/pore water concentrations of PCBs at 3-20 µg/L and DOC of 10-90 mg/L (Brownawell 1986). These materials and conditions also show little to no differential homolog partitioning between the filterable fraction and the solids. This is unlike the situation, such as in water column studies, where PCBs show minimal association with "colloid" (Rawling 1998) and where differential partitioning by homolog groups reveals enhanced concentrations of higher homologs on solids and enhancements of lower homologs in the soluble/filterable phase (M-Y Chen et al., 2011)[7]. In other words, sediment and interstitial water PCB homolog profiles are similar if not the same in high-concentration sediments/soils where supposed "colloid effects" are identified as significant. The water column studies show hydrophobic organic contaminants, including PCBs, partitioning between solids and water according to predictions employing two-phase thermal equilibrium partitioning concepts (AM Gunn et al., 1992; M-Y Chen et al., 2011). Groundwater samples from upgradient/background wells DOF-MW3 and DOF-MW5 exhibit no association of PCBs with solids where PCB concentrations are barely distinguishable from those reported in the analytical method/procedural blank. This may be due to the fact that the water-bearing zone for upgradient/background wells are in what appears to be a glacially-derived sand formation and likely contains low TOC on associated solids/soils that would impart low affinity for any upgradient PCBs contamination.

Despite attempts to minimize the collection of particulate matter during sampling of groundwater, suspended solids are a typical and practically unavoidable component of groundwater samples, and the presence of PCB-contaminated solids bias reported results, even at

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[7] Water column studies performed by Rawling (1998) and Chen, et al. (2011) were conducted in samples with DOC $\leq$ 12 mg/L and $\leq$ 7 mg/L, respectively. Site downgradient groundwater sample DOC levels overlapped that of the Rawling and Chen studies.

what are considered relatively low turbidities and TSS levels[8]. This bias is variable for each sample dependent on the amount of solids collected and analyzed in the groundwater sample, and, if not accounted for, could be incorrectly assumed to be representative of the soluble/mobile PCB component in the groundwater system. An analysis of the potential bias imparted to PCB levels in groundwater samples by TSS is presented in Table 2 using a two-phase equilibrium partitioning model. The partition factors (K_{oc}s and Kd's) used in this analysis are presented and summarized in DMD 2020 (the f_{oc} or carbon content on upgradient well TSS is assumed to be negligible or near zero). TSS is analyzed and reported as solids with effective diameters greater than 1.0 µm. In the downgradient wells, good correlation is found between total suspended solids (TSS) and PCBs on suspended solids [µg/kg] (R=0.84)(R=0.30 for TSS *vs.* total PCBs). The percentage of total sample PCBs associated with TSS ranges from 27% to 86%. The sample with the lowest level of TSS, SA-MW3, also exhibits the greatest enrichments in lower homologs, which supports the use of a two-phase equilibrium partitioning model (solids and water) for the downgradient groundwaters. Similarly, samples with greater TSS levels exhibit greater enhancements of the higher homologs, indicating that two-phase equilibrium partitioning is occurring, as predicted. Facilitated or colloidal transport is not apparent in downgradient wells. The greater the level of TSS (which contains adsorbed PCBs), the greater the potential error in estimating [mobile] groundwater PCB concentrations if not considering solids phase partitioning and adsorption. Table 2 reveals a lack of correspondence between turbidity and TSS in downgradient well samples. Samples from MW-Fu and MW-IL with turbidities < 10 NTUs show 82% and 86% of total PCBs, respectively, to likely be bound to suspended solids. *Note that studies have demonstrated that filtration of particulate matter from environmental water samples can result in the adsorption of any soluble hydrophobic constituents onto the filter media, which yields negative bias reporting of contaminants in the soluble fraction. U.S.EPA policy and guidance discourages the filtration of solids from aqueous environmental samples for the analysis of hydrophobic organic constituents due to negative bias effects. PCBs are typically the most hydrophobic contaminants addressed on cleanup sites.*

Fate of PCBs During Groundwater Migration

The 2018 Geochemical Assessment report (2021 revision) identifies significant attenuation of groundwater PCBs by three possible mechanisms: a) low or restricted groundwater flow from source areas, b) groundwater advection/dispersion during migration, and c) soil adsorption and sequestration of contaminants from the dissolved/mobile phase between source and downgradient areas. Figure D quantifies the amount of attenuation as a function of migration distance from an ICS/NW Cooperage source area (former lagoon). A comparison plot of PCB homolog profiles for ICS/NW Cooperage source and downgradient areas in Figure E shows a similar but shifted centroid for the homolog groups – the source area has a centroid at 5.8 chlorines, whereas the downgradient group is at a centroid of 6.03 chlorines (the mean of three downgradient samples). The homolog profile for MW-Fu (see Table 2) reveals an even greater enhancement of higher homologs at a centroid of 6.8. The enrichment/enhancement of higher homolog groups (which are less mobile in aqueous systems) on an equilibrated system (assumed

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[8] The Ecology (2021) guidance uses a turbidity of 10 NTUs as a filtering threshold for groundwater samples (i.e., filter samples with turbidities greater than 10 NTUs to assess the presence of colloids). This may erroneously suggest that suspended solids are not an issue in assessing sample PCB contributions and bias if the turbidity is less than 10 NTUs. Given the very low PQL of the PCB congener analytical method and the extremely low PCB thresholds to protect sediment and surface water, this assumption is not valid.

to be in equilibrium based on distance from the source(s) and the relatively low concentration of contaminants) supports the significance of the two-phase [solids-water] partition/adsorption component of the attenuation process. This is also demonstrated between MW-Eu (a source area well) and MW-IL (a downgradient well) where the total PCBs concentration decreases by 1100x and the homolog distribution centroid shifts from Cl-5 to Cl-6. Eighty-five percent of the PCBs in the sample from MW-Eu is determined to be bound to suspended solids.

The association of a modified PCB homologous series profile with particulate matter in the downgradient wells allows the estimation of the amount of partitioning occurring on site soils, and thus an evaluation of a site-specific partition coefficient (Kd) by homolog group. This partition coefficient is defined as:

$$\text{Kd} = (\text{contaminant concentration in soil}) / (\text{contaminant concentration in water})$$

The Kd is dependent on and calculated from the contaminant K_{oc} and soil or particulate matter organic content. The following relations are employed to estimate a site PCB homolog Kd, soil PCB homolog concentrations, and soluble groundwater PCBs concentrations:

$$\log(K_{oc}) = 0.00028 + 0.983 \times \log(K_{ow}) \quad \text{(from Di Toro 1985)}$$

$$\text{Kd} = K_{oc} \times (\text{organic carbon content of solids/soils})$$

$$\text{total sample PCBs} = \text{particulate-bound (soil) PCBs} + \text{soluble PCBs}$$

Partitioning/Adsorption of PCBs in Downgradient Groundwater

(Wells MW-Fu, MW-Gu and SA-MW3)

	Pentachloro- (Cl_5) homolog group	Heptachloro- (Cl_7) homolog group
K_{ow}	2,510,000	14,800,000
K_{oc}	1,950,000	11,220,000
Sample PCB concentration (ng/L)	0.045	0.074
TSS concentration (mg/L)	44	44
Solids/soils mean organic carbon content (%)	2	2
Mass of PCBs on suspended solids (ng)	0.029	0.067
PCB conc. on solids/soils (ng/kg)	663	1526
PCB conc. in water (soluble) (ng/L)	0.017	0.0068
PCB conc. in upgradient/background (ng/L)	0.015 – 0.017	0.0055 – 0.0074
% PCB on TSS	65	91
Kd (L/kg)	38,996	224,400

The Kd is established by contaminant K_{oc} and soil TOC levels. The PCB homolog centroid for ICS/NW Cooperage downgradient wells is 6.03 or centered at hexachlorobiphenyl, which yields a **mean site Kd for PCBs of 134,500**. Application of a homolog-specific Kd allows the determination of the amount of solids-bound PCBs *vs.* soluble PCBs in groundwater samples, as demonstrated in the above Table and Table 2. Downgradient well soluble pentachlorobiphenyls and heptachlorobiphenyls concentrations are near equivalent to upgradient/background groundwater concentrations. This is primarily a consequence of the partition/adsorption phenomenon of PCBs in a TOC-containing soils/aqueous system. The effective site Kd is controlled by several variables, including soil TOC levels, aqueous DOC levels, dissolved solids (TDS), and temperature. ICS/NW Cooperage downgradient upper aquifer groundwater conditions are: TOC = DOC = 14.2 mg/L (mean) and < 5% estuarine water contribution (relatively low TDS). Higher contributions of estuarine water[9] (increased dissolved solids [TDS]) and higher levels of soil TOC will increase the effective Kd. Monitoring results for 2017 revealed in all cases that groundwater TOC and DOC were equivalent, and therefore assumed to be equivalent for this event (TOC data only were collected in 2019). Also, groundwater TOC and TSS showed no relationship during this monitoring event – these two parameters are independent; with a correlation coefficient of R = -0.27. This is consistent with the 2017 observations that most organic carbon in site groundwater samples is in the soluble phase. It is noted that some Agency guidances for partition modeling identify PCB and Aroclor K_{ow}s and K_{oc}s that are near 1/10th the values applied in this assessment. The values used here are taken from a recent treatise on PCB congeners and homologs (WHO-IARC Monograph 107, 2016) and are presented in DMD 2020. K_{oc}s were calculated from K_{ow}s by the method of Di Toro (1985). A comparison of actual PCB K_{oc}s developed from estuarine water column studies by Chen, et al. (2011) *vs.* predicted K_{oc}s revealed that environmental modifiers (i.e., TDS, DOC, etc.) could increase K_{oc}s by as much as 10-50x. Also, Agency guidance recommends using a default soil TOC (f_{oc}) value of 0.1% in partition calculations where site data are not available, whereas a site mean soil TOC (mean for alluvial sediments not impacted by PCBs and TPH beneath the embayment) of 2% was applied here. It should be noted that site soils are comprised of alluvial fill material and do not appear to be glacially-derived sands with low/minimal organic carbon content.

This evaluation indicates that soluble groundwater PCB concentrations in selected ICS/NW Cooperage downgradient wells are [near] equivalent to soluble PCB concentrations in upgradient/background wells. Reported PCB levels in ICS/NW Cooperage downgradient well samples are primarily due to collection of suspended solids/soils containing adsorbed PCBs. TOC-containing soils scavenge groundwater PCBs by a partition/adsorption mechanism, especially for the higher PCB homologs. The 2019 groundwater monitoring results indicate that site [fill] soils can provide sufficient attenuation of lagoon source area groundwater PCBs by partition/adsorption to reduce soluble concentrations to background levels when flow paths are approximately 120 feet.

Summary

The 2019 groundwater monitoring event was successful in addressing the objectives and resolving issues identified in the 2018 WP/SAP; most of which are presented and evaluated in this assessment. Two [complementary] analytical methods were employed for site and surrounding areas characterization of PCBs – U.S. EPA Method 8082 (reporting of Aroclors) and EPA Method 1668 (reporting of congeners and homologs). Method 1668 LOD shows about

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[9] Brownawell (1986) identifies a potential salting-out effect for PCBs of 23-32% when going from fresh water to marine water with a salinity of ~30 ppth. Rawling (1998) identifies a salting-out effect of 14% with an increase in salinity to 33.7 ppth for 2,2',5,5'-tetrachlorobiphenyl.

a factor of 1000x more sensitivity (per congener) than Method 8082 LOD (per Aroclor mixture). While Method 1668 possesses sufficient sensitivity for characterization of low-level samples in upgradient/background and source downgradient areas, the practical quantitation limit is elevated above method capabilities due to analytical method/procedural blank levels, which are congener and homolog group specific. The determination of Aroclors by Method 8082 is entirely sufficient for most of the site characterization and in contaminant source areas where groundwater Aroclor concentrations are greater than 0.01-0.02 µg/L (10-20 ng/L). Determination of PCB levels by congener analyses is most useful outside of source areas, such as upgradient/background and in the vicinity of points-of-compliance, and for refined partition/adsorption studies and modeling. PCB levels in groundwater outside of source areas can be effectively characterized with a two-phase partitioning model where facilitated solubilization and transport, including the colloid effect, are negligible and unimportant. This is supported by EPA guidance (2013) where facilitated transport is determined to be unlikely in groundwater with total PCBs < 0.014 µg/L (PCB AWQC) and where homolog enhancements due to partitioning are observed. Both analytical methods were complementary and in conjunction with other conventional parameters, major ions, and field-generated data allowed for the development and evaluation of site-specific factors for use in remedial design.

PCBs reported in groundwater samples were primarily associated with the suspended solids (TSS) entrained in the samples. Groundwater monitoring for low-level contaminants, such as PCBs, have high potential for reporting bias due to collection of low levels of suspended solids. Several mg/L of TSS in groundwater can significantly bias [low-level] PCB congener results. A 10 NTU threshold (Ecology 2021 and EPA 2013) may not be sufficient to allow use of groundwater PCB congener data without consideration of positive bias introduced by several mg/L of TSS. The principal homolog groups reported in both ICS/NW Cooperage and Douglas Property groundwater/soil systems are tetrachlorobiphenyls through heptachlorobiphenyls with K_{oc}s ranging from 273,000 to 38,000,000. These contaminant groups partition and adsorb strongly to soils containing organic carbon. Site-specific data indicate significant attenuation of groundwater PCBs occurs before surface water discharge in relatively short distances. This also indicates that PCB contamination in embayment sediments is primarily due to historic direct surface discharges and leakage of contaminated oils (facilitated transport in the SA-MW1 area) to the embayment. PCBs are not migrating in groundwater to sediment or surface water at any measureable extent.

Remedial Management Strategy

This geochemical assessment of the fates and migration of groundwater PCBs reinforces and validates the recommended strategy presented in the 2018 Geochemical Assessment (2021 revision). Site data continues to support the concept of augmenting sediment caps or barriers with organic carbon to sequester and retain any groundwater PCBs migrating towards the Lower Duwamish Waterway (LDW) or embayment prior to surface discharge. Consideration may be given that during [low TDS] groundwater and estuarine water mixing, salinity will increase leading to the salting-out effect of any groundwater contaminants and DOC. This is likely to result in an increase in effective K_{oc}s and Kd’s, perhaps by as much as 20-30%. Estuarine water column PCB K_{oc}s have been reported to be 10-50x greater than predicted K_{oc}s.

References

Brownawell, BJ, 1986. The Role of Colloidal Organic Matter in the Marine Geochemistry of PCBs; PhD research thesis, Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution; April 1986.

Chen, M-Y, et al., 2011. The factors controlling the partitioning of polybrominated diphenyl ethers and polychlorinated biphenyls in the water-column of the Pearl River Estuary in South China. M-Y Chen, M Yu, X-J Luo, S-J Chen and B-X Mai. Marine Pollution Bulletin **62** 29-35 (2011), Elsevier.

Di Toro, D.M., 1985. A particle interaction model of reversible organic chemical sorption. *Chemosphere* 14(10): 1503-1538.

DMD, Inc., 2018 (2021 revision). Geochemical Assessment of PCBs at the ICS/[former] Northwest Cooperage Site, Seattle, WA; January 15, 2018 (revised February 24, 2021).

DMD, Inc., 2019. [DVR] Data Evaluation/Assessment for 14 Groundwaters Collected from Monitoring Wells during a Supplemental Characterization Event Performed during February 2019 from the ICS / [former] NW Cooperage and Douglas Management Property Sites, Seattle, WA; May 8, 2019.

DMD, Inc., 2020. Derivation of PCB/Aroclor Equilibrium Partition Coefficients for Use at the ICS/[former] Northwest Cooperage Site, Seattle, WA; March 29, 2020.

DOF (Dalton, Olmsted & Fuglevand, Inc.), 2012. Remedial Investigation/Feasibility Study (RI/FS) Work Plan, Industrial Container Services/Former NW Cooperage Site, Seattle, Washington; February 2012.

DOF, 2020. Remedial Investigation Report, Industrial Container Services, WA, LLC [former Northwest Cooperage Site], Seattle, Washington, Vols 1 & 2; Public Review Draft: February 2020.

DOF, 2018. Work Plan to Complete Additional Groundwater Sampling Along Embayment Shoreline ICS RI/FS; November 12, 2018.

Ecology, 2021. Technical Memo: Polychlorinated Biphenyl (PCB) Groundwater Sampling Guidance for the Lower Duwamish River; B Era-Miller, January 11, 2021.

EPA Region 4, 2013. U.S. EPA Region 4 Technical Services Section Issue Paper for Polychlorinated Biphenyl Characterization at Region 4 Superfund and RCRA Sites; HK Wischkaemper, Beliveau, AF, and Henderson, RW, May 15, 2013.

Frame, G.M., Cochran, J.W., and Boewadt, S.S., 1996. Complete PCB congener distributions for 17 Aroclor mixtures determined by 3 HRGC systems optimized for comprehensive, quantitative, congener-specific analyses. *J. High Res. Chromatogr.* <u>19</u>, 657-668.

Gunn, AM, et al., 1992. Investigation of Partitioning of Contaminants between Water and Sediment. AM Gunn, HR Rogers and SDW Comber; National Rivers Authority R&D 016/6/N; July 1992.

Howard, P. (ed.), 1990. Handbook of Environmental Fates and Exposure Data for Organic Chemicals, VII Solvents; Lewis Publishers.

IARC 2016. World Health Organization – International Agency for Research on Cancer Monograph 107, Polychlorinated Biphenyls and Polybrominated Biphenyls. *(This treatise is considered a more up to date resource than many of the older Agency guidances and documents regarding environmental exposures, biological effects, and chemical/physical characteristics of PCBs. Consequently, this geochemical evaluation utilized this reference as a current resource where appropriate.)*

MTCA Cleanup Regulation, 10/2007. 173-340-900.

Rawling, MC, 1998. Particle-Water Interactions of Hydrophobic Organic Micropollutants in Marine Systems; research thesis at University of Plymouth, 10026.1/1926.

Table 1.

Characteristics of PCB Homolog Groups and Weight Percent in Aroclors

PCB Homolog Group	Formula	# of Congeners	% Cl by wt.	log(Kow)	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260
1	$C_{12}H_9Cl$	3	18.79	4.46 - 4.69	0.75	0.07		0.02
2	$C_{12}H_8Cl_2$	12	31.77	4.65 - 5.30	15.04	1.55	0.24	0.08
3	$C_{12}H_7Cl_3$	24	41.30	5.02 - 5.89	44.91	21.27	1.26	0.21
4	$C_{12}H_6Cl_4$	42	48.65	5.53 - 6.48	20.16	32.77	10.25	0.35
5	$C_{12}H_5Cl_5$	46	54.30	5.71 - 6.95	18.85	42.92	59.12	8.74
6	$C_{12}H_4Cl_6$	42	58.93	6.22 - 7.42	0.31	1.64	26.76	43.35
7	$C_{12}H_3Cl_7$	24	62.77	6.69 - 7.71		0.02	2.66	38.54
8	$C_{12}H_2Cl_8$	12	65.98	7.20 - 8.00			0.04	8.27
9	$C_{12}HCl_9$	3	68.73	7.71 - 8.09			0.04	0.70
10	$C_{12}Cl_{10}$	1	71.10	8.18				

from IARC 2016

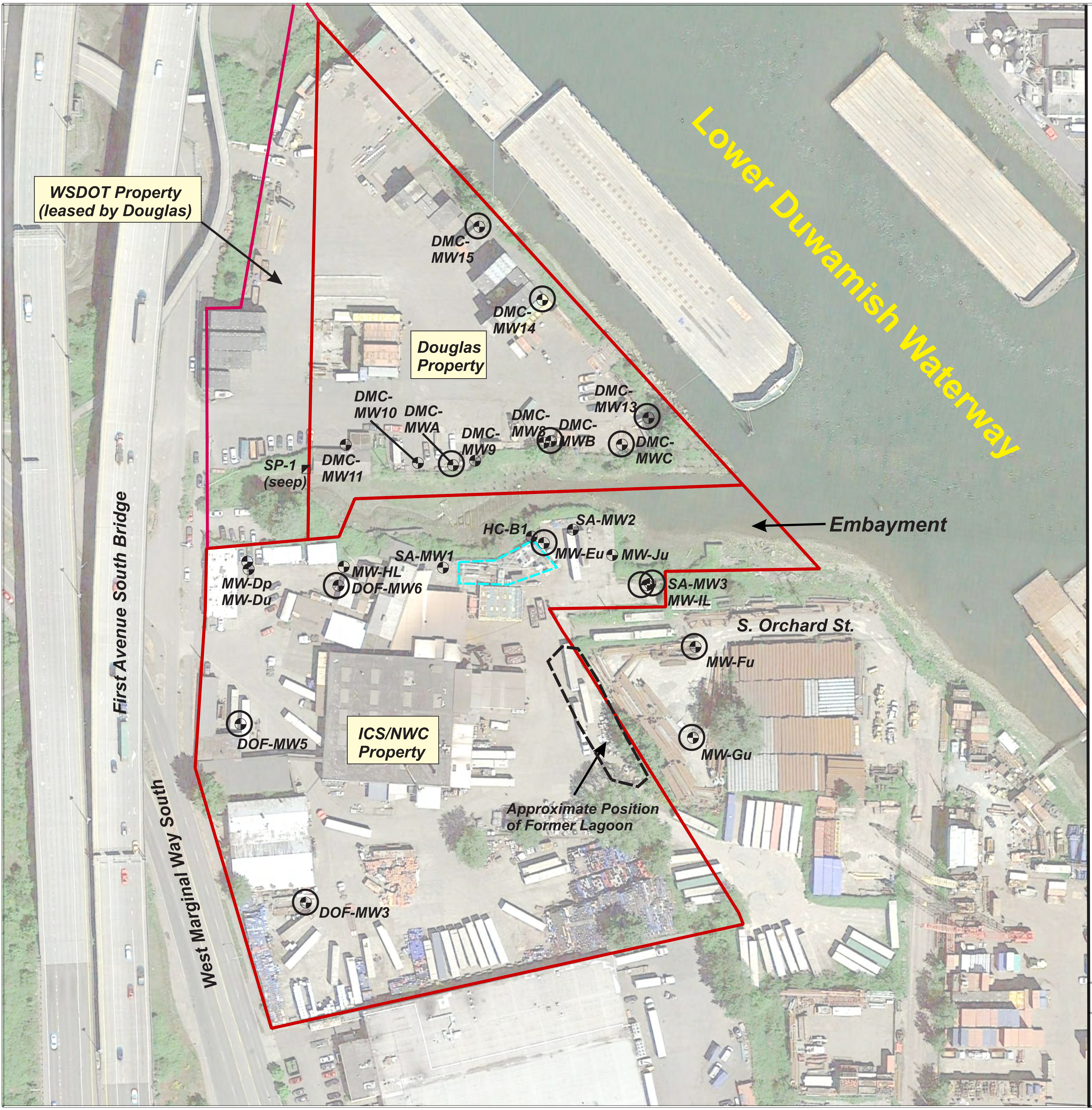
% Chlorine by Weight:	42	48	54	60
Average # of Chlorine Atoms per Molecule:	3	4	5	6

from Frame et al. 1996

Table 2.

ICS / NW Cooperage PCB Homolog Distributions and Concentrations in Groundwater and Suspended Solids

Location (collect date)	Turbidity (NTUs)	TSS (mg/L)	TOC (mg/L)		total PCBs corrected for MB (pg/L)	total Cl(1)-biphenyls (pg/L)	total Cl(2)-biphenyls (pg/L)	total Cl(3)-biphenyls (pg/L)	total Cl(4)-biphenyls (pg/L)	total Cl(5)-biphenyls (pg/L)	total Cl(6)-biphenyls (pg/L)	total Cl(7)-biphenyls (pg/L)	total Cl(8)-biphenyls (pg/L)	total Cl(9)-biphenyls (pg/L)	Decachloro-biphenyl (pg/L)	
Upgradient Wells:																
DOF-MW3	3.3	1 U	119	total	62.1	0	5.7	5.9	13.7	11.12	15.09	6.31	3.712	0.604	0	
(02/28/19)				soluble (pg/L)		0	5.7	5.9	13.7	11.12	15.09	6.31	3.712	0.604	0	**0.062 ng/L**
				% assoc with solids		-	-	-	-	-	-	-	-	-	-	**< 0.1 µg/kg**
DOF-MW5	6.8	19	17.7	total	38.1	0	0	12	3.3	9.12	9.09	4.43	0.129	0	0	
(02/28/19)				soluble (pg/L)		0	0	12	3.3	9.12	9.09	4.43	0.129	0	0	**0.038 ng/L**
				% assoc with solids		-	-	-	-	-	-	-	-	-	-	**< 0.1 µg/kg**
Downgradient Wells:																
MW-Fu	5.4	38	9.2	total	208.4	0	0	0	13.2	17.42	43.89	112.91	19.612	1.374	0	
(02/28/19)				soluble (pg/L)		0	0	0	8.38	6.99	9.46	11.9	0.993	0.034	0	**0.038 ng/L**
				% assoc with solids		-	-	-	37	60	78	89	95	98	-	**4.5 µg/kg**
MW-Gu	11	88	31.2	total	266.9	0	0	1.4	37.9	30.62	94.09	73.11	25.712	4.074	0	
(02/28/19)				soluble (pg/L)		0	0	0.932	16.25	6.87	9.98	3.54	0.579	0.044	0	**0.038 ng/L**
				% assoc with solids		-	-	33	57	78	89	95	98	99	-	**2.6 µg/kg**
SA-MW3	29	6	2.1	total	255.5	0	0	10.4	64.1	68.62	74.79	31.21	5.042	0.774	0.6	
(02/27/19)				soluble (pg/L)		0	0	10.05	58.8	55.55	47.5	13.34	1.273	0.107	0.042	**0.187 ng/L**
				% assoc with solids		-	-	3	8	19	36	57	75	86	93	**11 µg/kg**
MW-IL	5.9	63	11.5	total	707.7	0	0	4.3	23.6	92.92	376.29	191.91	17.712	0.984	0	
(02/27/19)				soluble (pg/L)		0	0	3.16	12.06	26.75	53.5	12.73	0.55	0.015	0	**0.109 ng/L**
				% assoc with solids		-	-	27	49	71	86	93	97	98	-	**9.5 µg/kg**



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Property Boundary

Image: Google Maps Pro
Date: 05-22-17

- ◉ Monitoring Well
- ◪ Seep
- ○ Selected Well To Sample

N

0 120
Scale in Feet

Ref: Selected Well Locations.cdr

ICS/NW Cooperage Site
Seattle, Washington

Selected Well Locations

DOF DALTON OLMSTED FUGLEVAND

FIGURE
Aa

November 2018

Figure B. Analytical Method Blank and Upgradient/Background Wells PCB Homolog Concentrations

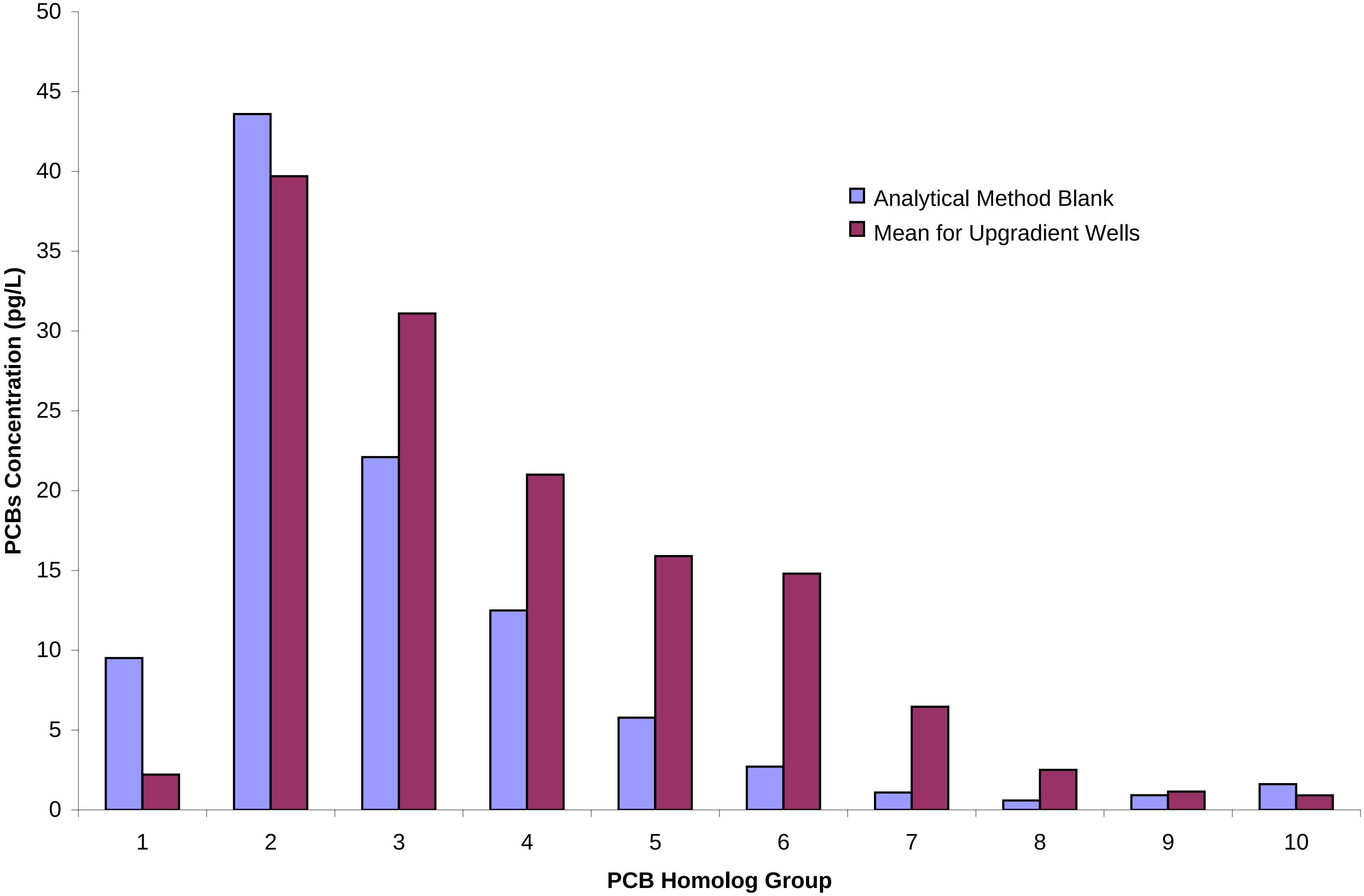
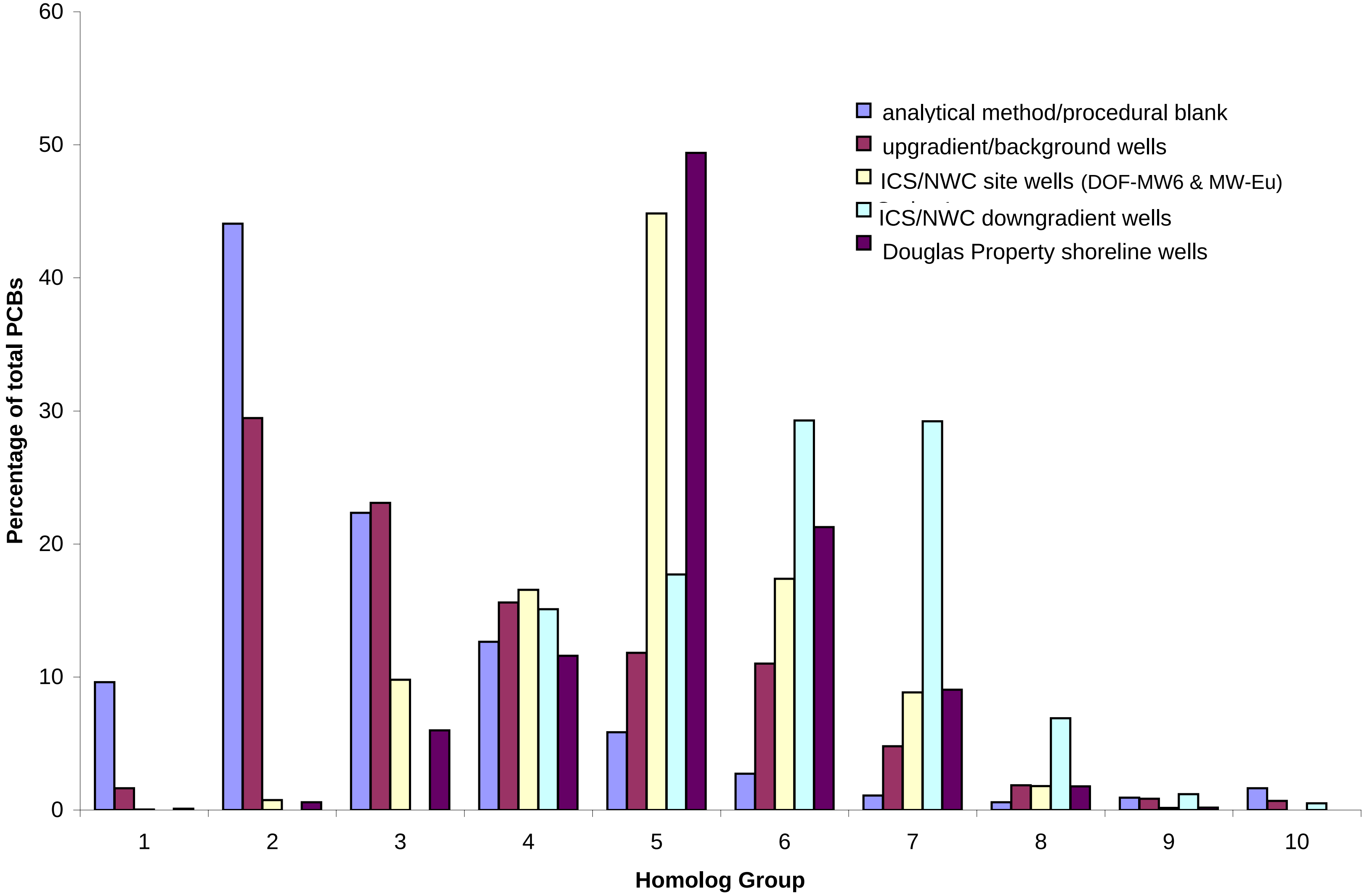


Figure C.
Comparison of PCB Homolog Profiles



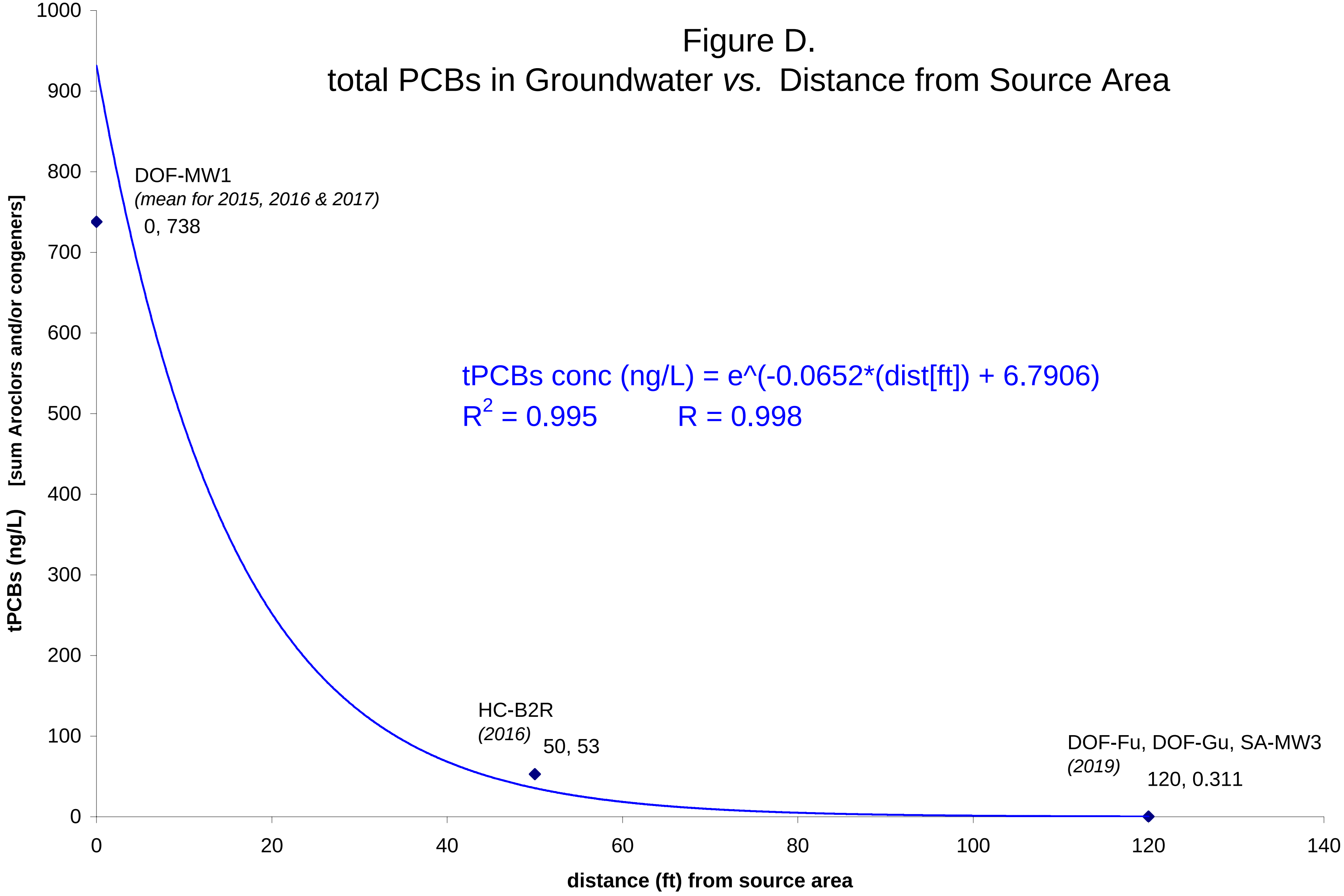


Figure D.
total PCBs in Groundwater *vs.* Distance from Source Area

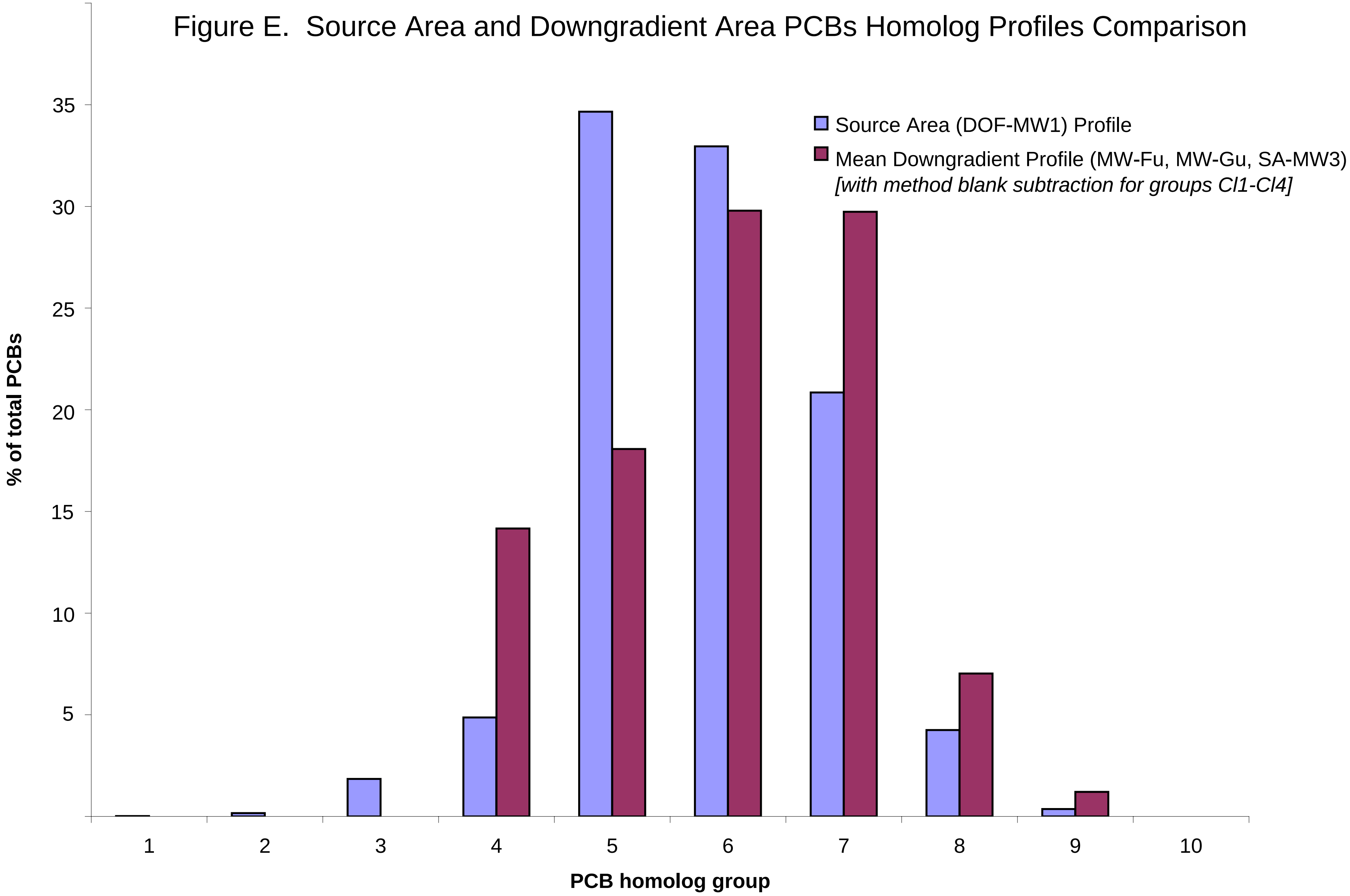


Figure E. Source Area and Downgradient Area PCBs Homolog Profiles Comparison
Source Area (DOF-MW1) Profile
Mean Downgradient Profile (MW-Fu, MW-Gu, SA-MW3)
[with method blank subtraction for groups Cl1-Cl4]
% of total PCBs
35
30
25
20
15
10
5
1
2
3
4
5
6
7
8
9
10
PCB homolog group

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MEMORANDUM

TO: Matt Dalton (DOF)

FROM: Raleigh Farlow

DATE: March 29, 2020

SUBJECT: Derivation of PCB/Aroclor Equilibrium Partition Coefficients for Use at the ICS/[former] Northwest Cooperage Site, Seattle, WA

Per your request, an explanation and "walk through" of how Aroclor K_{oc}'s were developed from current and updated physicochemical data is presented here. The approach employed utilizes information presented and described in *Geochemical Assessment of PCB's at the ICS/[former] Northwest Cooperage Site, Seattle, WA – ADDENDUM*, dated May 16, 2019, from R. Farlow (DMD) to M. Dalton (DOF). The Geochemical Assessment (DMD 2019) relies on three technical documents available in the scientific literature, specifically:

- Di Toro, D.M., 1985. A particle interaction model of reversible organic chemical sorption. *Chemosphere* 14(10): 1503-1538. (Determination of the relationship between PCB K_{ow} and K_{oc}.)
- Frame, G.M., Cochran, J.W., and Boewadt, S.S., 1996. Complete PCB congener distributions for 17 Aroclor mixtures determined by 3 HRGC systems optimized for comprehensive, quantitative congener-specific analyses. *J. High Res. Chromatogr.* 19, 657-668. (Determination of PCB congener and homolog compositions of Aroclors.)
- IARC 2016. World Health Organization – International Agency for Research on Cancer Monograph 107, Polychlorinated Biphenyls and Polybrominated Biphenyls. (Comprehensive and up-to-date resource for environmental exposures, biological effects, and chemical/physical characteristics of PCB's. Presentation of log(K_{ow})'s for all 209 PCB congeners.)

A variety of historical documents and Agency guidances have presented physicochemical data and thermodynamic partition constants/factors for use in describing environmental behaviors, fates and distributions of PCB's. A review of current and modern technical literature was performed to determine and evaluate critical physicochemical data for use in understanding and characterizing PCB's behavior at the ICS/Northwest Cooperage site. Environmental PCB's data at the ICS/NWC site are reported and expressed in terms of Aroclors and individual PCB congeners concentrations in multiple matrix types (groundwaters, surface waters, soils, and estuarine sediments). Source area and contaminated media characterizations at the site have determined that commercial PCB mixtures as Aroclors (Aroclor 1248, Aroclor 1254 and Aroclor 1260) are readily recognized as the primary contaminants of concern.

Pertinent characteristics of PCB's and Aroclors are described under *Characteristics of PCB's* (DMD 2019, pg. 1-2) and Table 1 in DMD (2019). Aroclor compositions have been determined by Frame et al. (1996) and are summarized by PCB homolog content in Table 1. Mean log(K_{ow})'s for each homolog group are presented in the attached Table 2, entitled *PCB homologs partition factors*, and are derived from Table 1.3 of IARC 107 (2016). The IARC treatise presents log(K_{ow})'s for all 209 individual PCB congeners. Thus, the mean log(K_{ow}) for each homolog group is calculated by averaging the log(K_{ow})'s for all congeners within each respective group (found in Table 1.3 of IARC 107 (2016)). For example, in the case of monochlorobiphenyls, three congener log(K_{ow})'s (4.46, 4.69, and 4.69) were averaged to yield a mean log(K_{ow}) of 4.61, which is summarized in the attached Table 2, *PCB homologs partition factors*. This process was performed for all ten homolog groups and presented in *PCB homologs partition factors*. The associated homolog group mean log(K_{oc})'s found in *PCB homologs partition factors* are derived from the relationship developed and described by Di Toro (1985) as the following (see pg. 6 in DMD 2019):

$$\log(K_{oc}) = 0.00028 + 0.983 \times \log(K_{ow})$$

Thus, in the case of pentachlorobiphenyls (PCBP):

$$\log(K_{oc})_{PCBP} = 0.00028 + 0.983 \times 6.40 = 6.29$$

Calculation of a mean K_{oc} for each Aroclor is performed by determining a weighted log(K_{oc}) by relative proportion of homolog group in each Aroclor (from Table 1). In the case of Aroclor 1254:

$$\log(K_{oc})_{\text{Aroclor 1254}} = 0.0024\text{x}5.00 + 0.0126\text{x}5.46 + 0.1025\text{x}5.88 + 0.5912\text{x}6.29 + 0.2676\text{x}6.68 + 0.0266\text{x}7.05 + 0.0004\text{x}7.39 + 0.0004\text{x}7.72 = 6.35$$

The mean K_{oc} for Aroclor 1254 is determined to be: $10^{6.35}$ or 10^(6.35) = 2,247,362

Consequently, mean K_{oc}'s for the three Aroclors of concern at this site are estimated to be the following:

Aroclor 1248 mean K_{oc} = 863,337
Aroclor 1254 mean K_{oc} = 2,247,362
Aroclor 1260 mean K_{oc} = 7,708,355

These Aroclor K_{oc}'s are greater than those recommended in previous guidances (using older and historical data) by factors of 9-35x. The effect of site modifiers on actual K_{oc}'s and Kd's are presented and described in DMD 2019. The use of the [greater] Aroclor K_{oc}'s developed using updated PCB's thermal equilibrium data and factors yields dissolved aqueous and solids' PCB concentrations consistent with those reported in site media.

Table 1.

Characteristics of PCB Homolog Groups and Weight Percent in Aroclors

PCB Homolog Group	Formula	# of Congeners	% Cl by wt.	log(Kow)	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260
1	$C_{12}H_9Cl$	3	18.79	4.46 - 4.69	0.75	0.07		0.02
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3	$C_{12}H_7Cl_3$	24	41.30	5.02 - 5.89	44.91	21.27	1.26	0.21
4	$C_{12}H_6Cl_4$	42	48.65	5.53 - 6.48	20.16	32.77	10.25	0.35
5	$C_{12}H_5Cl_5$	46	54.30	5.71 - 6.95	18.85	42.92	59.12	8.74
6	$C_{12}H_4Cl_6$	42	58.93	6.22 - 7.42	0.31	1.64	26.76	43.35
7	$C_{12}H_3Cl_7$	24	62.77	6.69 - 7.71		0.02	2.66	38.54
8	$C_{12}H_2Cl_8$	12	65.98	7.20 - 8.00			0.04	8.27
9	$C_{12}HCl_9$	3	68.73	7.71 - 8.09			0.04	0.70
10	$C_{12}Cl_{10}$	1	71.10	8.18				
from IARC 2016				% Chlorine by Weight:	42	48	54	60
				Average # of Chlorine Atoms per Molecule:	3	4	5	6

from Frame et al. 1996

Table 2.
PCB homologs partition factors

Chlorinated biphenyl homologs		Mean log(Kow) *	Mean log(Koc) **	Kd (L/kg) @ 2% foc
Monochlorobiphenyls	Cl-1	4.61	4.54	686
Dichlorobiphenyls	Cl-2	5.09	5.00	2,019
Trichlorobiphenyls	Cl-3	5.55	5.46	5,715
Tetrachlorobiphenyls	Cl-4	5.98	5.88	15,137
Pentachlorobiphenyls	Cl-5	6.40	6.29	39,267
Hexachlorobiphenyls	Cl-6	6.80	6.68	95,726
Heptachlorobiphenyls	Cl-7	7.17	7.05	223,373
Octachlorobiphenyls	Cl-8	7.52	7.39	493,208
Nonachlorobiphenyls	Cl-9	7.85	7.72	1,042,389
Decachlorobiphenyl	Cl-10	8.18	8.04	2,198,012

* calculated mean from IARC 107 (2016)

** from Di Toro (1985)

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MEMORANDUM

TO: Matt Dalton (DOF)

FROM: Raleigh Farlow

DATE: May 8, 2019

SUBJECT: Data Evaluation/Assessment for 14 Groundwaters Collected from Monitoring Wells during a Supplemental Characterization Event Performed during February 2019 from the **ICS / [former] NW Cooperage and Douglas Management Property** Sites, Seattle, WA

Fourteen groundwater well samples were collected by Dalton, Olmsted & Fuglevand (DOF) staff on February 25-28, 2019 for chemical characterization with a focus on selected groundwater COPC's that could impact surface waters. Samples were hand-delivered in four delivery groups (SDG's 19B0296, 19B0339, 19B0342 and 19C0011) to Analytical Resources Inc. (ARI) of Tukwila, Washington within 22 hours of collection (on ice) at 0.4 – 5.2 °C. PCB congener analyses were subcontracted to SGS AXYS Analytical Services, Ltd. of Sidney, British Columbia; samples were received by AXYS (from ARI via FedEx) in a single delivery group (WG67480, SDG L30872) on March 15, 2019 (on ice) at -0.1 °C. Samples were maintained at the project laboratories at 4 °C prior to analyses. Appropriate chemical preservatives were specified and used for water samples; nitric acid (HNO_3) for total metals (major cations), and sulfuric acid (H_2SO_4) for organic carbon (TOC; nonfiltered).

Sample collection, handling, and analyses were conducted in accordance with the project sampling and analysis plans (SAPs) (*Sampling and Analysis Plan to Complete Remedial Investigation Sampling ICS / Former NW Cooperage Site, Seattle, Washington*, prepared by DOF, February 2012) and *Work Plan to Complete Additional Groundwater Sampling Along Embayment Shoreline ICS RI/FS*, 11/12/18, from M. Dalton (DOF) to V. Sutton (WDOE). Analyses were performed by the following methods.

PCB's as congeners	EPA-M.1668C; AXYS SOP MLA-010
benzene	EPA-M.8260C
petroleum hydrocarbons	NWTPH-Dx w/ H_2SO_4 & silica gel cleanup
metals (Ca & Mg)	EPA-M.6010C
suspended solids (TSS)	EPA-SM2540D-97

PCB's as Aroclors	EPA-M.8082A w/ silica gel, H_2SO_4 & S_x cleanup
PAH	EPA-M.8270D-SIM
organic carbon (TOC)	EPA-M.9060A
chloride & sulfate	EPA-M.300.0

Special effort was made to minimize the generation and collection of contaminated solids during groundwater sampling by utilizing low-flow technique with a peristaltic pump at each well. To minimize inadvertent trace contamination by PCB's and other organics, pre-cleaned copper tubing was used and dropped into each well for sampling. Pre-cleaning consisted of flushing the copper tubing with 3 volumes of pesticide(ultralow residue)-grade methanol and rinsing with laboratory-grade water (performed at the project laboratory). Tubing was dedicated to each well and not shared or transferred between wells.

Polychlorinated biphenyl (PCB) congener analyses were performed by EPA M.1668C and AXYS SOP MLA-010, revision 11, version 06, by HRGC/HRMS SIM mode in conjunction with stable isotope dilution (^{13}C-labeled analogs) technique. In summary, site samples, a procedural/method blank (1 liter each; analytical batch WG67480), and an Ongoing Precision and Recovery (OPR) sample were spiked with ^{13}C-labeled quantification standards and extracted (39 days after collection) with methylene chloride via liquid/liquid extractor. (PCB's are very stable, and recent guidance suggests that aqueous sample holding times up to one year are acceptable, and extract maximum holding times between 40 days and one year are acceptable.) Extracts were subsequently spiked with ^{13}C-labeled cleanup standards and cleaned up with a series of liquid chromatography columns (multi-layered acid/base silica, alumina and Florisil®). The cleaned extracts were reduced in volume to 20 µL and spiked with labeled recovery standards prior to instrumental analyses. Instrumental analyses of 1 µL of final extracts were performed (after 18 days from initiating extraction and extract cleanups) by high resolution GC on an SPB-Octyl capillary gas chromatographic column coupled to a high-resolution ($R \geq 10{,}000$; 100 ppm mass peak widths at 6% peak height demonstrated) mass spectrometer (HRGC/HRMS) operated in SIM mode. Two masses from the molecular cluster were used to monitor each of the target analytes and labeled standards. Ion/mass ratios and retention times were used for analyte assignments. The laboratory reported congener results to 3 significant digits, whereas this evaluation reports individual congener results to 2 significant digits for values less than 100 pg/L due to associated precision at the lower reporting range of concentrations, where most of the project data is reported. Only 30 of 1431 (2%) reported congener values for site samples exceeded 100 pg/L (0.0001 µg/L). Some congeners exhibit chromatographic coelution/overlap and are reported as such in the attached results table. Toxic congeners, as identified by the World Health Organization (WHO-2005) and identified in the attached table with an asterisk ("*"), are used to calculate a TCDD toxicity equivalence concentration (TEQ). Two separate and different TEQ values are determined for each sample. The lower value was calculated using zero for nondetected analytes, and the other/higher value was determined by applying the reported nondetect concentration (even though it was not detected).

Samples were relinquished by DOF under chain-of-custody (C-O-C) procedure. All analyses for parameters reported in the attached results table were completed within the technical holding time requirements identified in the project SAPs and/or within [U.S. EPA] recommended maximum holding times for aqueous samples. Sample holding times/conditions are determined to be acceptable or within SAP specifications.

Lower **reporting limits** for PCB congeners are recovery-corrected based on the percent recovery of [^{13}C] labeled surrogate standards and an LOQ (or PQL) established by a 1 ng/ml initial calibration lower calibration limit. Detected analytes greater than a 2.5x S/N level and less than the lower calibration quantitation limit (LOQ of 20 pg/L [0.020 ng/L or 0.00002 µg/L] equivalent) are assigned the "J" qualifier code as estimated. The lower detection limit (LOD) for most analytes was generally observed at approximately 0.5 pg/L for site samples. Analyte concentrations for detected compounds are also recovery-corrected based on stable isotope labeled analyte recoveries. Frequently, "J" qualified results also exhibited slightly noncompliant ion abundance ratios due to potential interferences. This may result in slight positive bias in reporting for some "J" qualified results. For PCB congeners, lower reporting limits were significantly less than work plan specifications (work plan PQL = 100 pg/L compared to achieved PQL of 20 pg/L and detection limit (LOD) of 0.5 pg/L). PCB Aroclor lower reporting limits (LOQ based on a verifiable lower calibration standard) are 0.010 µg/L (per Aroclor mixture) with an LOD of approximately 0.002 µg/L. Aroclors detected between the LOQ and the LOD are qualified with the "J" qualifier code as estimated. Individual PAH lower reporting limits (LOQ) are 0.010 µg/L with an LOD of 0.0008-0.004 µg/L. Nondetected parameters are qualified with the "U" descriptor code at the associated lower reporting limit. LOQ's (PQL's) for all reported parameters met or surpassed work plan (SAP) requirements.

Method blanks (MB) were analyzed and reported for all analytical parameters. Method blanks for all parameters reported nondetects, with the exception of low levels for selected PCB congeners. A single blank was generated and reported for the PCB congeners analyses. The PCB congener method blank exhibited some background contamination mostly for mono-, di-, tri-, and tetra-chlorobiphenyls, and decachlorobiphenyl, with IUPAC congener 11 [3,3'-dichlorobiphenyl] showing the greatest level at up to 18 pg/L. Any reported congener sample results at up to 2x the greatest level reported for the method blank were "J_B" code qualified as estimated due to potentially significant blank contributions.

Results that required qualification with the "J_B" code are found in the attached results table for individual/selected congeners. With the exception of IUPAC congener 11 in sample ICS-DOFMW3-W-022819, all "J_B" qualified results are associated with method blank results at less than the verifiable lower quantitation limit (between the detection and lower reporting limits [LOQ]). PCB #3 (4-chlorobiphenyl) and the associated [^{13}C] labeled surrogate exhibited some interference from the PFK (perfluorokerosene) lock mass. The interference was sufficiently low to not adversely impact reported results, which were assigned the "J_B" qualifier code due to potential bias from laboratory method blank contamination. Congener levels in three laboratory method blanks reported by AXYS in 2017 are similar to method blank results reported for this analytical group; however, PCB congener #11 reported a greater level in 2017 (mean from three analyses of 56 pg/L).

Laboratory control sample (**LCS**), matrix spike (**MS**), duplicates/replicates, and OPR recoveries were within acceptable ranges for all reported analytes. The OPR performance in the range of 50 – 100 ng/ml for PCB congeners exhibited recoveries of approximately 100%. All stable isotope labeled surrogate recoveries for PCB congeners and associated surrogates for all other organic analytes were compliant with method specifications. No results required qualification due to noncompliant recoveries.

Initial calibration for PCB congeners was performed with 6 points for most analytes and 5 points for monochloro-congeners. A low-level calibration at 1 ng/ml, establishing a congener LOQ (or PQL) was performed for this project. A mid-level calibration check was performed and checked every 12 hours and was found to be within acceptable performance. PCB Aroclors initial calibration consisted of 6 calibration points for Aroclors 1016 and 1260 and single point calibration for the remaining Aroclors, per method specifications. Initial and continuing calibrations and checks for all reported parameters were within method specifications.

It should be noted that the actual project LOQ's and LOD's achieved for PCB congeners is significantly lower or less than the work plan objective of 0.0001 µg/L (0.1 ng/L or 100 pg/L). These [achieved] lower reporting levels are necessary for distinguishing the differences in congener concentrations in method blanks, background/upgradient wells and site downgradient wells. Congener concentrations for mono-, di-, tri-, and tetra-chlorobiphenyls in method blanks, background groundwater and site downgradient groundwaters were similar, if not equivalent, and are well below 100 pg/L (0.0001 µg/L) and generally between the reported LOD (0.5 pg/L) and LOQ (20 pg/L). It is determined that a lower reporting limit (or detection limit) of approximately 5 pg/L (0.000005 µg/L), or less, (which was achieved for this project) is necessary to distinguish environmental background levels from potentially impacted surface and groundwaters. The PCB congener lower reporting limits achieved for this monitoring event are sufficiently low to distinguish differences between all samples (collected from upgradient/background, downgradient and source areas) and blanks. A limitation in the evaluation of potential groundwater impacts from PCB's in site perimeter and background areas is the [in]ability to minimize/prevent inadvertent [trace] contamination contributed by sampling equipment and analytical method/procedural blanks. For this project, special ultra-trace level techniques were successfully employed during sample collection, handling and analyses to yield reliable sample results for distinguishing real data from "noise" introduced by inadvertent background contamination. The lower reporting limit for *PCB's as Aroclors* by EPA-M.8082A (LOQ of 0.010 µg/L and LOD of 0.002 µg/L) is demonstrated to be sufficient for comprehensive contaminant source and site characterizations, and no method/procedural blank contamination is observed at these lower reporting limits.

Sample results reported here and associated data quality are determined to be in compliance with method and SAP requirements. Work plan requirements have been met (or were improved upon) and data completeness is determined to be 100%.

Remedial Investigation

ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA

Supplemental GW monitoring, February 2019

Field I.D.	Matrix	Collection Date	Comments	Lab I.D.	Total Suspended Solids (TSS) mg/L	Organic Carbon (TOC) total mg/L	Sulfate 14808-79-8 total mg/L	Chloride 16887-00-6 total mg/L	Calcium 7440-70-2 total µg/L	Magnesium 7439-95-4 total µg/L	Hardness mg-CaCO$_3$/L
Douglas Management Property Shoreline Wells:											
DMC-MW13-W-022619	GW-mon. well	2/26/2019	nonfiltered	19B0339-01	3						
DMC-MW14-W-022519	GW-mon. well	2/25/2019	nonfiltered	19B0296-01 / L30872-1	1						
DMC-MW14-W-022719	GW-mon. well	2/27/2019	nonfiltered	19B0342-01		**4.57**	**39.8**	**863**	**120,000**	**76,000**	613
DMC-MW15-W-022519	GW-mon. well	2/25/2019	nonfiltered	19B0296-02 / L30872-2	45						
DMC-MW15-W-022719	GW-mon. well	2/27/2019	nonfiltered	19B0342-02		**8.52**	**12.3**	**889**	**171,000**	**88,800**	793
DMC-MWA-W-022619	GW-mon. well	2/26/2019	nonfiltered	19B0339-02	263						
DMC-MWB-W-022619	GW-mon. well	2/26/2019	nonfiltered	19B0339-03	102						
DMC-MWC-W-022519	GW-mon. well	2/25/2019	nonfiltered	19B0296-03 / L30872-3	60						
DMC-MWC-W-022719	GW-mon. well	2/27/2019	nonfiltered	19B0342-03		**2.98**	**626**	**4800**	**324,000**	**459,000**	2701
ICS - NWC Upgradient Wells:											
ICS-DOFMW3-W-022819	GW-mon. well	2/28/2019	nonfiltered	19C0011-01 / L30872-6	1 U	**119**	0.50 U	**286**	**21,000**	**45,000**	238
ICS-DOFMW5-W-022819	GW-mon. well	2/28/2019	nonfiltered	19C0011-02 / L30872-7	19	**17.7**	**3.0**	**683**	**22,100**	**37,400**	209
ICS - NWC Site Wells:											
ICS-DOFMW6-W-022719	GW-mon. well	2/27/2019	nonfiltered	19B0342-05	1						
ICS-MWEU-W-022719	GW-mon. well	2/27/2019	nonfiltered	19B0342-04	78						
ICS - NWC Downgradient Wells:											
ICS-DOFFU-W-022819	GW-mon. well	2/28/2019	nonfiltered	19C0011-03 / L30872-8	38	**9.17**	**91.3**	**143**	**106,000**	**50,000**	471
ICS-DOFGU-W-022819	GW-mon. well	2/28/2019	nonfiltered	19C0011-04 / L30872-9	88	**31.2**	**45.4**	**230**	**102,000**	**104,000**	683
ICS-SAMW3-W-022719	GW-mon. well	2/27/2019	nonfiltered	19B0342-06 / L30872-4	6	**2.12**	**208**	**1050**	**28,800**	**59,700**	318
ICS-MWIL-W-022719	GW-mon. well	2/27/2019	nonfiltered	19B0342-07 / L30872-5	63	**11.5**	**57.7**	**2330**	**87,800**	**137,000**	784
Trip Blank		2/26/2019	*VOC's trip blank*	19B0339-04							
Method Blank 4-22-19		4/22/2019	*PCB congeners*	WG67480-101 :4323							

U = nondetected at the associated lower reporting limit.

Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
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Field I.D.	Matrix	Diesel-range Organics (C12-C24) mg/L	Motor Oil-range Organics (C24-C38) mg/L	Benzene 71-43-2 µg/L	Naphthalene 91-20-3 µg/L	Acenaph-thylene 208-96-8 µg/L	Acenaph-thene 83-32-9 µg/L	Dibenzo-furan 132-64-9 µg/L	Fluorene 86-73-7 µg/L	Phenan-threne 85-01-8 µg/L	Anthra-cene 120-12-7 µg/L	LPAH µg/L	Fluoran-thene 206-44-0 µg/L	Pyrene 129-00-0 µg/L	Benzo(a)-anthracene 56-55-3 µg/L
Douglas Management Property Shoreline Wells:															
DMC-MW13-W-022619	GW-mon. well														
DMC-MW14-W-022519	GW-mon. well														
DMC-MW14-W-022719	GW-mon. well														
DMC-MW15-W-022519	GW-mon. well														
DMC-MW15-W-022719	GW-mon. well														
DMC-MWA-W-022619	GW-mon. well	**1.36**	**2.05**	**13.9**	**0.687**	0.010 U	**3.00**	**0.242**	**0.741**	**0.980**	**0.324**	**5.73**	**0.094**	**0.125**	**0.013**
DMC-MWB-W-022619	GW-mon. well				**0.656**	0.010 U	**3.63**	**0.127**	**0.906**	**0.269**	**0.037**	**5.50**	**0.034**	**0.029**	**0.003 J**
DMC-MWC-W-022519	GW-mon. well														
DMC-MWC-W-022719	GW-mon. well														
ICS - NWC Upgradient Wells:															
ICS-DOFMW3-W-022819	GW-mon. well														
ICS-DOFMW5-W-022819	GW-mon. well														
ICS - NWC Site Wells:															
ICS-DOFMW6-W-022719	GW-mon. well														
ICS-MWEU-W-022719	GW-mon. well														
ICS - NWC Downgradient Wells:															
ICS-DOFFU-W-022819	GW-mon. well														
ICS-DOFGU-W-022819	GW-mon. well														
ICS-SAMW3-W-022719	GW-mon. well														
ICS-MWIL-W-022719	GW-mon. well														
Trip Blank				0.20 U											
Method Blank 4-22-19															

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ).
U = nondetected at the associated lower reporting limit.

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Field I.D.	Matrix	Chrysene 218-01-9 µg/L	total Benzo-fluoranthenes µg/L	Benzo(a)-pyrene 50-32-8 µg/L	Indeno(1,2,3-cd)pyrene 193-39-5 µg/L	Dibenzo(a,h)-anthracene 53-70-3 µg/L	Benzo(g,h,i)-perylene 191-24-2 µg/L	HPAH µg/L	Aroclor 1016 12674-11-2 µg/L	Aroclor 1221 11104-28-2 µg/L	Aroclor 1232 11141-16-5 µg/L	Aroclor 1242 53469-21-9 µg/L	Aroclor 1248 12672-29-6 µg/L
Douglas Management Property Shoreline Wells:													
DMC-MW13-W-022619	GW-mon. well								0.010 U	0.010 U	0.010 U	0.010 U	**0.008 J**
DMC-MW14-W-022519	GW-mon. well												
DMC-MW14-W-022719	GW-mon. well												
DMC-MW15-W-022519	GW-mon. well												
DMC-MW15-W-022719	GW-mon. well												
DMC-MWA-W-022619	GW-mon. well	**0.027**	**0.008 J**	**0.005 J**	0.010 U	0.010 U	**0.005 J**	**0.277**	0.010 U	0.010 U	0.010 U	0.010 U	**0.049**
DMC-MWB-W-022619	GW-mon. well	**0.005 J**	0.010 U	0.010 U	0.010 U	0.010 U	0.010 U	**0.071**	0.010 U	0.010 U	0.010 U	0.010 U	**0.019**
DMC-MWC-W-022519	GW-mon. well												
DMC-MWC-W-022719	GW-mon. well												
ICS - NWC Upgradient Wells:													
ICS-DOFMW3-W-022819	GW-mon. well												
ICS-DOFMW5-W-022819	GW-mon. well												
ICS - NWC Site Wells:													
ICS-DOFMW6-W-022719	GW-mon. well								0.010 U	0.010 U	0.010 U	0.010 U	0.010 U
ICS-MWEU-W-022719	GW-mon. well								0.010 U	0.010 U	0.010 U	0.010 U	**0.405**
ICS - NWC Downgradient Wells:													
ICS-DOFFU-W-022819	GW-mon. well												
ICS-DOFGU-W-022819	GW-mon. well												
ICS-SAMW3-W-022719	GW-mon. well												
ICS-MWIL-W-022719	GW-mon. well												
Trip Blank													
Method Blank 4-22-19													

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ).
U = nondetected at the associated lower reporting limit.

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Field I.D.	Matrix	Aroclor 1254 11097-69-1 µg/L	Aroclor 1260 11096-82-5 µg/L	total Cl(1)-biphenyls 27323-18-8 pg/L	total Cl(2)-biphenyls 25512-42-9 pg/L	total Cl(3)-biphenyls 25323-68-6 pg/L	total Cl(4)-biphenyls 26914-33-0 pg/L	total Cl(5)-biphenyls 25429-29-2 pg/L	total Cl(6)-biphenyls 26601-64-9 pg/L	total Cl(7)-biphenyls 28655-71-2 pg/L	total Cl(8)-biphenyls 55722-26-4 pg/L	total Cl(9)-biphenyls 53742-07-7 pg/L	Decachloro-biphenyl 2051-24-3 pg/L	total PCBs 1336-36-3 pg/L
Douglas Management Property Shoreline Wells:														
DMC-MW13-W-022619	GW-mon. well	**0.005 J**	0.010 U											**13,000**
DMC-MW14-W-022519	GW-mon. well			**11.0**	**114**	**380**	**505**	**506**	**267**	**53.2**	**5.18**	**1.35**	**2.49**	**1845**
DMC-MW14-W-022719	GW-mon. well													
DMC-MW15-W-022519	GW-mon. well			**45.3**	**251**	**1210**	**2160**	**998**	**232**	**29.1**	**4.88**	0.84 U	**1.12**	**4931**
DMC-MW15-W-022719	GW-mon. well													
DMC-MWA-W-022619	GW-mon. well	**0.143**	**0.057**											**249,000**
DMC-MWB-W-022619	GW-mon. well	**0.023**	**0.014**											**56,000**
DMC-MWC-W-022519	GW-mon. well			**190**	**330**	**1250**	**2280**	**1120**	**327**	**116**	**1.91**	**3.48**	**4.00**	**5622**
DMC-MWC-W-022719	GW-mon. well													
ICS - NWC Upgradient Wells:														
ICS-DOFMW3-W-022819	GW-mon. well			**2.42**	**49.3**	**28.0**	**26.2**	**16.9**	**17.8**	**7.40**	**4.30**	1.5 U	**0.876**	**153**
ICS-DOFMW5-W-022819	GW-mon. well			**1.99**	**30.0**	**34.1**	**15.8**	**14.9**	**11.8**	**5.52**	**0.717**	0.79 U	**0.958**	**116**
ICS - NWC Site Wells:														
ICS-DOFMW6-W-022719	GW-mon. well	**0.017**	**0.010 J**											**27,000**
ICS-MWEU-W-022719	GW-mon. well	**0.276**	**0.184**											**865,000**
ICS - NWC Downgradient Wells:														
ICS-DOFFU-W-022819	GW-mon. well			**1.94**	**17.8**	**19.3**	**25.7**	**23.2**	**46.6**	**114**	**20.2**	**2.29**	**0.672**	**272**
ICS-DOFGU-W-022819	GW-mon. well			**1.90**	**22.2**	**23.5**	**50.4**	**36.4**	**96.8**	**74.2**	**26.3**	**4.99**	**0.931**	**338**
ICS-SAMW3-W-022719	GW-mon. well			**1.92**	**24.0**	**32.5**	**76.6**	**74.4**	**77.5**	**32.3**	**5.63**	**1.69**	**2.21**	**327**
ICS-MWIL-W-022719	GW-mon. well			**0.593**	**20.0**	**26.4**	**36.1**	**98.7**	**379**	**193**	**18.3**	**1.90**	**0.928**	**775**
Trip Blank														
Method Blank 4-22-19				9.51	43.6	22.1	12.5	5.78	2.71	1.09	0.59 U	0.92 U	1.61	98.9

U = nondetected at the associated lower reporting limit.

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Field I.D.	Matrix	PCB's TEQ (WHO-2005 TEF) pg/L	pg/L	2-MoCB [1] 2051-60-7 pg/L	3-MoCB [2] 2051-61-8 pg/L	4-MoCB [3] 2051-62-9 pg/L	2,2'-DiCB [4] 13029-08-8 pg/L	2,3-DiCB [5] 16605-91-7 pg/L	2,3'-DiCB [6] 25569-80-6 pg/L	2,4-DiCB [7] 33284-50-3 pg/L	2,4'-DiCB [8] 34883-43-7 pg/L	2,5-DiCB [9] 34883-39-1 pg/L	2,6-DiCB [10] 33146-45-1 pg/L	3,3'-DiCB [11] 2050-67-1 pg/L
Douglas Management Property Shoreline Wells:														
DMC-MW13-W-022619	GW-mon. well													
DMC-MW14-W-022519	GW-mon. well	0.00149	0.0628	**11 J**	0.47 U	**1.3 J_B**	**77**	1.6 U	**4.5 J**	1.4 U	**7.4 J_B**	1.4 U	**5.8 J**	**14 J_B**
DMC-MW14-W-022719	GW-mon. well													
DMC-MW15-W-022519	GW-mon. well	0.00151	0.0641	**39**	**1.2 J_B**	**4.8 J_B**	**82**	**2.5 J_B**	**59**	**4.6 J**	**59**	**6.6 J**	**4.7 J**	**16 J_B**
DMC-MW15-W-022719	GW-mon. well													
DMC-MWA-W-022619	GW-mon. well													
DMC-MWB-W-022619	GW-mon. well													
DMC-MWC-W-022519	GW-mon. well	0.00292	0.0675	**186**	**3.8 J**	**2.4 J_B**	**110**	**4.4 J_B**	**70**	**10 J**	**85**	**13 J**	**8.8 J**	**13 J_B**
DMC-MWC-W-022719	GW-mon. well													
ICS - NWC Upgradient Wells:														
ICS-DOFMW3-W-022819	GW-mon. well	0.000182	0.0628	**1.4 J_B**	**1.1 J_B**	**1.5 J_B**	**2.2 J_B**	1.4 U	**1.7 J_B**	1.2 U	**6.7 J_B**	1.2 U	1.2 U	**35 J_B**
ICS-DOFMW5-W-022819	GW-mon. well	0.000151	0.0628	**1.5 J_B**	**0.48 J_B**	**1.1 J_B**	**4.9 J_B**	0.85 U	**1.6 J_B**	0.77 U	**5.9 J_B**	0.75 U	0.77 U	**15 J_B**
ICS - NWC Site Wells:														
ICS-DOFMW6-W-022719	GW-mon. well													
ICS-MWEU-W-022719	GW-mon. well													
ICS - NWC Downgradient Wells:														
ICS-DOFFU-W-022819	GW-mon. well	0.000393	0.0630	**1.9 J_B**	**0.72 J_B**	**0.76 J_B**	**2.1 J_B**	1.1 U	**1.4 J_B**	0.92 U	**4.4 J_B**	0.89 U	0.91 U	**11 J_B**
ICS-DOFGU-W-022819	GW-mon. well	0.000270	0.0681	**0.99 J_B**	0.48 U	**0.91 J_B**	**3.0 J_B**	0.82 U	**1.4 J_B**	0.75 U	**5.2 J_B**	0.73 U	0.75 U	**11 J_B**
ICS-SAMW3-W-022719	GW-mon. well	0.000523	0.0631	**0.95 J_B**	0.48 U	**0.97 J_B**	**2.0 J_B**	0.85 U	**1.3 J_B**	0.77 U	**4.7 J_B**	0.74 U	0.76 U	**13 J_B**
ICS-MWIL-W-022719	GW-mon. well	0.000638	0.0645	**0.93 J_B**	**0.59 J_B**	**0.89 J_B**	**1.9 J_B**	0.66 U	**1.1 J_B**	0.59 U	**4.5 J_B**	0.58 U	0.59 U	**12 J_B**
Trip Blank														
Method Blank 4-22-19		0.0000840	0.0654	4.5 J	1.1 J	4.0 J	3.2 J	7.2 J	1.7 J	1.5 U	6.4 J	1.4 U	1.4 U	18 J
		toxic PCB congeners marked "" applied in TEQ calculation.*												
		ND(U)=0 for TEQ calculation.	*ND(U) value applied to TEQ calculation.*											

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.

J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.

U = nondetected at the associated lower reporting limit.

Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	3,4(3,4')-DiCB [12+13] 2974-92-7 / 2974-90-5 pg/L	3,5-DiCB [14] 34883-41-5 pg/L	4,4'-DiCB [15] 2050-68-2 pg/L	2,2',3-TriCB [16] 38444-78-9 pg/L	2,2',4-TriCB [17] 37680-66-3 pg/L	2,2',5(2,4,6)-TriCB [18+30] 37680-65-2 / 35693-92-6 pg/L	2,2',6-TriCB [19] 38444-73-4 pg/L	2,3,3'(2,4,4')-TriCB [20+28] 38444-84-7 / 7012-37-5 pg/L	2,3,4(2',3,4)-TriCB [21+33] 55702-46-0 / 38444-86-9 pg/L	2,3,4'-TriCB [22] 38444-85-8 pg/L
Douglas Management Property Shoreline Wells:											
DMC-MW13-W-022619	GW-mon. well										
DMC-MW14-W-022519	GW-mon. well	1.5 U	1.5 U	**6.0 J_B**	**33**	**40**	**120**	**50**	**23**	**4.5 J_B**	**3.6 J_B**
DMC-MW14-W-022719	GW-mon. well										
DMC-MW15-W-022519	GW-mon. well	**5.0 J**	1.2 U	**12 J**	**87**	**112**	**270**	**46**	**126**	**36**	**34**
DMC-MW15-W-022719	GW-mon. well										
DMC-MWA-W-022619	GW-mon. well										
DMC-MWB-W-022619	GW-mon. well										
DMC-MWC-W-022519	GW-mon. well	**3.3 J_B**	0.86 U	**13 J**	**107**	**148**	**287**	**34**	**147**	**58**	**41**
DMC-MWC-W-022719	GW-mon. well										
ICS - NWC Upgradient Wells:											
ICS-DOFMW3-W-022819	GW-mon. well	1.3 U	1.3 U	**3.4 J_B**	**2.6 J_B**	**3.1 J_B**	**5.6 J_B**	**1.2 J_B**	**6.9 J_B**	**4.0 J_B**	**2.6 J_B**
ICS-DOFMW5-W-022819	GW-mon. well	**0.85 J_B**	0.80 U	**2.9 J_B**	**2.3 J_B**	**3.2 J_B**	**5.1 J_B**	**1.5 J_B**	**5.8 J_B**	**3.1 J_B**	**1.9 J_B**
ICS - NWC Site Wells:											
ICS-DOFMW6-W-022719	GW-mon. well										
ICS-MWEU-W-022719	GW-mon. well										
ICS - NWC Downgradient Wells:											
ICS-DOFFU-W-022819	GW-mon. well	0.98 U	0.96 U	**1.8 J_B**	**2.4 J_B**	**2.3 J_B**	**4.1 J_B**	**0.88 J_B**	**4.5 J_B**	**2.6 J_B**	**1.7 J_B**
ICS-DOFGU-W-022819	GW-mon. well	0.80 U	0.78 U	**2.6 J_B**	**2.6 J_B**	**3.4 J_B**	**5.2 J_B**	**1.4 J_B**	**6.0 J_B**	**3.4 J_B**	**2.3 J_B**
ICS-SAMW3-W-022719	GW-mon. well	0.82 U	0.80 U	**3.3 J_B**	**2.5 J_B**	**2.6 J_B**	**5.6 J_B**	**3.0 J_B**	**6.2 J_B**	**2.9 J_B**	**1.9 J_B**
ICS-MWIL-W-022719	GW-mon. well	0.64 U	0.62 U	**2.8 J_B**	**2.1 J_B**	**2.4 J_B**	**4.0 J_B**	**0.75 J_B**	**6.0 J_B**	**3.0 J_B**	**2.2 J_B**
Trip Blank											
Method Blank 4-22-19		2.2 J	1.5 U	4.7 J	2.0 J	2.1 J	4.1 J	1.8 J	5.2 J	3.7 J	1.9 J

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J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.
U = nondetected at the associated lower reporting limit.

Remedial Investigation

ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA

Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,3,5-TriCB [23] 55720-44-0 pg/L	2,3,6-TriCB [24] 55702-45-9 pg/L	2,3',4-TriCB [25] 55712-37-3 pg/L	2,3',5(2,4,5)-TriCB [26+29] 38444-81-4 / 15862-07-4 pg/L	2,3',6-TriCB [27] 38444-76-7 pg/L	2,4',5-TriCB [31] 16606-02-3 pg/L	2,4',6-TriCB [32] 38444-77-8 pg/L	2',3,5-TriCB [34] 37680-68-5 pg/L	3,3',4-TriCB [35] 37680-69-6 pg/L	3,3',5-TriCB [36] 38444-87-0 pg/L	3,4,4'-TriCB [37] 38444-90-5 pg/L	3,4,5-TriCB [38] 53555-66-1 pg/L
Douglas Management Property Shoreline Wells:													
DMC-MW13-W-022619	GW-mon. well												
DMC-MW14-W-022519	GW-mon. well	0.47 U	**0.71 J_B**	**7.5 J**	**20**	**11 J**	**26**	**41**	0.47 U	**0.50 J_B**	0.47 U	**1.7 J_B**	0.47 U
DMC-MW14-W-022719	GW-mon. well												
DMC-MW15-W-022519	GW-mon. well	0.48 U	**2.1 J**	**68**	**197**	**27**	**131**	**66**	**2.8 J**	**0.54 J_B**	**0.81 J**	**4.4 J**	0.48 U
DMC-MW15-W-022719	GW-mon. well												
DMC-MWA-W-022619	GW-mon. well												
DMC-MWB-W-022619	GW-mon. well												
DMC-MWC-W-022519	GW-mon. well	0.52 U	**2.0 J**	**47**	**138**	**18 J**	**142**	**66**	**4.6 J**	**0.61 J_B**	0.49 U	**7.6 J**	0.49 U
DMC-MWC-W-022719	GW-mon. well												
ICS - NWC Upgradient Wells:													
ICS-DOFMW3-W-022819	GW-mon. well	0.48 U	0.48 U	**0.60 J**	**1.4 J_B**	**0.62 J**	**5.7 J_B**	**1.6 J_B**	0.48 U	**1.6 J**	0.48 U	**1.6 J_B**	0.48 U
ICS-DOFMW5-W-022819	GW-mon. well	0.48 U	0.48 U	**0.64 J**	**1.3 J_B**	**0.57 J**	**5.3 J_B**	**1.9 J_B**	0.48 U	**0.56 J_B**	0.48 U	**0.95 J_B**	0.48 U
ICS - NWC Site Wells:													
ICS-DOFMW6-W-022719	GW-mon. well												
ICS-MWEU-W-022719	GW-mon. well												
ICS - NWC Downgradient Wells:													
ICS-DOFFU-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	**0.72 J_B**	0.48 U	**3.9 J_B**	**1.3 J_B**	0.48 U	0.48 U	0.48 U	**0.96 J_B**	0.48 U
ICS-DOFGU-W-022819	GW-mon. well	0.48 U	0.48 U	**0.49 J**	**1.3 J_B**	**0.88 J**	**5.1 J_B**	**2.0 J_B**	0.48 U	0.48 U	0.48 U	**1.4 J_B**	0.48 U
ICS-SAMW3-W-022719	GW-mon. well	0.48 U	0.48 U	**0.64 J**	**1.1 J_B**	**0.85 J**	**4.8 J_B**	**3.1 J**	0.48 U	**0.65 J_B**	0.48 U	**1.7 J_B**	0.48 U
ICS-MWIL-W-022719	GW-mon. well	0.49 U	0.49 U	0.49 U	**1.1 J_B**	0.49 U	**4.7 J_B**	**1.6 J_B**	0.49 U	0.49 U	0.49 U	**1.5 J_B**	0.49 U
Trip Blank													
Method Blank 4-22-19		1.3 J	0.51 J	0.50 U	1.1 J	0.50 U	4.5 J	1.2 J	0.88 J	0.63 J	0.50 U	1.4 J	0.50 U

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Remedial Investigation

ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA

Supplemental GW monitoring, February 2019

Field I.D.	Matrix	3,4',5-TriCB [39] 38444-88-1 pg/L	2,2',3,3'(2,2',3,4)(2,3',4',6)-TeCB [40+41+71] 38444-93-8 / 52663-59-9 / 41464-46-4 pg/L	2,2',3,4'-TeCB [42] 36559-22-5 pg/L	2,2',3,5-TeCB [43] 70362-46-8 pg/L	2,2',3,5'(2,2',4,4')(2,3,5,6)-TeCB [44+47+65] 41464-39-5 / 2437-79-8 / 33284-54-7 pg/L	2,2',3,6(2,2',4,6')-TeCB [45+51] 70362-45-7 / 68194-04-7 pg/L	2,2',3,6'-TeCB [46] 41464-47-5 pg/L	2,2',4,5-TeCB [48] 70362-47-9 pg/L
Douglas Management Property Shoreline Wells:									
DMC-MW13-W-022619	GW-mon. well								
DMC-MW14-W-022519	GW-mon. well	0.47 U	**34**	**18 J**	**2.3 J**	**80**	**39**	**17 J**	**8.1 J**
DMC-MW14-W-022719	GW-mon. well								
DMC-MW15-W-022519	GW-mon. well	**1.7 J**	**111**	**60**	**9.9 J**	**327**	**81**	**37**	**31**
DMC-MW15-W-022719	GW-mon. well								
DMC-MWA-W-022619	GW-mon. well								
DMC-MWB-W-022619	GW-mon. well								
DMC-MWC-W-022519	GW-mon. well	**2.7 J**	**116**	**73**	**11 J**	**349**	**78**	**27**	**46**
DMC-MWC-W-022719	GW-mon. well								
ICS - NWC Upgradient Wells:									
ICS-DOFMW3-W-022819	GW-mon. well	0.48 U	**2.6 J**	0.48 U	0.48 U	**6.7 J_B**	**1.5 J_B**	0.48 U	**1.1 J_B**
ICS-DOFMW5-W-022819	GW-mon. well	0.48 U	**1.7 J_B**	**0.91 J_B**	0.48 U	**11 J_B**	**2.5 J**	0.48 U	**0.92 J_B**
ICS - NWC Site Wells:									
ICS-DOFMW6-W-022719	GW-mon. well								
ICS-MWEU-W-022719	GW-mon. well								
ICS - NWC Downgradient Wells:									
ICS-DOFFU-W-022819	GW-mon. well	0.48 U	**1.8 J_B**	**0.67 J_B**	0.48 U	**5.4 J_B**	**1.2 J_B**	**0.56 J**	**1.0 J_B**
ICS-DOFGU-W-022819	GW-mon. well	0.48 U	**3.9 J**	**1.8 J_B**	0.53 U	**9.9 J_B**	**2.2 J**	**0.80 J**	**1.3 J_B**
ICS-SAMW3-W-022719	GW-mon. well	0.48 U	**6.4 J**	**3.5 J**	0.48 U	**14 J**	**6.0 J**	**2.0 J**	**1.1 J_B**
ICS-MWIL-W-022719	GW-mon. well	0.49 U	**3.5 J**	**1.8 J_B**	0.49 U	**7.5 J_B**	**1.6 J_B**	**0.50 J**	**1.2 J_B**
Trip Blank									
Method Blank 4-22-19		0.50 U	0.93 J	0.55 J	0.50 U	5.9 J	1.0 J	0.50 U	0.78 J

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Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,2',4,5'(2,3',4,6)-TeCB [49+69] 41464-40-8 / 60233-24-1 pg/L	2,2',4,6(2,2',5,6')-TeCB [50+53] 62796-65-0 / 41464-41-9 pg/L	2,2',5,5'-TeCB [52] 35693-99-3 pg/L	2,2',6,6'-TeCB [54] 15968-05-5 pg/L	2,3,3',4-TeCB [55] 74338-24-2 pg/L	2,3,3',4'-TeCB [56] 41464-43-1 pg/L	2,3,3',5-TeCB [57] 70424-67-8 pg/L	2,3,3',5'-TeCB [58] 41464-49-7 pg/L	2,3,3',6(2,3,4,6)(2,4,4',6)-TeCB [59+62+75] 74472-33-6 / 54230-22-7 / 32598-12-2 pg/L
Douglas Management Property Shoreline Wells:										
DMC-MW13-W-022619	GW-mon. well									
DMC-MW14-W-022519	GW-mon. well	**89**	**45**	**167**	**1.4 J_B**	0.54 U	**3.6 J**	0.52 U	0.52 U	**8.1 J**
DMC-MW14-W-022719	GW-mon. well									
DMC-MW15-W-022519	GW-mon. well	**314**	**91**	**769**	**1.6 J_B**	**1.5 J**	**23**	**2.7 J**	**1.9 J**	**45**
DMC-MW15-W-022719	GW-mon. well									
DMC-MWA-W-022619	GW-mon. well									
DMC-MWB-W-022619	GW-mon. well									
DMC-MWC-W-022519	GW-mon. well	**312**	**78**	**744**	**1.2 J_B**	**1.8 J**	**37**	**2.0 J**	**1.8 J**	**34**
DMC-MWC-W-022719	GW-mon. well									
ICS - NWC Upgradient Wells:										
ICS-DOFMW3-W-022819	GW-mon. well	**2.7 J_B**	**1.0 J_B**	**5.8 J_B**	0.48 U	0.48 U	**1.3 J_B**	0.48 U	0.48 U	**0.60 J**
ICS-DOFMW5-W-022819	GW-mon. well	**2.2 J_B**	**0.83 J_B**	**4.9 J_B**	0.48 U	0.48 U	**0.91 J_B**	0.48 U	0.48 U	0.48 U
ICS - NWC Site Wells:										
ICS-DOFMW6-W-022719	GW-mon. well									
ICS-MWEU-W-022719	GW-mon. well									
ICS - NWC Downgradient Wells:										
ICS-DOFFU-W-022819	GW-mon. well	**3.0 J_B**	**0.84 J**	**5.8 J_B**	0.48 U	0.48 U	**0.86 J_B**	0.48 U	0.48 U	0.48 U
ICS-DOFGU-W-022819	GW-mon. well	**5.1 J**	**1.8 J**	**20**	0.48 U	0.48 U	**1.6 J**	0.48 U	0.48 U	**0.74 J**
ICS-SAMW3-W-022719	GW-mon. well	**6.9 J**	**5.9 J**	**16 J**	0.48 U	0.48 U	**1.7 J**	0.48 U	0.48 U	**0.96 J**
ICS-MWIL-W-022719	GW-mon. well	**3.5 J_B**	**1.1 J**	**7.3 J_B**	0.49 U	0.49 U	**2.5 J**	0.49 U	0.49 U	0.49 U
Trip Blank										
Method Blank 4-22-19		2.0 J	0.52 J	3.7 J	0.88 J	0.50 U	0.70 J	0.50 U	0.50 U	0.50 U

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Remedial Investigation

ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA

Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,3,4,4'-TeCB [60] 33025-41-1 pg/L	2,3,4,5(2,3',4',5)(2,4,4',5)(2',3,4,5)-TeCB [61+70+74+76] 33284-53-6 / 32598-10-0 / 32690-93-0 / 70362-48-0 pg/L	2,3,4',5-TeCB [63] 74472-34-7 pg/L	2,3,4',6-TeCB [64] 52663-58-8 pg/L	2,3',4,4'-TeCB [66] 32598-11-1 pg/L	2,3',4,5-TeCB [67] 73575-53-8 pg/L	2,3',4,5'-TeCB [68] 73575-52-7 pg/L	2,3',5,5'-TeCB [72] 41464-42-0 pg/L	2,3',5',6-TeCB [73] 74338-23-1 pg/L	3,3',4,4'-TeCB [77] * 32598-13-3 pg/L
Douglas Management Property Shoreline Wells:											
DMC-MW13-W-022619	GW-mon. well										
DMC-MW14-W-022519	GW-mon. well	**1.0 J**	**35**	**0.60 J**	**23**	**11 J**	**0.53 J**	**1.8 J**	**2.5 J**	**0.74 J**	**0.81 J**
DMC-MW14-W-022719	GW-mon. well										
DMC-MW15-W-022519	GW-mon. well	**4.2 J**	**109**	**3.7 J**	**75**	**46**	**4.9 J**	**4.2 J**	**9.5 J**	**1.6 J**	**1.2 J**
DMC-MW15-W-022719	GW-mon. well										
DMC-MWA-W-022619	GW-mon. well										
DMC-MWB-W-022619	GW-mon. well										
DMC-MWC-W-022519	GW-mon. well	**6.1 J**	**164**	**5.1 J**	**91**	**79**	**4.6 J**	**4.0 J**	**10 J**	**1.3 J**	**2.1 J**
DMC-MWC-W-022719	GW-mon. well										
ICS - NWC Upgradient Wells:											
ICS-DOFMW3-W-022819	GW-mon. well	**0.55 J**	**4.3 J_B**	0.48 U	**1.6 J_B**	**2.0 J**	0.48 U	**0.56 J_B**	0.48 U	0.48 U	0.48 U
ICS-DOFMW5-W-022819	GW-mon. well	**0.58 J**	**3.7 J_B**	0.48 U	**1.5 J_B**	**1.9 J_B**	0.48 U	**0.90 J_B**	0.48 U	0.48 U	0.48 U
ICS - NWC Site Wells:											
ICS-DOFMW6-W-022719	GW-mon. well										
ICS-MWEU-W-022719	GW-mon. well										
ICS - NWC Downgradient Wells:											
ICS-DOFFU-W-022819	GW-mon. well	**0.49 J**	**3.9 J_B**	0.48 U	**1.8 J_B**	**1.6 J_B**	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U
ICS-DOFGU-W-022819	GW-mon. well	**0.84 J**	**6.5 J**	0.48 U	**2.6 J**	**4.2 J**	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U
ICS-SAMW3-W-022719	GW-mon. well	**0.72 J**	**6.7 J**	0.48 U	**4.1 J**	**4.5 J**	0.48 U	**0.73 J_B**	0.48 U	0.48 U	**1.1 J**
ICS-MWIL-W-022719	GW-mon. well	**0.81 J**	**7.7 J**	0.49 U	**2.5 J**	**4.7 J**	0.49 U	**0.55 J_B**	0.49 U	0.49 U	**0.68 J**
Trip Blank											
Method Blank 4-22-19		0.50 U	2.6 J	0.50 U	1.0 J	0.97 J	0.50 U	0.81 J	0.50 U	0.50 U	0.55 U

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Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	3,3',4,5-TeCB [78] 70362-49-1 pg/L	3,3',4,5'-TeCB [79] 41464-48-6 pg/L	3,3',5,5'-TeCB [80] 33284-52-5 pg/L	3,4,4',5-TeCB [81] * 70362-50-4 pg/L	2,2',3,3',4-PeCB [82] 52663-62-4 pg/L	2,2',3,3',5(2,2',4,4',5)-PeCB [83+99] 60145-20-2 / 38380-01-7 pg/L	2,2',3,3',6-PeCB [84] 52663-60-2 pg/L	2,2',3,4,4'(2,3,4,5,6)(2,3,4',5,6)-PeCB [85+116+117] 65510-45-4 / 18259-05-7 / 68194-11-6 pg/L
Douglas Management Property Shoreline Wells:									
DMC-MW13-W-022619	GW-mon. well								
DMC-MW14-W-022519	GW-mon. well	0.53 U	**0.87 J**	0.49 U	0.56 U	**4.5 J**	**39**	**33**	**8.2 J**
DMC-MW14-W-022719	GW-mon. well								
DMC-MW15-W-022519	GW-mon. well	0.60 U	**1.2 J**	0.55 U	0.61 U	**7.6 J**	**74**	**82**	**12 J**
DMC-MW15-W-022719	GW-mon. well								
DMC-MWA-W-022619	GW-mon. well								
DMC-MWB-W-022619	GW-mon. well								
DMC-MWC-W-022519	GW-mon. well	0.61 U	**2.3 J**	0.54 U	0.67 U	**10 J**	**90**	**81**	**16 J**
DMC-MWC-W-022719	GW-mon. well								
ICS - NWC Upgradient Wells:									
ICS-DOFMW3-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U	**1.8 J_B**	**1.2 J_B**	**1.2 J**
ICS-DOFMW5-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U	**1.8 J_B**	**0.88 J_B**	**0.79 J**
ICS - NWC Site Wells:									
ICS-DOFMW6-W-022719	GW-mon. well								
ICS-MWEU-W-022719	GW-mon. well								
ICS - NWC Downgradient Wells:									
ICS-DOFFU-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	0.48 U	**0.84 J**	**3.8 J_B**	**0.74 J_B**	**0.52 J**
ICS-DOFGU-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	0.48 U	**0.85 J**	**3.4 J_B**	**1.8 J_B**	**2.3 J**
ICS-SAMW3-W-022719	GW-mon. well	0.48 U	0.48 U	0.48 U	0.48 U	**1.4 J**	**7.3 J**	**3.9 J**	**2.8 J**
ICS-MWIL-W-022719	GW-mon. well	0.49 U	0.49 U	0.49 U	0.49 U	**1.3 J**	**5.7 J**	**2.8 J**	**1.5 J**
Trip Blank									
Method Blank 4-22-19		0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	1.0 J	1.0 J	0.50 U

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.

J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.

U = nondetected at the associated lower reporting limit.

Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,2',3,4,5(2,2',3,4,5')(2,2',3',4,5)(2,3,3',4,6)(2,3',4,4',6)(2',3,4,5,6')-PeCB [86+87+97+109+119+125] 55312-69-1 / 38380-02-8 / 41464-51-1 / 74472-35-8 / 56558-17-9 / 74472-39-2 pg/L	2,2',3,4,6(2,2',3,4',6)-PeCB [88+91] 55215-17-3 / 68194-07-0 pg/L	2,2',3,4,6'-PeCB [89] 73575-57-2 pg/L	2,2',3,4',5(2,2',4,5,5')(2,3,3',5',6)-PeCB [90+101+113] 68194-07-0 / 37680-73-2 / 68194-10-5 pg/L	2,2',3,5,5'-PeCB [92] 52663-61-3 pg/L
Douglas Management Property Shoreline Wells:						
DMC-MW13-W-022619	GW-mon. well					
DMC-MW14-W-022519	GW-mon. well	**45**	**20**	**1.4 J**	**76**	**24**
DMC-MW14-W-022719	GW-mon. well					
DMC-MW15-W-022519	GW-mon. well	**71**	**50**	**1.6 J**	**148**	**47**
DMC-MW15-W-022719	GW-mon. well					
DMC-MWA-W-022619	GW-mon. well					
DMC-MWB-W-022619	GW-mon. well					
DMC-MWC-W-022519	GW-mon. well	**87**	**46**	**2.9 J**	**179**	**51**
DMC-MWC-W-022719	GW-mon. well					
ICS - NWC Upgradient Wells:						
ICS-DOFMW3-W-022819	GW-mon. well	**3.2 J**	**0.71 J**	0.48 U	**5.4 J**	**1.1 J**
ICS-DOFMW5-W-022819	GW-mon. well	**2.1 J_B**	**0.61 J**	0.48 U	**3.7 J_B**	**0.54 J**
ICS - NWC Site Wells:						
ICS-DOFMW6-W-022719	GW-mon. well					
ICS-MWEU-W-022719	GW-mon. well					
ICS - NWC Downgradient Wells:						
ICS-DOFFU-W-022819	GW-mon. well	**3.4 J**	**0.84 J**	0.48 U	**8.8 J**	**0.86 J**
ICS-DOFGU-W-022819	GW-mon. well	**7.7 J**	**1.4 J**	0.53 U	**17 J**	**4.1 J**
ICS-SAMW3-W-022719	GW-mon. well	**8.2 J**	**2.4 J**	0.48 U	**13 J**	**2.3 J**
ICS-MWIL-W-022719	GW-mon. well	**8.8 J**	**1.5 J**	0.49 U	**29**	**4.0 J**
Trip Blank						
Method Blank 4-22-19		1.6 J	0.50 U	0.50 U	2.2 J	0.50 U

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.

J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.

U = nondetected at the associated lower reporting limit.

Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,2',3,5,6(2,2',3,5',6)(2,2',3',4,6)(2,2',4,4',6)(2,2',4,5,6')-PeCB [93+95+98+100+102] 73575-56-1 / 38379-99-6 / 60233-25-2 / 39485-83-1 / 68194-06-9 pg/L	2,2',3,5,6'-PeCB [94] 73575-55-0 pg/L	2,2',3,6,6'-PeCB [96] 73575-54-9 pg/L	2,2',4,5',6-PeCB [103] 60145-21-3 pg/L	2,2',4,6,6'-PeCB [104] 56558-16-8 pg/L	2,3,3',4,4'-PeCB [105] * 32598-14-4 pg/L	2,3,3',4,5-PeCB [106] 70424-69-0 pg/L	2,3,3',4',5-PeCB [107] 70424-68-9 pg/L
Douglas Management Property Shoreline Wells:									
DMC-MW13-W-022619	GW-mon. well								
DMC-MW14-W-022519	GW-mon. well	**134**	**0.63 J**	**1.0 J**	**4.7 J**	0.47 U	**7.4 J**	0.47 U	**2.4 J**
DMC-MW14-W-022719	GW-mon. well								
DMC-MW15-W-022519	GW-mon. well	**323**	**1.7 J**	**3.7 J**	**9.9 J**	0.48 U	**8.7 J**	0.48 U	**2.8 J**
DMC-MW15-W-022719	GW-mon. well								
DMC-MWA-W-022619	GW-mon. well								
DMC-MWB-W-022619	GW-mon. well								
DMC-MWC-W-022519	GW-mon. well	**311**	**1.7 J**	**3.4 J**	**11 J**	0.48 U	**15 J**	0.48 U	**4.9 J**
DMC-MWC-W-022719	GW-mon. well								
ICS - NWC Upgradient Wells:									
ICS-DOFMW3-W-022819	GW-mon. well	**4.9 J_B**	0.48 U	0.48 U	0.48 U	0.48 U	**2.0 J_B**	0.48 U	0.48 U
ICS-DOFMW5-W-022819	GW-mon. well	**3.2 J_B**	0.48 U	0.48 U	0.48 U	0.48 U	**1.5 J_B**	0.48 U	0.48 U
ICS - NWC Site Wells:									
ICS-DOFMW6-W-022719	GW-mon. well								
ICS-MWEU-W-022719	GW-mon. well								
ICS - NWC Downgradient Wells:									
ICS-DOFFU-W-022819	GW-mon. well	**5.2 J**	0.48 U	0.48 U	0.48 U	0.48 U	**1.6 J_B**	0.48 U	0.48 U
ICS-DOFGU-W-022819	GW-mon. well	**10 J**	0.53 U	0.48 U	0.48 U	0.48 U	**2.4 J**	0.48 U	0.48 U
ICS-SAMW3-W-022719	GW-mon. well	**15 J**	0.48 U	0.48 U	0.48 U	0.48 U	**4.1 J**	0.48 U	0.48 U
ICS-MWIL-W-022719	GW-mon. well	**19 J**	0.49 U	0.49 U	0.49 U	0.49 U	**3.6 J**	0.49 U	**0.87 J**
Trip Blank									
Method Blank 4-22-19		3.3 J	0.50 U	0.50 U	0.50 U	0.63 J	1.1 J	0.50 U	0.50 U

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J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.

U = nondetected at the associated lower reporting limit.

Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,3,3',4,5'(2',3,4,5,5')-PeCB [108+124] 70362-41-3 / 70424-70-3 pg/L	2,3,3',4',6(2,3,4,4',6)-PeCB [110+115] 38380-03-9 / 74472-38-1 pg/L	2,3,3',5,5'-PeCB [111] 39635-32-0 pg/L	2,3,3',5,6-PeCB [112] 74472-36-9 pg/L	2,3,4,4',5-PeCB [114] * 74472-37-0 pg/L	2,3',4,4',5-PeCB [118] * 31508-00-6 pg/L	2,3',4,5,5'-PeCB [120] 68194-12-7 pg/L	2,3',4,5',6-PeCB [121] 56558-18-0 pg/L	2',3,3',4,5-PeCB [122] 76842-07-4 pg/L	2',3,4,4',5-PeCB [123] * 65510-44-3 pg/L	3,3',4,4',5-PeCB [126] * 57465-28-8 pg/L
Douglas Management Property Shoreline Wells:												
DMC-MW13-W-022619	GW-mon. well											
DMC-MW14-W-022519	GW-mon. well	**0.98 J**	**75**	0.47 U	0.47 U	**0.51 J**	**34**	0.47 U	0.47 U	0.47 U	**0.57 J**	0.47 U
DMC-MW14-W-022719	GW-mon. well											
DMC-MW15-W-022519	GW-mon. well	**1.5 J**	**134**	0.48 U	0.48 U	**0.50 J**	**33**	**0.59 J**	0.48 U	0.48 U	**0.66 J**	0.48 U
DMC-MW15-W-022719	GW-mon. well											
DMC-MWA-W-022619	GW-mon. well											
DMC-MWB-W-022619	GW-mon. well											
DMC-MWC-W-022519	GW-mon. well	**2.2 J**	**149**	0.48 U	0.48 U	**1.3 J**	**59**	**1.1 J**	0.48 U	**0.63 J**	**1.2 J**	0.50 U
DMC-MWC-W-022719	GW-mon. well											
ICS - NWC Upgradient Wells:												
ICS-DOFMW3-W-022819	GW-mon. well	0.48 U	**4.9 J**	0.48 U	0.48 U	0.48 U	**3.1 J_B**	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U
ICS-DOFMW5-W-022819	GW-mon. well	0.48 U	**3.6 J_B**	0.48 U	0.48 U	0.48 U	**2.8 J_B**	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U
ICS - NWC Site Wells:												
ICS-DOFMW6-W-022719	GW-mon. well											
ICS-MWEU-W-022719	GW-mon. well											
ICS - NWC Downgradient Wells:												
ICS-DOFFU-W-022819	GW-mon. well	0.48 U	**6.1 J**	0.48 U	0.48 U	0.48 U	**4.5 J**	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U
ICS-DOFGU-W-022819	GW-mon. well	**1.0 J**	**7.5 J**	0.48 U	0.48 U	0.48 U	**3.9 J**	0.48 U	0.48 U	0.48 U	0.50 U	0.52 U
ICS-SAMW3-W-022719	GW-mon. well	0.48 U	**16 J**	0.48 U	0.48 U	0.48 U	**7.0 J**	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U
ICS-MWIL-W-022719	GW-mon. well	0.49 U	**17 J**	0.49 U	0.49 U	0.49 U	**11 J**	0.49 U	0.49 U	0.49 U	0.49 U	0.49 U
Trip Blank												
Method Blank 4-22-19		0.50 U	2.4 J	0.50 U	0.50 U	0.50 U	1.7 J	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.
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U = nondetected at the associated lower reporting limit.

Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	3,3',4,5,5'-PeCB [127] 39635-33-1 pg/L	2,2',3,3',4,4'(2,3,4,4',5,6)-HxCB [128+166] 38380-07-3 / 41411-63-6 pg/L	2,2',3,3',4,5(2,2',3,4,4',5')(2,3,3',4,5,6)(2,3,3',4',5,6)-HxCB [129+138+160+163] 55215-18-4 / 35065-28-2 / 41411-62-5 / 74472-44-9 pg/L	2,2',3,3',4,5'-HxCB [130] 52663-66-8 pg/L	2,2',3,3',4,6-HxCB [131] 61798-70-7 pg/L	2,2',3,3',4,6'-HxCB [132] 38380-05-1 pg/L	2,2',3,3',5,5'-HxCB [133] 35694-04-3 pg/L	2,2',3,3',5,6(2,2',3,4,5,6')-HxCB [134+143] 52704-70-8 / 68194-14-9 pg/L
Douglas Management Property Shoreline Wells:									
DMC-MW13-W-022619	GW-mon. well								
DMC-MW14-W-022519	GW-mon. well	0.47 U	**5.5 J**	**46**	**2.8 J**	0.56 U	**31**	**1.8 J**	**2.9 J**
DMC-MW14-W-022719	GW-mon. well								
DMC-MW15-W-022519	GW-mon. well	0.48 U	**3.6 J**	**30**	**2.5 J**	0.48 U	**20**	**1.0 J**	**3.9 J**
DMC-MW15-W-022719	GW-mon. well								
DMC-MWA-W-022619	GW-mon. well								
DMC-MWB-W-022619	GW-mon. well								
DMC-MWC-W-022519	GW-mon. well	0.48 U	**5.7 J**	**44**	**3.4 J**	**0.99 J**	**24**	**1.5 J**	**4.7 J**
DMC-MWC-W-022719	GW-mon. well								
ICS - NWC Upgradient Wells:									
ICS-DOFMW3-W-022819	GW-mon. well	0.48 U	**1.1 J_B**	**6.0 J**	0.60 U	0.56 U	**2.3 J**	0.54 U	0.56 U
ICS-DOFMW5-W-022819	GW-mon. well	0.48 U	**1.2 J_B**	**4.7 J_B**	0.48 U	0.48 U	**1.6 J**	0.48 U	0.48 U
ICS - NWC Site Wells:									
ICS-DOFMW6-W-022719	GW-mon. well								
ICS-MWEU-W-022719	GW-mon. well								
ICS - NWC Downgradient Wells:									
ICS-DOFFU-W-022819	GW-mon. well	0.48 U	**1.3 J_B**	**8.7 J**	0.57 U	0.53 U	**2.9 J**	0.52 U	0.53 U
ICS-DOFGU-W-022819	GW-mon. well	0.48 U	**1.4 J_B**	**15 J**	0.74 U	0.68 U	**3.8 J**	0.67 U	0.69 U
ICS-SAMW3-W-022719	GW-mon. well	0.48 U	**3.3 J**	**22**	**0.77 J**	0.48 U	**5.5 J**	0.48 U	**1.2 J**
ICS-MWIL-W-022719	GW-mon. well	0.49 U	**3.9 J**	**65**	**2.6 J**	**0.68 J**	**24**	**1.2 J**	**3.2 J**
Trip Blank									
Method Blank 4-22-19		0.50 U	0.77 J	2.7 J	0.50 U	0.50 U	0.51 J	0.50 U	0.50 U

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.
J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.
U = nondetected at the associated lower reporting limit.

Field I.D.	Matrix	2,2',3,3',5,6'(2,2',3,5,5',6)(2,2',4,4',5,6')-HxCB [135+151+154] 52744-13-5 / 52663-63-5 / 60145-22-4 pg/L	2,2',3,3',6,6'-HxCB [136] 38411-22-2 pg/L	2,2',3,4,4',5-HxCB [137] 35694-06-5 pg/L	2,2',3,4,4',6(2,2',3,4,4',6')-HxCB [139+140] 56030-56-9 / 59291-64-4 pg/L	2,2',3,4,5,5'-HxCB [141] 52712-04-6 pg/L	2,2',3,4,5,6-HxCB [142] 41411-61-4 pg/L	2,2',3,4,5',6-HxCB [144] 68194-14-9 pg/L	2,2',3,4,6,6'-HxCB [145] 74472-40-5 pg/L	2,2',3,4',5,5'-HxCB [146] 51908-16-8 pg/L	2,2',3,4',5,6(2,2',3,4',5',6)-HxCB [147+149] 56030-56-9 / 59291-64-4 pg/L
Douglas Management Property Shoreline Wells:											
DMC-MW13-W-022619	GW-mon. well										
DMC-MW14-W-022519	GW-mon. well	**29**	**9.3 J**	**1.5 J**	**1.2 J**	**7.4 J**	0.62 U	**2.0 J**	0.47 U	**11 J**	**53**
DMC-MW14-W-022719	GW-mon. well										
DMC-MW15-W-022519	GW-mon. well	**31**	**17 J**	**1.1 J**	**1.3 J**	**7.2 J**	0.48 U	**2.5 J**	0.48 U	**9.5 J**	**59**
DMC-MW15-W-022719	GW-mon. well										
DMC-MWA-W-022619	GW-mon. well										
DMC-MWB-W-022619	GW-mon. well										
DMC-MWC-W-022519	GW-mon. well	**34**	**18 J**	**1.7 J**	**1.3 J**	**13 J**	0.48 U	**2.8 J**	0.48 U	**15 J**	**62**
DMC-MWC-W-022719	GW-mon. well										
ICS - NWC Upgradient Wells:											
ICS-DOFMW3-W-022819	GW-mon. well	**2.4 J**	**0.72 J**	0.54 U	0.50 U	**1.8 J**	0.55 U	0.48 U	0.48 U	**1.6 J**	**4.8 J**
ICS-DOFMW5-W-022819	GW-mon. well	**2.3 J**	**0.66 J**	0.48 U	0.48 U	**0.73 J**	0.48 U	0.48 U	0.48 U	**0.70 J**	**2.9 J_B**
ICS - NWC Site Wells:											
ICS-DOFMW6-W-022719	GW-mon. well										
ICS-MWEU-W-022719	GW-mon. well										
ICS - NWC Downgradient Wells:											
ICS-DOFFU-W-022819	GW-mon. well	**2.6 J**	**0.75 J**	0.51 U	0.48 U	**5.1 J**	0.52 U	0.48 U	0.48 U	**1.9 J**	**4.6 J**
ICS-DOFGU-W-022819	GW-mon. well	**10 J**	**1.9 J**	0.66 U	0.61 U	**12 J**	0.67 U	**0.77 J**	0.48 U	**4.6 J**	**15 J**
ICS-SAMW3-W-022719	GW-mon. well	**5.1 J**	**2.0 J**	**0.86 J**	0.48 U	**4.2 J**	0.48 U	0.48 U	0.48 U	**3.2 J**	**13 J**
ICS-MWIL-W-022719	GW-mon. well	**45**	**13 J**	0.49 U	0.49 U	**22**	0.49 U	**5.0 J**	0.49 U	**14 J**	**78**
Trip Blank											
Method Blank 4-22-19		0.80 J	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	1.8 J

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.
J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.
U = nondetected at the associated lower reporting limit.

Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,2',3,4',5,6'-HxCB [148] 74472-41-6 pg/L	2,2',3,4',6,6'-HxCB [150] 68194-08-1 pg/L	2,2',3,5,6,6'-HxCB [152] 68194-09-2 pg/L	2,2',4,4',5,5'(2,3',4,4',5',6)-HxCB [153+168] 35065-27-1 / 59291-65-5 pg/L	2,2',4,4',6,6'-HxCB [155] 33979-03-2 pg/L	2,3,3',4,4',5(2,3,3',4,4',5')-HxCB [156+157] * 38380-08-4 / 69782-90-7 pg/L	2,3,3',4,4',6-HxCB [158] 74472-42-7 pg/L	2,3,3',4,5,5'-HxCB [159] 39635-35-3 pg/L	2,3,3',4,5',6-HxCB [161] 74472-43-8 pg/L	2,3,3',4',5,5'-HxCB [162] 39635-34-2 pg/L	2,3,3',4',5',6-HxCB [164] 74472-45-0 pg/L
Douglas Management Property Shoreline Wells:												
DMC-MW13-W-022619	GW-mon. well											
DMC-MW14-W-022519	GW-mon. well	0.47 U	0.47 U	0.47 U	**61**	0.47 U	**2.9 J**	**2.9 J**	0.47 U	0.47 U	0.47 U	**3.2 J**
DMC-MW14-W-022719	GW-mon. well											
DMC-MW15-W-022519	GW-mon. well	0.48 U	**0.65 J**	0.48 U	**43**	0.48 U	**2.6 J**	**2.6 J**	0.48 U	0.48 U	0.48 U	**2.7 J**
DMC-MW15-W-022719	GW-mon. well											
DMC-MWA-W-022619	GW-mon. well											
DMC-MWB-W-022619	GW-mon. well											
DMC-MWC-W-022519	GW-mon. well	0.48 U	**0.66 J**	0.48 U	**83**	0.48 U	**8.8 J**	**4.0 J**	0.48 U	0.48 U	0.48 U	**4.1 J**
DMC-MWC-W-022719	GW-mon. well											
ICS - NWC Upgradient Wells:												
ICS-DOFMW3-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	**7.8 J**	0.48 U	**0.98 J**	**0.66 J**	0.48 U	0.48 U	0.48 U	**0.67 J**
ICS-DOFMW5-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	**4.3 J_B**	0.48 U	**0.72 J**	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U
ICS - NWC Site Wells:												
ICS-DOFMW6-W-022719	GW-mon. well											
ICS-MWEU-W-022719	GW-mon. well											
ICS - NWC Downgradient Wells:												
ICS-DOFFU-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	**26**	0.48 U	**1.4 J**	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U
ICS-DOFGU-W-022819	GW-mon. well	0.63 U	0.48 U	0.48 U	**40**	0.48 U	**1.4 J**	**1.1 J**	0.48 U	0.48 U	0.49 U	**0.75 J**
ICS-SAMW3-W-022719	GW-mon. well	0.48 U	0.48 U	0.48 U	**20**	0.48 U	**1.8 J**	**1.2 J**	0.48 U	0.48 U	0.48 U	**1.8 J**
ICS-MWIL-W-022719	GW-mon. well	0.49 U	0.49 U	0.49 U	**96**	0.49 U	**3.3 J**	**5.1 J**	0.49 U	0.49 U	**0.82 J**	**5.3 J**
Trip Blank												
Method Blank 4-22-19		0.50 U	0.50 U	0.50 U	2.7 J	0.62 J	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.
J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.
U = nondetected at the associated lower reporting limit.

Remedial Investigation

ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA

Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,3,3',5,5',6-HxCB [165] 74472-46-1 pg/L	2,3',4,4',5,5'-HxCB [167] * 52663-72-6 pg/L	3,3',4,4',5,5'-HxCB [169] * 32774-16-6 pg/L	2,2',3,3',4,4',5-HpCB [170] 35065-30-6 pg/L	2,2',3,3',4,4',6(2,2',3,3',4,5,6)-HpCB [171+173] 52663-71-5 / 68194-16-1 pg/L	2,2',3,3',4,5,5'-HpCB [172] 52663-74-8 pg/L	2,2',3,3',4,5,6'-HpCB [174] 38411-25-5 pg/L	2,2',3,3',4,5',6-HpCB [175] 40186-70-7 pg/L	2,2',3,3',4,6,6'-HpCB [176] 52663-65-7 pg/L	2,2',3,3',4',5,6-HpCB [177] 52663-70-4 pg/L	2,2',3,3',5,5',6-HpCB [178] 52663-67-9 pg/L
Douglas Management Property Shoreline Wells:												
DMC-MW13-W-022619	GW-mon. well											
DMC-MW14-W-022519	GW-mon. well	0.47 U	**1.5 J**	0.47 U	**6.6 J**	**2.2 J**	**1.4 J**	**8.3 J**	0.47 U	**1.2 J**	**8.2 J**	**2.7 J**
DMC-MW14-W-022719	GW-mon. well											
DMC-MW15-W-022519	GW-mon. well	0.48 U	**0.72 J**	0.48 U	**3.2 J**	**1.5 J**	**0.82 J**	**5.6 J**	0.48 U	**0.68 J**	**3.7 J**	**1.3 J**
DMC-MW15-W-022719	GW-mon. well											
DMC-MWA-W-022619	GW-mon. well											
DMC-MWB-W-022619	GW-mon. well											
DMC-MWC-W-022519	GW-mon. well	0.48 U	**3.5 J**	0.48 U	**14 J**	**2.1 J**	**1.8 J**	**7.6 J**	0.48 U	**1.1 J**	**4.2 J**	**1.8 J**
DMC-MWC-W-022719	GW-mon. well											
ICS - NWC Upgradient Wells:												
ICS-DOFMW3-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	**2.5 J**	**0.73 J**	0.56 U	**2.6 J**	0.48 U	0.48 U	**2.1 J**	0.49 U
ICS-DOFMW5-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	**1.9 J**	**0.67 J**	0.48 U	**1.3 J**	0.48 U	0.48 U	**0.95 J_B**	0.48 U
ICS - NWC Site Wells:												
ICS-DOFMW6-W-022719	GW-mon. well											
ICS-MWEU-W-022719	GW-mon. well											
ICS - NWC Downgradient Wells:												
ICS-DOFFU-W-022819	GW-mon. well	0.48 U	**1.9 J**	0.48 U	**15 J**	0.54 U	**4.6 J**	**1.5 J**	0.48 U	0.48 U	**3.0 J**	0.48 U
ICS-DOFGU-W-022819	GW-mon. well	0.54 U	**1.3 J**	0.52 U	**9.5 J**	**2.2 J**	**1.6 J**	**9.5 J**	0.49 U	**1.0 J**	**3.8 J**	**2.3 J**
ICS-SAMW3-W-022719	GW-mon. well	0.48 U	**0.88 J**	0.48 U	**6.3 J**	**1.6 J**	**1.4 J**	**7.1 J**	0.48 U	0.48 U	**2.9 J**	**1.2 J**
ICS-MWIL-W-022719	GW-mon. well	0.49 U	**1.1 J**	0.49 U	**16 J**	**6.8 J**	**3.6 J**	**26**	**1.1 J**	**3.5 J**	**13 J**	**6.6 J**
Trip Blank												
Method Blank 4-22-19		0.50 U	0.50 U	0.50 U	0.82 J	0.50 U	0.50 U	0.50 U	0.48 U	0.48 U	0.52 J	0.48 U

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.

J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.

U = nondetected at the associated lower reporting limit.

Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,2',3,3',5,6,6'- HpCB [179] 52663-64-6 pg/L	2,2',3,4,4',5,5'(2,3,3',4',5,5',6)- HpCB [180+193] 35065-29-3 / 69782-91-8 pg/L	2,2',3,4,4',5,6- HpCB [181] 74472-47-2 pg/L	2,2',3,4,4',5,6'- HpCB [182] 60145-23-5 pg/L	2,2',3,4,4',5',6(2,2',3,4,5,5',6)- HpCB [183+185] 52663-69-1 / 52712-05-7 pg/L	2,2',3,4,4',6,6'- HpCB [184] 74472-48-3 pg/L	2,2',3,4,5,6,6'- HpCB [186] 74472-49-4 pg/L	2,2',3,4',5,5',6- HpCB [187] 52663-68-0 pg/L	2,2',3,4',5,6,6'- HpCB [188] 74487-85-7 pg/L	2,3,3',4,4',5,5'- HpCB [189] * 39635-31-9 pg/L
Douglas Management Property Shoreline Wells:											
DMC-MW13-W-022619	GW-mon. well										
DMC-MW14-W-022519	GW-mon. well	**4.9 J**	**21**	0.47 U	0.47 U	**5.4 J**	0.47 U	0.47 U	**14 J**	0.47 U	0.47 U
DMC-MW14-W-022719	GW-mon. well										
DMC-MW15-W-022519	GW-mon. well	**3.0 J**	**14**	0.48 U	0.48 U	**2.9 J**	0.48 U	0.48 U	**7.2 J**	0.48 U	0.48 U
DMC-MW15-W-022719	GW-mon. well										
DMC-MWA-W-022619	GW-mon. well										
DMC-MWB-W-022619	GW-mon. well										
DMC-MWC-W-022519	GW-mon. well	**4.3 J**	**86**	0.48 U	0.48 U	**4.7 J**	0.48 U	0.48 U	**9.7 J**	0.48 U	**1.6 J**
DMC-MWC-W-022719	GW-mon. well										
ICS - NWC Upgradient Wells:											
ICS-DOFMW3-W-022819	GW-mon. well	**0.83 J**	**9.2 J**	0.50 U	0.48 U	**1.9 J**	0.48 U	0.48 U	**3.6 J**	0.48 U	0.48 U
ICS-DOFMW5-W-022819	GW-mon. well	0.48 U	**5.5 J**	0.48 U	0.48 U	**0.76 J_B**	0.48 U	0.48 U	**1.8 J_B**	0.48 U	0.48 U
ICS - NWC Site Wells:											
ICS-DOFMW6-W-022719	GW-mon. well										
ICS-MWEU-W-022719	GW-mon. well										
ICS - NWC Downgradient Wells:											
ICS-DOFFU-W-022819	GW-mon. well	**0.69 J**	**109**	0.50 U	0.48 U	**1.6 J**	0.48 U	0.48 U	**2.4 J**	0.48 U	**3.7 J**
ICS-DOFGU-W-022819	GW-mon. well	**3.6 J**	**44**	0.53 U	0.49 U	**6.2 J**	0.48 U	0.48 U	**13 J**	0.48 U	0.48 U
ICS-SAMW3-W-022719	GW-mon. well	**1.7 J**	**18 J**	0.48 U	0.48 U	**3.5 J**	0.48 U	0.48 U	**6.9 J**	0.48 U	0.48 U
ICS-MWIL-W-022719	GW-mon. well	**15 J**	**54**	0.49 U	0.49 U	**19 J**	0.49 U	0.49 U	**35**	0.49 U	0.49 U
Trip Blank											
Method Blank 4-22-19		0.48 U	2.5 J	0.50 U	0.50 U	0.58 J	0.50 U	0.50 U	1.1 J	0.50 U	0.50 U

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.
J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.
U = nondetected at the associated lower reporting limit.

Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,3,3',4,4',5,6-HpCB [190] 41411-64-7 pg/L	2,3,3',4,4',5',6-HpCB [191] 74472-50-7 pg/L	2,3,3',4,5,5',6-HpCB [192] 74472-51-8 pg/L	2,2',3,3',4,4',5,5'-OcCB [194] 35694-08-7 pg/L	2,2',3,3',4,4',5,6-OcCB [195] 52663-78-2 pg/L	2,2',3,3',4,4',5,6'-OcCB [196] 42740-50-1 pg/L	2,2',3,3',4,4',6,6'(2,2',3,3',4,5,6,6')-OcCB [197+200] 33091-17-7 / 52663-73-7 pg/L	2,2',3,3',4,5,5',6(2,2',3,3',4,5,5',6)-OcCB [198+199] 68194-17-2 / 52663-75-9 pg/L
Douglas Management Property Shoreline Wells:									
DMC-MW13-W-022619	GW-mon. well								
DMC-MW14-W-022519	GW-mon. well	**1.1 J**	0.47 U	0.47 U	**2.9 J**	**1.3 J**	**1.0 J**	**0.55 J**	**3.1 J**
DMC-MW14-W-022719	GW-mon. well								
DMC-MW15-W-022519	GW-mon. well	**0.64 J**	**0.49 J**	0.48 U	**1.4 J**	**0.58 J**	0.48 U	0.48 U	**1.8 J**
DMC-MW15-W-022719	GW-mon. well								
DMC-MWA-W-022619	GW-mon. well								
DMC-MWB-W-022619	GW-mon. well								
DMC-MWC-W-022519	GW-mon. well	**1.4 J**	0.48 U	0.48 U	**4.2 J**	**1.4 J**	**1.5 J**	**0.90 J**	**3.6 J**
DMC-MWC-W-022719	GW-mon. well								
ICS - NWC Upgradient Wells:									
ICS-DOFMW3-W-022819	GW-mon. well	**0.52 J**	0.48 U	0.48 U	**1.9 J**	**0.80 J**	0.74 U	0.55 U	**1.7 J**
ICS-DOFMW5-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	**0.72 J**	0.48 U	**0.66 J**	0.48 U	**1.2 J**
ICS - NWC Site Wells:									
ICS-DOFMW6-W-022719	GW-mon. well								
ICS-MWEU-W-022719	GW-mon. well								
ICS - NWC Downgradient Wells:									
ICS-DOFFU-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	**17 J**	**0.54 J**	**0.74 J**	0.49 U	**2.4 J**
ICS-DOFGU-W-022819	GW-mon. well	**1.6 J**	0.48 U	0.48 U	**9.0 J**	**3.3 J**	**3.3 J**	**1.2 J**	**8.1 J**
ICS-SAMW3-W-022719	GW-mon. well	**1.1 J**	0.48 U	0.48 U	**2.5 J**	**1.0 J**	**1.7 J**	**0.74 J**	**3.2 J**
ICS-MWIL-W-022719	GW-mon. well	**3.5 J**	**0.95 J**	0.49 U	**6.3 J**	**2.9 J**	**3.7 J**	**2.0 J**	**8.1 J**
Trip Blank									
Method Blank 4-22-19		0.50 U	0.50 U	0.50 U	0.54 J	0.50 U	0.54 U	0.50 U	0.59 U

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.

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U = nondetected at the associated lower reporting limit.

Remedial Investigation
ICS / [former] NW Cooperage and Douglas Management Property, Seattle, WA
Supplemental GW monitoring, February 2019

Field I.D.	Matrix	2,2',3,3',4,5',6,6'- OcCB [201] 40186-71-8 pg/L	2,2',3,3',5,5',6,6'- OcCB [202] 2136-99-4 pg/L	2,2',3,4,4',5,5',6- OcCB [203] 52663-76-0 pg/L	2,2',3,4,4',5,6,6'- OcCB [204] 74472-52-9 pg/L	2,3,3',4,4',5,5',6- OcCB [205] 74472-53-0 pg/L	2,2',3,3',4,4',5,5',6- NoCB [206] 40186-72-9 pg/L	2,2',3,3',4,4',5,6,6'- NoCB [207] 52663-79-3 pg/L	2,2',3,3',4,5,5',6,6'- NoCB [208] 52663-77-1 pg/L	2,2',3,3',4,4',5,5',6,6'- DeCB [209] 2051-24-3 pg/L
Douglas Management Property Shoreline Wells:										
DMC-MW13-W-022619	GW-mon. well									
DMC-MW14-W-022519	GW-mon. well	**1.1 J**	**0.71 J**	**2.1 J**	0.47 U	0.47 U	**1.4 J**	0.65 U	0.68 U	**2.5 J_B**
DMC-MW14-W-022719	GW-mon. well									
DMC-MW15-W-022519	GW-mon. well	0.48 U	0.48 U	**1.1 J**	0.48 U	0.48 U	0.84 U	0.59 U	0.61 U	**1.1 J_B**
DMC-MW15-W-022719	GW-mon. well									
DMC-MWA-W-022619	GW-mon. well									
DMC-MWB-W-022619	GW-mon. well									
DMC-MWC-W-022519	GW-mon. well	**0.55 J**	**0.62 J**	**2.2 J**	0.48 U	0.48 U	**2.5 J**	0.48 U	**1.0 J**	**4.0 J**
DMC-MWC-W-022719	GW-mon. well									
ICS - NWC Upgradient Wells:										
ICS-DOFMW3-W-022819	GW-mon. well	0.55 U	0.57 U	**0.74 J**	0.55 U	0.48 U	1.5 U	0.96 U	0.97 U	**0.88 J_B**
ICS-DOFMW5-W-022819	GW-mon. well	0.48 U	0.48 U	0.48 U	0.48 U	0.48 U	0.79 U	0.51 U	0.53 U	**0.96 J_B**
ICS - NWC Site Wells:										
ICS-DOFMW6-W-022719	GW-mon. well									
ICS-MWEU-W-022719	GW-mon. well									
ICS - NWC Downgradient Wells:										
ICS-DOFFU-W-022819	GW-mon. well	0.50 U	0.52 U	**3.3 J**	0.50 U	**0.51 J**	**2.3 J**	0.54 U	0.57 U	**0.67 J_B**
ICS-DOFGU-W-022819	GW-mon. well	**1.0 J**	**1.6 J**	**5.9 J**	0.50 U	0.53 U	**5.0 J**	0.71 U	**0.85 J**	**0.93 J_B**
ICS-SAMW3-W-022719	GW-mon. well	0.48 U	**0.62 J**	**1.4 J**	0.48 U	0.48 U	**1.7 J**	0.58 U	**0.61 J**	**2.2 J_B**
ICS-MWIL-W-022719	GW-mon. well	**1.0 J**	**1.7 J**	**4.5 J**	0.49 U	0.49 U	**1.9 J**	0.49 U	0.49 U	**0.93 J_B**
Trip Blank										
Method Blank 4-22-19		0.50 U	0.50 U	0.53 U	0.50 U	0.50 U	0.92 U	0.63 U	0.63 U	1.61 J

J = estimate associated with value less than the verifiable lower quantitation limit (LOQ), and may be an upper limit due to chemical interference.

J_B = estimate; associated value is likely biased with contribution from sampling/laboratory background or method blank.

U = nondetected at the associated lower reporting limit.

	PCB's TEQ (WHO-2005 TEF)		
	pg/L	pg/L	pg/L
Douglas Management Property Shoreline Wells:			
DMC-MW14-W-022519	0.00149	0.0321	0.0628
DMC-MW15-W-022519	0.00151	0.0328	0.0641
DMC-MWC-W-022519	0.00292	0.0352	0.0675
ICS - NWC Upgradient Wells:			
ICS-DOFMW3-W-022819	0.000182	0.0315	0.0628
ICS-DOFMW5-W-022819	0.000151	0.0315	0.0628
ICS - NWC Downgradient Wells:			
ICS-DOFFU-W-022819	0.000393	0.0317	0.0630
ICS-DOFGU-W-022819	0.000270	0.0342	0.0681
ICS-SAMW3-W-022719	0.000523	0.0318	0.0631
ICS-MWIL-W-022719	0.000638	0.0326	0.0645
Method Blank 4-22-19	0.0000840	0.0327	0.0654
	ND(U)=0 for TEQ calculation.	ND(U)=0.5 x value for TEQ calculation.	ND(U) value applied to TEQ calculation.

D.M.D., Inc.
Environmental & Toxicological Services
13706 SW Caster Road, Vashon, WA 98070-7428 (206) 463-6223 email: dmdinc111@gmail.com

MEMORANDUM

TO: Matt Dalton (DOF)

FROM: Raleigh Farlow

DATE: March 29, 2020

SUBJECT: Derivation of PCB/Aroclor Equilibrium Partition Coefficients for Use at the ICS/[former] Northwest Cooperage Site, Seattle, WA

Per your request, an explanation and "walk through" of how Aroclor K_{oc}'s were developed from current and updated physicochemical data is presented here. The approach employed utilizes information presented and described in *Geochemical Assessment of PCB's at the ICS/[former] Northwest Cooperage Site, Seattle, WA – ADDENDUM*, dated May 16, 2019, from R. Farlow (DMD) to M. Dalton (DOF). The Geochemical Assessment (DMD 2019) relies on three technical documents available in the scientific literature, specifically:

- Di Toro, D.M., 1985. A particle interaction model of reversible organic chemical sorption. *Chemosphere* 14(10): 1503-1538. (Determination of the relationship between PCB K_{ow} and K_{oc}.)
- Frame, G.M., Cochran, J.W., and Boewadt, S.S., 1996. Complete PCB congener distributions for 17 Aroclor mixtures determined by 3 HRGC systems optimized for comprehensive, quantitative congener-specific analyses. *J. High Res. Chromatogr.* 19, 657-668. (Determination of PCB congener and homolog compositions of Aroclors.)
- IARC 2016. World Health Organization – International Agency for Research on Cancer Monograph 107, Polychlorinated Biphenyls and Polybrominated Biphenyls. (Comprehensive and up-to-date resource for environmental exposures, biological effects, and chemical/physical characteristics of PCB's. Presentation of log(K_{ow})'s for all 209 PCB congeners.)

A variety of historical documents and Agency guidances have presented physicochemical data and thermodynamic partition constants/factors for use in describing environmental behaviors, fates and distributions of PCB's. A review of current and modern technical literature was performed to determine and evaluate critical physicochemical data for use in understanding and characterizing PCB's behavior at the ICS/Northwest Cooperage site. Environmental PCB's data at the ICS/NWC site are reported and expressed in terms of Aroclors and individual PCB congeners concentrations in multiple matrix types (groundwaters, surface waters, soils, and estuarine sediments). Source area and contaminated media characterizations at the site have determined that commercial PCB mixtures as Aroclors (Aroclor 1248, Aroclor 1254 and Aroclor 1260) are readily recognized as the primary contaminants of concern.

Pertinent characteristics of PCB's and Aroclors are described under *Characteristics of PCB's* (DMD 2019, pg. 1-2) and Table 1 in DMD (2019). Aroclor compositions have been determined by Frame et al. (1996) and are summarized by PCB homolog content in Table 1. Mean log(K_{ow})'s for each homolog group are presented in the attached Table, entitled *PCB homologs partition factors*, and are derived from Table 1.3 of IARC 107 (2016). The IARC treatise presents log(K_{ow})'s for all 209 individual PCB congeners. Thus, the mean log(K_{ow}) for each homolog group is calculated by averaging the log(K_{ow})'s for all congeners within each respective group (found in Table 1.3 of IARC 107 (2016)). For example, in the case of monochlorobiphenyls, three congener log(K_{ow})'s (4.46, 4.69, and 4.69) were averaged to yield a mean log(K_{ow}) of 4.61, which is summarized in the attached Table *PCB homologs partition factors*. This process was performed for all ten homolog groups and presented in *PCB homologs partition factors*. The associated homolog group mean log(K_{oc})'s found in *PCB homologs partition factors* are derived from the relationship developed and described by Di Toro (1985) as the following (see pg. 6 in DMD 2019):

$$\log(K_{oc}) = 0.00028 + 0.983 \times \log(K_{ow})$$

Thus, in the case of pentachlorobiphenyls (PCBP):

$$\log(K_{oc})_{PCBP} = 0.00028 + 0.983 \times 6.40 = 6.29$$

Calculation of a mean K_{oc} for each Aroclor is performed by determining a weighted log(K_{oc}) by relative proportion of homolog group in each Aroclor (from Table 1). In the case of Aroclor 1254:

$$\log(K_{oc})_{Aroclor\ 1254} = 0.0024x5.00 + 0.0126x5.46 + 0.1025x5.88 + 0.5912x6.29 + 0.2676x6.68 + 0.0266x7.05 + 0.0004x7.39 + 0.0004x7.72 = 6.35$$

The mean K_{oc} for Aroclor 1254 is determined to be: $10^{6.35}$ or 10^(6.35) = 2,247,362

Consequently, mean K_{oc}'s for the three Aroclors of concern at this site are estimated to be the following:

Aroclor 1248 mean K_{oc} = 863,337
Aroclor 1254 mean K_{oc} = 2,247,362
Aroclor 1260 mean K_{oc} = 7,708,355

These Aroclor K_{oc}'s are greater than those recommended in previous guidances (using older and historical data) by factors of 9-35x. The effect of site modifiers on actual K_{oc}'s and Kd's are presented and described in DMD 2019. The use of the [greater] Aroclor K_{oc}'s developed using updated PCB's thermal equilibrium data and factors yields dissolved aqueous and solids' PCB concentrations consistent with those reported in site media.

Table 1.

Characteristics of PCB Homolog Groups and Weight Percent in Aroclors

PCB Homolog Group	Formula	# of Congeners	% Cl by wt.	log(Kow)	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260
1	$C_{12}H_9Cl$	3	18.79	4.46 - 4.69	0.75	0.07		0.02
2	$C_{12}H_8Cl_2$	12	31.77	4.65 - 5.30	15.04	1.55	0.24	0.08
3	$C_{12}H_7Cl_3$	24	41.30	5.02 - 5.89	44.91	21.27	1.26	0.21
4	$C_{12}H_6Cl_4$	42	48.65	5.53 - 6.48	20.16	32.77	10.25	0.35
5	$C_{12}H_5Cl_5$	46	54.30	5.71 - 6.95	18.85	42.92	59.12	8.74
6	$C_{12}H_4Cl_6$	42	58.93	6.22 - 7.42	0.31	1.64	26.76	43.35
7	$C_{12}H_3Cl_7$	24	62.77	6.69 - 7.71		0.02	2.66	38.54
8	$C_{12}H_2Cl_8$	12	65.98	7.20 - 8.00			0.04	8.27
9	$C_{12}HCl_9$	3	68.73	7.71 - 8.09			0.04	0.70
10	$C_{12}Cl_{10}$	1	71.10	8.18				

from IARC 2016

	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260
% Chlorine by Weight:	42	48	54	60
Average # of Chlorine Atoms per Molecule:	3	4	5	6

from Frame et al. 1996

PCB homologs partition factors

Chlorinated biphenyl homologs		Mean log(Kow) *	Mean log(Koc) **	Kd (L/kg) @ 2% foc
Monochlorobiphenyls	Cl-1	4.61	4.54	686
Dichlorobiphenyls	Cl-2	5.09	5.00	2,019
Trichlorobiphenyls	Cl-3	5.55	5.46	5,715
Tetrachlorobiphenyls	Cl-4	5.98	5.88	15,137
Pentachlorobiphenyls	Cl-5	6.40	6.29	39,267
Hexachlorobiphenyls	Cl-6	6.80	6.68	95,726
Heptachlorobiphenyls	Cl-7	7.17	7.05	223,373
Octachlorobiphenyls	Cl-8	7.52	7.39	493,208
Nonachlorobiphenyls	Cl-9	7.85	7.72	1,042,389
Decachlorobiphenyl	Cl-10	8.18	8.04	2,198,012

* calculated mean from IARC 107 (2016)

** from Di Toro (1985)

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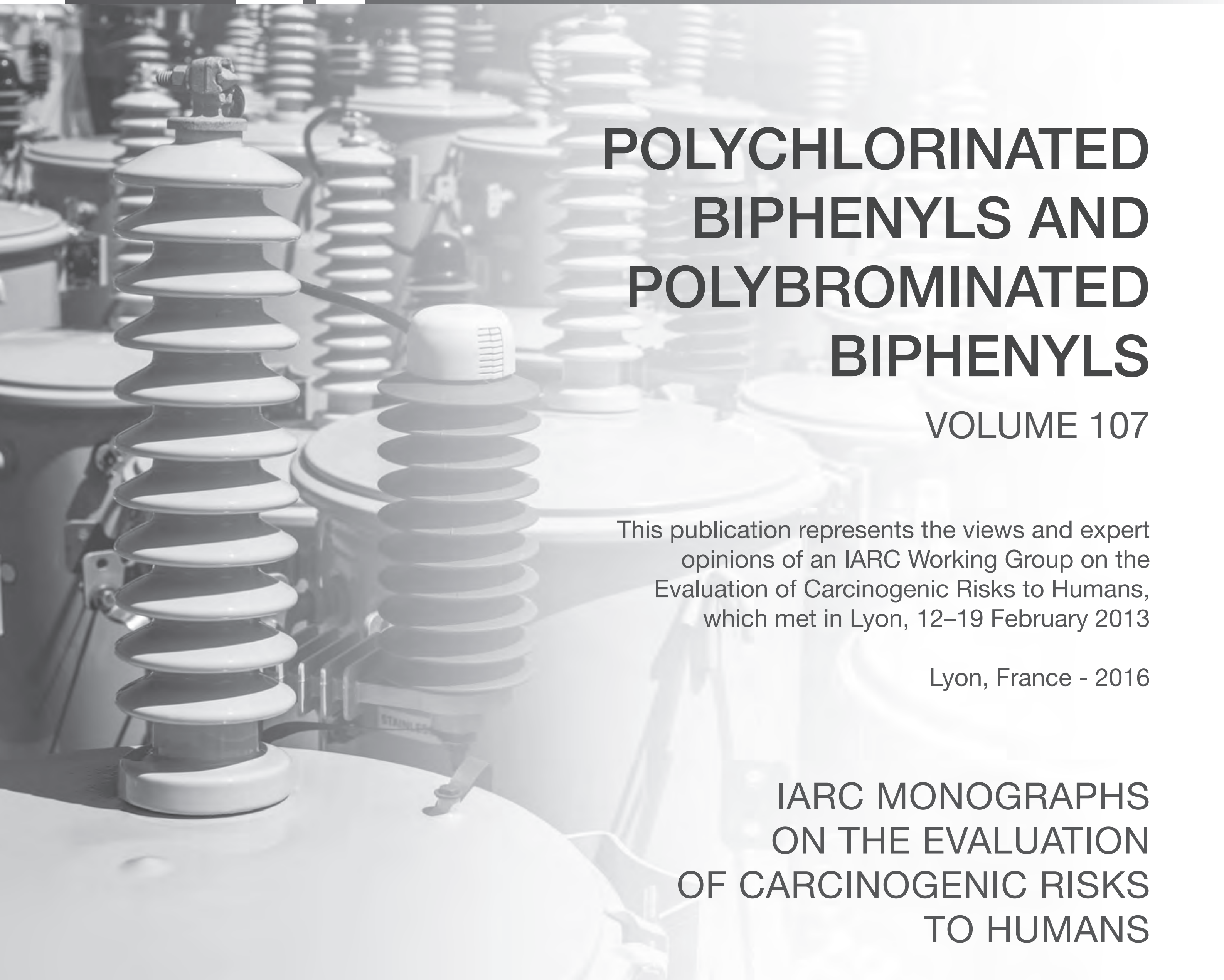


POLYCHLORINATED BIPHENYLS AND POLYBROMINATED BIPHENYLS

VOLUME 107

This publication represents the views and expert
opinions of an IARC Working Group on the
Evaluation of Carcinogenic Risks to Humans,
which met in Lyon, 12–19 February 2013

Lyon, France - 2016

IARC MONOGRAPHS
ON THE EVALUATION
OF CARCINOGENIC RISKS
TO HUMANS

International Agency for Research on Cancer
World Health Organization

Table 1.3 Relationship between BZ number, CAS number, IUPAC name,[a] congener descriptor, and log K_{ow} for individual PCBs

BZ No.	IUPAC name	CAS No.	Descriptor[b]	Log K_{ow}	Vapour pressure (atm at 25 °C)[c]
1	2-CB	2051-60-7	CP1	4.46	
2	3-CB	2051-61-8	CP0	4.69	
3	4-CB	2051-62-9	CP0	4.69	
4	2,2′-DiCB	13029-08-8		4.65	1.5 to 4.2×10^{-6}
5	2,3-DiCB	16605-91-7	CP1	4.97	
6	2,3′-DiCB	25569-80-6	CP1	5.06	
7	2,4-DiCB	33284-50-3	CP1	5.07	9.9×10^{-7} to 2.1×10^{-6}
8	2,4′-DiCB	34883-43-7	CP1	5.07	
9	2,5-DiCB	34883-39-1	CP1	5.06	2.0 to 2.3×10^{-6}
10	2,6-DiCB	33146-45-1		4.84	
11	3,3′-DiCB	2050-67-1	CP0, 2M	5.28	4.1 to 9.1×10^{-7}
12	3,4-DiCB	2974-92-7	CP0	5.22	1.3×10^{-8} to 7.8×10^{-7}
13	3,4′-DiCB	2974-90-5	CP0	5.29	
14	3,5-DiCB	34883-41-5	CP0, 2M	5.28	
15	4,4′-DiCB	2050-68-2	CP0, PP	5.30	5.0 to 7.4×10^{-7}
16	2,2′,3-TriCB	38444-78-9		5.16	
17	2,2′,4-TriCB	37680-66-3		5.25	
18	2,2′,5-TriCB	37680-65-2		5.24	3.5×10^{-7} to 1.2×10^{-6}
19	2,2′,6-TriCB	38444-73-4		5.02	
20	2,3,3′-TriCB	38444-84-7	CP1, 2M	5.57	
21	2,3,4-TriCB	55702-46-0	CP1	5.51	
22	2,3,4′-TriCB	38444-85-8	CP1	5.58	
23	2,3,5-TriCB	55720-44-0	CP1, 2M	5.57	
24	2,3,6-TriCB	55702-45-9		5.35	
25	2,3′,4-TriCB	55712-37-3	CP1	5.67	
26	2,3′,5-TriCB	38444-81-4	CP1, 2M	5.66	1.8 to 4.5×10^{-7}
27	2,3′,6-TriCB	38444-76-7		5.44	
28	2,4,4′-TriCB	7012-37-5	CP1, PP	5.67	1.5 to 3.3×10^{-7}
29	2,4,5-TriCB	15862-07-4	CP1	5.60	
30	2,4,6-TriCB	35693-92-6		5.44	9.3×10^{-7} to 1.5×10^{-6}
31	2,4′,5-TriCB	16606-02-3	CP1	5.67	
32	2,4′,6-TriCB	38444-77-8		5.44	
33	2,3′,4′-TriCB	38444-86-9	CP1	5.60	
34	2,3′,5′-TriCB	37680-68-5	CP1, 2M	5.66	
35	3,3′,4-TriCB	37680-69-6	CP0, 2M	5.82	
36	3,3′,5-TriCB	38444-87-0	CP0, 2M	5.88	
37	3,4,4′-TriCB	38444-90-5	CP0, PP	5.83	
38	3,4,5-TriCB	53555-66-1	CP0, 2M	5.76	
39	3,4′,5-TriCB	38444-88-1	CP0, 2M	5.89	
40	2,2′,3,3′-TetraCB	38444-93-8	4CL, 2M	5.66	4.5×10^{-8} to 1.1×10^{-7}
41	2,2′,3,4-TetraCB	52663-59-9	4CL	5.69	
42	2,2′,3,4′-TetraCB	36559-22-5	4CL	5.76	
43	2,2′,3,5-TetraCB	70362-46-8	4CL, 2M	5.75	
44	2,2′,3,5′-TetraCB	41464-39-5	4CL, 2M	5.75	

Table 1.3 (continued)

BZ No.	IUPAC name	CAS No.	Descriptor[b]	Log K_{ow}	Vapour pressure (atm at 25 °C)[c]
45	2,2′,3,6-TetraCB	70362-45-7	4CL	5.53	
46	2,2′,3,6′-TetraCB	41464-47-5	4CL	5.53	
47	2,2′,4,4′-TetraCB	2437-79-8	4CL, PP	5.85	
48	2,2′,4,5-TetraCB	70362-47-9	4CL	5.78	
49	2,2′,4,5′-TetraCB	41464-40-8	4CL	5.85	
50	2,2′,4,6-TetraCB	62796-65-0	4CL	5.63	
51	2,2′,4,6′-TetraCB	68194-04-7	4CL	5.63	
52	2,2′,5,5′-TetraCB	35693-99-3	4CL, 2M	5.84	1.8 to 8.9 × 10^{-7}
53	2,2′,5,6′-TetraCB	41464-41-9	4CL	5.62	1.1 to 4.0 × 10^{-7}
54	2,2′,6,6′-TetraCB	15968-05-5	4CL	5.21	1.2 × 10^{-6} to 6.5 × 10^{-7}
55	2,3,3′,4-TetraCB	74338-24-2	CP1, 4CL, 2M	6.11	
56	2,3,3′,4′-TetraCB	41464-43-1	CP1, 4CL, 2M	6.11	
57	2,3,3′,5-TetraCB	70424-67-8	CP1, 4CL, 2M	6.17	
58	2,3,3′,5′-TetraCB	41464-49-7	CP1, 4CL, 2M	6.17	
59	2,3,3′,6-TetraCB	74472-33-6	4CL, 2M	5.95	
60	2,3,4,4′-TetraCB	33025-41-1	CP1, 4CL, PP	6.11	
61	2,3,4,5-TetraCB	33284-53-6	CP1, 4CL, 2M	6.04	
62	2,3,4,6-TetraCB	54230-22-7	4CL	5.89	
63	2,3,4′,5-TetraCB	74472-34-7	CP1, 4CL, 2M	6.17	
64	2,3,4′,6-TetraCB	52663-58-8	4CL	5.95	
65	2,3,5,6-TetraCB	33284-54-7	4CL, 2M	5.86	
66	2,3′,4,4′-TetraCB	32598-10-0	CP1, 4CL, PP	6.20	
67	2,3′,4,5-TetraCB	73575-53-8	CP1, 4CL, 2M	6.20	
68	2,3′,4,5′-TetraCB	73575-52-7	CP1, 4CL, 2M	6.26	
69	2,3′,4,6-TetraCB	60233-24-1	4CL	6.04	
70	2,3′,4′,5-TetraCB	32598-11-1	CP1, 4CL, 2M	6.20	
71	2,3′,4′,6-TetraCB	41464-46-4	4CL	5.98	
72	2,3′,5,5′-TetraCB	41464-42-0	CP1, 4CL, 2M	6.26	
73	2,3′,5′,6-TetraCB	74338-23-1	4CL, 2M	6.04	
74	2,4,4′,5-TetraCB	32690-93-0	CP1, 4CL, PP	6.20	
75	2,4,4′,6-TetraCB	32598-12-2	4CL, PP	6.05	
76	2,3′,4′,5′-TetraCB	70362-48-0	CP1, 4CL, 2M	6.13	
77	3,3′,4,4′-TetraCB	32598-13-3	**CP0, 4CL, PP, 2M**	6.36	5.2 × 10^{-9} to 2.1 × 10^{-8}
78	3,3′,4,5-TetraCB	70362-49-1	CP0, 4CL, 2M	6.35	
79	3,3′,4,5′-TetraCB	41464-48-6	CP0, 4CL, 2M	6.42	
80	3,3′,5,5′-TetraCB	33284-52-5	CP0, 4CL, 2M	6.48	
81	3,4,4′,5-TetraCB	70362-50-4	**CP0, 4CL, PP, 2M**	6.36	
82	2,2′,3,3′,4-PentaCB	52663-62-4	4CL, 2M	6.20	
83	2,2′,3,3′,5-PentaCB	60145-20-2	4CL, 2M	6.26	
84	2,2′,3,3′,6-PentaCB	52663-60-2	4CL, 2M	6.04	
85	2,2′,3,4,4′-PentaCB	65510-45-4	4CL, PP	6.30	
86	2,2′,3,4,5-PentaCB	55312-69-1	4CL, 2M	6.23	
87	2,2′,3,4,5′-PentaCB	38380-02-8	4CL, 2M	6.29	
88	2,2′,3,4,6-PentaCB	55215-17-3	4CL	6.07	
89	2,2′,3,4,6′-PentaCB	73575-57-2	4CL	6.07	

Table 1.3 (continued)

BZ No.	IUPAC name	CAS No.	Descriptor[b]	Log K_{ow}	Vapour pressure (atm at 25 °C)[c]
90	2,2′,3,4′,5-PentaCB	68194-07-0	4CL, 2M	6.36	
91	2,2′,3,4′,6-PentaCB	68194-05-8	4CL	6.13	
92	2,2′,3,5,5′-PentaCB	52663-61-3	4CL, 2M	6.35	
93	2,2′,3,5,6-PentaCB	73575-56-1	4CL, 2M	6.04	
94	2,2′,3,5,6′-PentaCB	73575-55-0	4CL, 2M	6.13	
95	2,2′,3,5′,6-PentaCB	38379-99-6	4CL, 2M	6.13	
96	2,2′,3,6,6′-PentaCB	73575-54-9	4CL	5.71	
97	2,2′,3,4′,5′-PentaCB	41464-51-1	4CL, 2M	6.29	
98	2,2′,3,4′,6′-PentaCB	60233-25-2	4CL	6.13	
99	2,2′,4,4′,5-PentaCB	38380-01-7	4CL, PP	6.39	
100	2,2′,4,4′,6-PentaCB	39485-83-1	4CL, PP	6.23	
101	2,2′,4,5,5′-PentaCB	37680-73-2	4CL, 2M	6.38	1.4 to 3.5×10^{-8}
102	2,2′,4,5,6′-PentaCB	68194-06-9	4CL	6.16	
103	2,2′,4,5′,6-PentaCB	60145-21-3	4CL	6.22	
104	2,2′,4,6,6′-PentaCB	56558-16-8	4CL	5.81	4.3×10^{-8} to 1.7×10^{-7}
105	2,3,3′,4,4′-PentaCB	32598-14-4	**CP1, 4CL, PP, 2M**	6.65	8.6×10^{-9}
106	2,3,3′,4,5-PentaCB	70424-69-0	CP1, 4CL, 2M	6.64	
107	2,3,3′,4,5′-PentaCB	70424-68-9	CP1, 4CL, 2M	6.71	
108	2,3,3′,4,6-PentaCB	70362-41-3	4CL, 2M	6.72	
109	2,3,3′,4′,5-PentaCB	74472-35-8	CP1, 4CL, 2M	6.48	
110	2,3,3′,4′,6-PentaCB	38380-03-9	4CL, 2M	6.48	
111	2,3,3′,5,5′-PentaCB	39635-32-0	CP1, 4CL, 2M	6.76	
112	2,3,3′,5,6-PentaCB	74472-36-9	4CL, 2M	6.45	
113	2,3,3′,5′,6-PentaCB	68194-10-5	4CL, 2M	6.54	
114	2,3,4,4′,5-PentaCB	74472-37-0	**CP1, 4CL, PP, 2M**	6.65	
115	2,3,4,4′,6-PentaCB	74472-38-1	4CL, PP	6.49	
116	2,3,4,5,6-PentaCB	18259-05-7	4CL, 2M	6.33	
117	2,3,4′,5,6-PentaCB	68194-11-6	4CL, 2M	6.46	
118	2,3′,4,4′,5-PentaCB	31508-00-6	**CP1, 4CL, PP, 2M**	6.74	1.2×10^{-8}
119	2,3′,4,4′,6-PentaCB	56558-17-9	4CL, PP	6.58	
120	2,3′,4,5,5′-PentaCB	68194-12-7	CP1, 4CL, 2M	6.79	
121	2,3′,4,5′,6-PentaCB	56558-18-0	4CL, 2M	6.64	
122	2,3,3′,4′,5′-PentaCB	76842-07-4	CP1, 4CL, 2M	6.64	
123	2,3′,4,4′,5′-PentaCB	65510-44-3	**CP1, 4CL, PP, 2M**	6.74	
124	2,3′,4′,5,5′-PentaCB	70424-70-3	CP1, 4CL, 2M	6.73	
125	2,3′,4′,5′,6-PentaCB	74472-39-2	4CL, 2M	6.51	
126	3,3′,4,4′,5-PentaCB	57465-28-8	**CP0, 4CL, PP, 2M**	6.89	
127	3,3′,4,5,5′-PentaCB	39635-33-1	CP0, 4CL, 2M	6.95	
128	2,2′,3,3′,4,4′-HexaCB	38380-07-3	4CL, PP, 2M	6.74	1.0 to 3.6×10^{-9}
129	2,2′,3,3′,4,5-HexaCB	55215-18-4	4CL, 2M	6.73	
130	2,2′,3,3′,4,5′-HexaCB	52663-66-8	4CL, 2M	6.80	
131	2,2′,3,3′,4,6-HexaCB	61798-70-7	4CL, 2M	6.58	
132	2,2′,3,3′,4,6′-HexaCB	38380-05-1	4CL, 2M	6.58	
133	2,2′,3,3′,5,5′-HexaCB	35694-04-3	4CL, 2M	6.86	
134	2,2′,3,3′,5,6-HexaCB	52704-70-8	4CL, 2M	6.55	

Table 1.3 (continued)

BZ No.	IUPAC name	CAS No.	Descriptor[b]	Log K_{ow}	Vapour pressure (atm at 25 °C)[c]
135	2,2′,3,3′,5,6′-HexaCB	52744-13-5	4CL, 2M	6.64	
136	2,2′,3,3′,6,6′-HexaCB	38411-22-2	4CL, 2M	6.22	
137	2,2′3,4,4′,5-HexaCB	35694-06-5	4CL, PP, 2M	6.83	
138	2,2′,3,4,4′,5′-HexaCB	35065-28-2	4CL, PP, 2M	6.83	5.2×10^{-9}
139	2,2′,3,4,4′,6-HexaCB	56030-56-9	4CL, PP	6.67	
140	2,2′,3,4,4′,6′-HexaCB	59291-64-4	4CL, PP	6.67	
141	2,2′,3,4,5,5′-HexaCB	52712-04-6	4CL, 2M	6.82	
142	2,2′,3,4,5,6-HexaCB	41411-61-4	4CL, 2M	6.51	
143	2,2′,3,4,5,6′-HexaCB	68194-15-0	4CL, 2M	6.60	
144	2,2′,3,4,5′,6-HexaCB	68194-14-9	4CL, 2M	6.67	
145	2,2′,3,4,6,6′-HexaCB	74472-40-5	4CL	6.25	
146	2,2′,3,4′,5,5′-HexaCB	51908-16-8	4CL, 2M	6.89	
147	2,2′,3,4′,5,6-HexaCB	68194-13-8	4CL, 2M	6.64	
148	2,2′,3,4′,5,6′-HexaCB	74472-41-6	4CL, 2M	6.73	
149	2,2′,3,4′,5′,6-HexaCB	38380-04-0	4CL, 2M	6.67	
150	2,2′,3,4′,6,6′-HexaCB	68194-08-1	4CL	6.32	
151	2,2′,3,5,5′,6-HexaCB	52663-63-5	4CL, 2M	6.64	
152	2,2′,3,5,6,6′-HexaCB	68194-09-2	4CL, 2M	6.22	
153	2,2′,4,4′,5,5′-HexaCB	35065-27-1	4CL, PP, 2M	6.92	1.9×10^{-9} to 6.9×10^{-8}
154	2,2′,4,4′,5,6′-HexaCB	60145-22-4	4CL, PP	6.76	
155	2,2′,4,4′,6,6′-HexaCB	33979-03-2	4CL, PP	6.41	3.5×10^{-9} to 4.4×10^{-8}
156	2,3,3′,4,4′,5-HexaCB	38380-08-4	**CP1, 4CL, PP, 2M**	7.18	2.1×10^{-9}
157	2,3,3′,4,4′,5′-HexaCB	69782-90-7	**CP1, 4CL, PP, 2M**	7.18	
158	2,3,3′,4,4′,6-HexaCB	74472-42-7	4CL, PP, 2M	7.02	
159	2,3,3′,4,5,5′-HexaCB	39635-35-3	CP1, 4CL, 2M	7.24	
160	2,3,3′,4,5,6-HexaCB	41411-62-5	4CL, 2M	6.93	
161	2,3,3′,4,5′,6-HexaCB	74472-43-8	4CL, 2M	7.08	
162	2,3,3′,4′,5,5′-HexaCB	39635-34-2	CP1, 4CL, 2M	7.24	
163	2,3,3′,4′,5,6-HexaCB	74472-44-9	4CL, 2M	6.99	7.9×10^{-10}
164	2,3,3′,4′,5′,6-HexaCB	74472-45-0	4CL, 2M	7.02	
165	2,3,3′,5,5′,6-HexaCB	74472-46-1	4CL, 2M	7.05	
166	2,3,4,4′,5,6-HexaCB	41411-63-6	4CL, PP, 2M	6.93	
167	2,3′,4,4′,5,5′-HexaCB	52663-72-6	**CP1, 4CL, PP, 2M**	7.27	
168	2,3′,4,4′,5′,6-HexaCB	59291-65-5	4CL, PP, 2M	7.11	
169	3,3′,4,4′,5,5′-HexaCB	32774-16-6	**CP0, 4CL, PP, 2M**	7.42	7.9×10^{-10}
170	2,2′,3,3′,4,4′,5-HeptaCB	35065-30-6	4CL, PP, 2M	7.27	
171	2,2′,3,3′,4,4′,6-HeptaCB	52663-71-5	4CL, PP, 2M	7.11	
172	2,2′,3,3′,4,5,5′-HeptaCB	52663-74-8	4CL, 2M	7.33	
173	2,2′,3,3′,4,5,6-HeptaCB	68194-16-1	4CL, 2M	7.02	
174	2,2′,3,3′,4,5,6′-HeptaCB	38411-25-5	4CL, 2M	7.11	
175	2,2′,3,3′,4,5′,6-HeptaCB	40186-70-7	4CL, 2M	7.17	
176	2,2′,3,3′,4,6,6′-HeptaCB	52663-65-7	4CL, 2M	6.76	
177	2,2′,3,3′,4,5′,6′-HeptaCB	52663-70-4	4CL, 2M	7.08	
178	2,2′,3,3′,5,5′,6-HeptaCB	52663-67-9	4CL, 2M	7.14	
179	2,2′,3,3′,5,6,6′-HeptaCB	52663-64-6	4CL, 2M	6.73	

Table 1.3 (continued)

BZ No.	IUPAC name	CAS No.	Descriptor[b]	Log K_{ow}	Vapour pressure (atm at 25 °C)[c]
180	2,2′,3,4,4′,5,5′-HeptaCB	35065-29-3	4CL, PP, 2M	7.36	1.3×10^{-9}
181	2,2′,3,4,4′,5,6-HeptaCB	74472-47-2	4CL, PP, 2M	7.11	
182	2,2′,3,4,4′,5,6′-HeptaCB	60145-23-5	4CL, PP, 2M	7.20	
183	2,2′,3,4,4′,5′,6-HeptaCB	52663-69-1	4CL, PP, 2M	7.20	
184	2,2′,3,4,4′,6,6′-HeptaCB	74472-48-3	4CL, PP	6.85	
185	2,2′,3,4,5,5′,6-HeptaCB	52712-05-7	4CL, 2M	7.11	
186	2,2′,3,4,5,6,6′-HeptaCB	74472-49-4	4CL, 2M	6.69	
187	2,2′,3,4′,5,5′,6-HeptaCB	52663-68-0	4CL, 2M	7.17	
188	2,2′,3,4′,5,6,6′-HeptaCB	74487-85-7	4CL, 2M	6.82	
189	2,3,3′,4,4′,5,5′-HeptaCB	39635-31-9	**CP1, 4CL, PP, 2M**	7.71	
190	2,3,3′,4,4′,5,6-HeptaCB	41411-64-7	4CL, PP, 2M	7.46	
191	2,3,3′,4,4′,5′,6-HeptaCB	74472-50-7	4CL, PP, 2M	7.55	
192	2,3,3′,4,5,5′,6-HeptaCB	74472-51-8	4CL, 2M	7.52	
193	2,3,3′,4′,5,5′,6-HeptaCB	69782-91-8	4CL, 2M	7.52	
194	2,2′,3,3′,4,4′,5,5′-OctaCB	35694-08-7	4CL, PP, 2M	7.80	
195	2,2′,3,3′,4,4′,5,6-OctaCB	52663-78-2	4CL, PP, 2M	7.56	
196	2,2′,3,3′,4,4′,5,6′-OctaCB	42740-50-1	4CL, PP, 2M	7.65	
197	2,2′,3,3′,4,4′,6,6′-OctaCB	33091-17-7	4CL, PP, 2M	7.30	
198	2,2′,3,3′,4,5,5′,6-OctaCB	68194-17-2	4CL, 2M	7.62	
199	2,2′,3,3′,4,5,5′,6′-OctaCB	52663-75-9	4CL, 2M	7.62	
200	2,2′,3,3′,4,5,6,6′-OctaCB	52663-73-7	4CL, 2M	7.20	
201	2,2′,3,3′,4,5′,6,6′-OctaCB	40186-71-8	4CL, 2M	7.27	
202	2,2′,3,3′,5,5′,6,6′-OctaCB	2136-99-4	4CL, 2M	7.24	
203	2,2′,3,4,4′,5,5′,6-OctaCB	52663-76-0	4CL, PP, 2M	7.65	
204	2,2′,3,4,4′,5,6,6′-OctaCB	74472-52-9	4CL, PP, 2M	7.30	
205	2,3,3′,4,4′,5,5′,6-OctaCB	74472-53-0	4CL, PP, 2M	8.00	
206	2,2′,3,3′,4,4′,5,5′,6-NonaCB	40186-72-9	4CL, PP, 2M	8.09	
207	2,2′,3,3′,4,4′,5,6,6′-NonaCB	52663-79-3	4CL, PP, 2M	7.74	
208	2,2′,3,3′,4,5,5′,6,6′-NonaCB	52663-77-1	4CL, 2M	7.71	
209	2,2′,3,3′,4,4′,5,5′,6,6′-DecaCB	2051-24-3	4CL, PP, 2M	8.18	

[a] The nomenclature in this table adheres to the IUPAC rules and thus primed and unprimed numbers may be interchanged compared with Table 1.1. Please see text for more details.

[b] Congener descriptors (CP0, CP1, 4Cl, PP, 2M) have been given where relevant; they give rapid access to geometry and substituent positions. 68 coplanar congeners fall into one of two groups CP0 or CP1.

The first group of 20 congeners consists of those without chlorine substitution at any of the "*ortho*" positions on the biphenyl backbone and are referred to as CP0 or non-"*ortho*" congeners. The second group of 48 congeners includes those with chlorine substitution at only one of the "*ortho*" positions and are referred to as CP1 or mono-"*ortho*" congeners. 175 congeners have a total of four or more chlorine substituents, regardless of position (4Cl). 54 congeners have both "*para*" positions chlorinated (PP). 146 congeners have two or more of the "*meta*" positions chlorinated (2M). The twelve congeners that have all four of the congener descriptors are referred to as being "dioxin-like," and are indicated in bold type.

In ATSDR (2000), PCB-63 was mistakenly attributed the CAS number of a pentachlorobiphenyl; for Henry's law constants, vapour pressure and solubility of most individual congeners, the reader is referred to Dunnivant & Elzerman (1988) and references within.

[c] Vapour pressures have been indicated for a selection of individual congeners.

BZ, Ballschmiter and Zell; CAS, Chemical Abstracts Service; CB, chlorinated biphenyl; IUPAC, International Union of Pure and Applied Chemistry

From Dunnivant & Elzerman (1988), ATSDR (2000), Mills *et al.* (2007), and Lindell (2012)

APPENDIX C
LAND USE MEMORANDUM
DOF – JUNE 14, 2019

FEASIBILITY STUDY REPORT
ICS/NWC RI/FS
SEATTLE, WASHINGTON

Dalton, Olmsted & Fuglevand, Inc.

DALTON
OLMSTED
FUGLEVAND

6034 N. Star Rd., Ferndale, Washington 98248
Telephone (cell) – (206) 498-6616

MEMORANDUM

TO: Vicki Sutton – Department of Ecology

FROM: Matt Dalton

DATE: June 14, 2019

SUBJECT: Land Use
ICS-NWC RI/FS
Seattle, Washington

REF. NO: SUM-003(FS)

CC: Ralph Palumbo – Yarmuth Wilsdon
Steve Thiele – Thiele Law

We prepared this memorandum to request information from Ecology concerning the land use that will be assumed for the upland portions of the site to prepare the Feasibility Study (FS). Land use affects cleanup levels to protect site workers via the soil exposure (direct contact) pathway and potentially terrestrial ecologic receptors. We understand that other factors also affect soil cleanup levels, such as to protect surface water via leaching/groundwater migration, that are not tied to land use. However, these latter factors are evaluated separately using different assumptions. It is our opinion that the site meets the definition of an industrial property under the Model Toxics Control Act (Chapter 173-340 WAC).

MTCA section WAC 173-340-200 defines an industrial property as follows:

*"**Industrial properties** means properties that are or have been characterized by, or are to be committed to, traditional industrial uses such as processing or manufacturing of materials, marine terminal and transportation areas and facilities, manufactured products, or storage of bulk materials, that are either:*

- *Zoned for industrial use by a city or county conducting land use planning under chapter 36.70A RCW (Growth Management Act); or*
- *For counties not planning under chapter 36.70A RCW (Growth Management Act) and the cities within them, zoned for industrial use and adjacent properties currently used or designated for industrial purposes."*

The site meets the first criterion because it has been continuously used since at least WWII for industrial purposes and lies well within an area that the City has designated for industrial use, the Greater Duwamish Manufacturing/Industrial (D/MI) Center area, based on review of the Seattle

2035 Comprehensive Plan (see Attachment A – Future Land Use Map). This plan was prepared as required by the Growth Management Act. One of the stated goals for the D/MI in the Seattle plan is:

> *"Land in the Duwamish Manufacturing/Industrial Center is maintained for industrial uses including manufacture, assembly, storage, repair, distribution, research about or development of tangible materials and advanced technologies; as well as transportation, utilities, and commercial fishing activities" (p. 311).*

As noted above, the present uses of the upland portions of the property are industrial in nature. The King County tax assessors web site indicates that manufacturing is the highest and best use if the property were vacant. Zoning, present use, and best use as developed are as follows for the upland parcels:

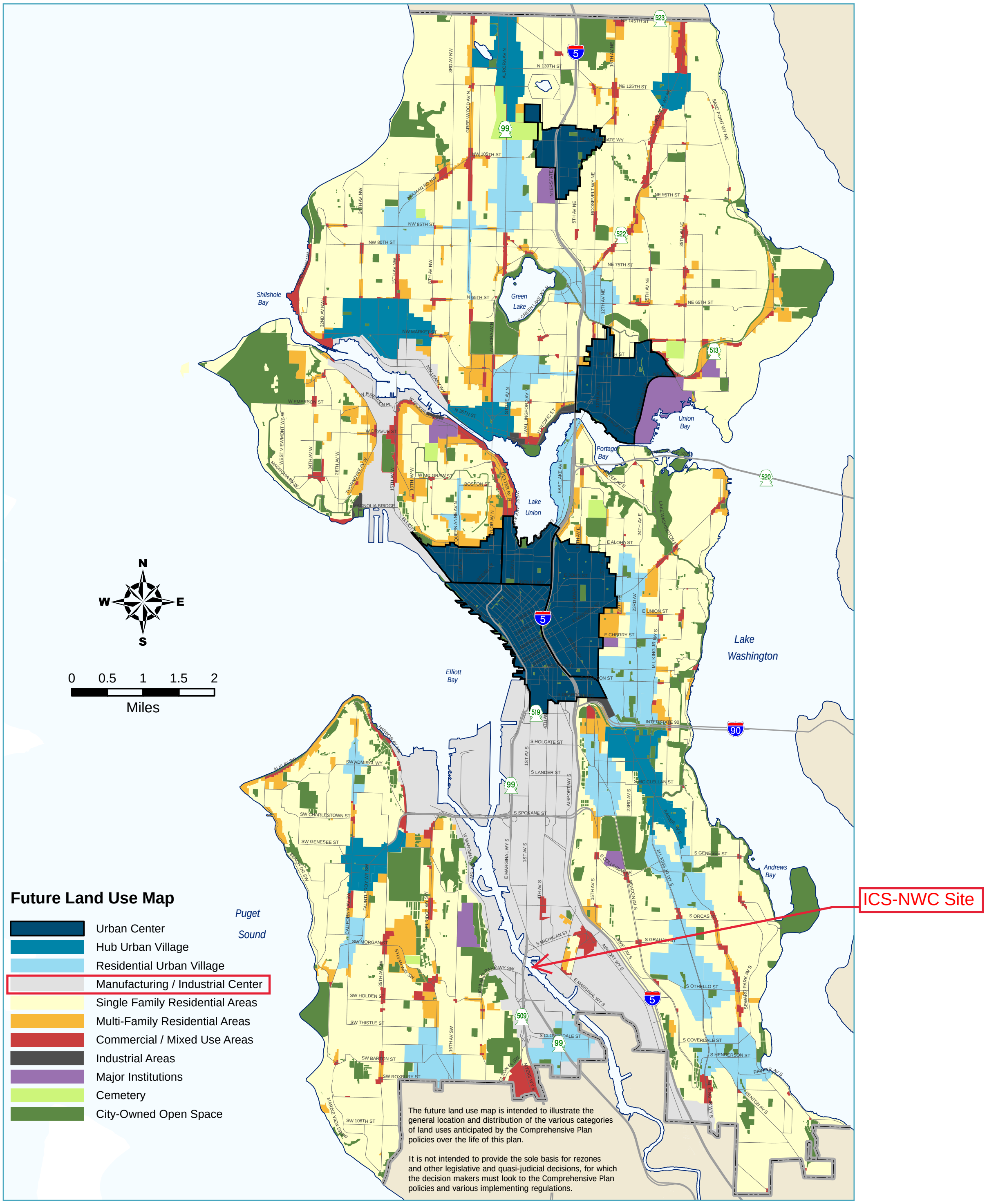
Parcel	Zoning	Present Use	Best Use	Comment
292404-9108	IG1	Vacant Industrial	Present Use	Embayment Parcel
292404-9030	IG1	Industrial(Gen. Purpose)		Main Parcel
292404-9004	IG2			South Parcel

IG1 and IG2 are industrial zoning designations. Typical land uses in these areas are general and heavy manufacturing, commercial uses, subject to some limits, high impact uses as a conditional use, institutional uses in existing buildings, entertainment uses other than adult, transportation and utility services, and salvage and recycling areas.

Summary: Under MTCA, the site meets the definition of an industrial property and there are no indications of possible non-industrial use under any criteria germane to the issue under the MTCA rules. Therefore, industrial cleanup levels outlined in WAC 173-340-745 apply and can be used to develop and evaluate cleanup alternatives in the FS to assess protectiveness via the direct contact and terrestrial ecologic exposure pathways.

Attachment – Seattle 2035 Future Land Use Map

Future Land Use Map



The future land use map is intended to illustrate the general location and distribution of the various categories of land uses anticipated by the Comprehensive Plan policies over the life of this plan.

It is not intended to provide the sole basis for rezones and other legislative and quasi-judicial decisions, for which the decision makers must look to the Comprehensive Plan policies and various implementing regulations.

Attachment A

APPENDIX E
POTENTIAL FOR VAPOR INTRUSION MEMORANDUM
DOF – OCTOBER 13, 2021

FEASIBILITY STUDY REPORT
ICS/NWC RI/FS
SEATTLE, WASHINGTON

Dalton, Olmsted & Fuglevand, Inc.

DALTON
OLMSTED
FUGLEVAND

6034 N. Star Rd., Ferndale, Washington 98248
Telephone (cell) – (206) 498-6616

TECHNICAL MEMORANDUM

TO: Vicki Sutton – Department of Ecology

FROM: Matt Dalton – Sr. Principal Hydrogeologist

RE: Potential for Vapor Concentration Exceedances by Subsurface
Vapor Intrusion (VI)
ICS Main Production Building

DATE: October 13, 2021

CC: Ralph Palumbo
Ken Bloch
Adam Trotsky
Steve Thiele
Dave Cooper

Ref: ICS Main Build Vapor MM 10-13-21.docx

This technical memorandum was prepared to transmit requested photographs of the main ICS production building to Ecology to document the openness of the building to ambient air-exchange/airflow. With this submittal, DOF took the opportunity to provide additional information related to possible subsurface vapor intrusion (VI) into the building to provide a more comprehensive conceptual site model (CSM). The central issue is whether contamination beneath and in the immediate vicinity of the building poses a risk to site industrial workers from vapors that could migrate upward through the building floor slab.

In general, risks posed by VI are associated with several factors as follows:

- Volatile contamination of soil and groundwater beneath and in the immediate vicinity of the building (i.e., source materials),
- Potential upward vapor migration pathways through the concrete flow slab (e.g., cracks/joints), and
- Air exchange (with outside air) and air flow (mixing) within the building.

Each of these factors is discussed below.

Volatile Contamination

The volatile chemicals of potential concern (COPCv) at the site include the following:

- Gasoline- and diesel-range hydrocarbons.
- Aromatic hydrocarbons (benzene, toluene, ethylbenzene and xylenes); and
- Solvents (tetrachloroethene – PCE, trichloroethene – TCE; cis-1,2-dichloroethene – cis-1,2-DCE; and vinyl chloride (VC).

Most of the COPCvs are petroleum constituents. Ecology guidance (Ecology 2018) states in Section 5.2 (p. 8): "*In general, the vast majority of sites that meet the Method A soil and groundwater cleanup levels* [CULs] *will be protective of the PVI* [petroleum vapor intrusion] *pathway, both now and if a building is constructed in the future*."[i] To provide perspective, available data for locations within and adjacent to the ICS main production building were summarized (attached Table 1 [soil data] and Table 2 [groundwater data]. These data are from the draft Remedial Investigation (RI) Report (DOF 2020). Sample locations are presented on Figure 1.

Most of the soil data is from the vadose zone. The depth to the water table, based on measurements made in wells MW-Ap, MW-Bp and MW-Cp ranges between 4.2 and 6.8 feet below existing grade. Groundwater flow direction estimates indicate the north and east walls of the building are downgradient with respect to groundwater flow. A comparison of Method A soil CULs to protect groundwater with the soil concentrations (Table 1) indicates only one soil concentration above CULs, benzene at P12 (35 ug/kg at 3-4.5'). Concentrations of PCE, TCE, cis-1,2-DCE and VC were well below CULs.

Table 2 summarizes available groundwater data. The groundwater concentrations are compared to Method C (industrial) groundwater screening levels (SLs from CLARC – updated February 2021) protective of the vapor intrusion pathway. The benzene groundwater concentration at P12 (48 ug/l vs. SL= 24 ug/l) exceeds the SL. The soil and groundwater comparisons suggest that benzene has the potential to be of concern via the vapor intrusion pathway based solely on source concentrations. Other factors are discussed below.

Vapor Migration Through the Floor Slab

The building interior is covered with a 4" concrete floor slab that appears to be in generally good condition. Upward vapor migration could occur through cracks and expansion joints between concrete panels. Given the condition of floor, it is expected that upward vapor migration would be minimal, although it cannot be ruled out.

Building Condition (air exchange and air-flow - mixing)

The main production building is an open space approximately 20,000 square feet in area with a 20-foot-high ceiling. It is an unheated well-ventilated space used to recondition used drums, and paint reconditioned/new drums. The walls of the building are perforated with large loading dock

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[i] We understand that this statement assumes a residential structure with normal air exchange and airflow within the building. Such structures are heated and sealed to a large degree to prevent the loss of heat during the winter months.

type doors that are rarely closed. Even if closed, there would be substantial air exchange/flow as the doors are not sealed as is typical for unheated industrial structures. In contrast, most heated spaces, regardless of use, are sealed to a far greater degree. The SLs assume heated sealed spaces.

Figure 2 generally illustrates the position of the wall openings. The wall openings are listed below. The referenced figures present photographs (taken in October 2021) of the openings and building interior.

- West Wall - two 20-feet high by 15-wide and one 20-feet wide by 10-feet high truck loading doors; and one man-door (Figures 3 and 4).
- South Wall – two 15-feet wide by 10-feet high access doors (Figures 5 and 6b).
- North Side – one 10-feet high by 10-feet wide access door (Figure 7a).

There is a man-door located on the northern portion of the east building wall (Figure 2). This opening has a door which is often closed. A 4-foot exhaust fan is located within the upper southeast corner of the east wall (Figure 6a). The fan runs continuously when workers are in the building and the fan opening would provide ventilation when not running.

Summary of Findings

The available data indicate that the VI pathway into the main production building is not of concern based on the following lines of evidence.

- Soil data beneath and in the immediate vicinity of the building are generally below Method A soil CULs. The Method A CUL for benzene was exceeded at location P12 located at the downgradient, northeastern edge of the building (Figure 1) where a benzene concentration of 35 ug/kg was detected that just exceeds the Method A CUL of 30 ug/kg. At P13, located approximately 50-60 feet west of P12, a benzene concentration of 0.9 ug/kg was detected, well below the Method A CUL. The data indicate that the P12 exceedance is very local to the P12 location.

- Groundwater data beneath and in the immediate vicinity of the building are below the Method C VI SLs except at location P12 where a benzene concentration of 48 ug/l was detected that exceeds the SL of 24 ug/l. Benzene was not detected at location P13.

- Substantial air exchange and air flow within the large, well ventilated industrial building further reduces the risk to site workers via the VI pathway.

Closing

The services described in this memorandum were performed consistent with generally accepted professional consulting principles and practices. No other warranty, expressed or implied, is made. These services were performed consistent with our agreement with our client. This report is solely for the use and information of our client unless otherwise noted. Any reliance on this report by a third party is at such party's sole risk.

Opinions and recommendations contained in this report apply to conditions existing when services were performed and are intended only for the client, purposes, locations, time frames, and project parameters indicated. We are not responsible for the impacts of any changes in environmental standards, practices, or regulations after performance of services. We do not warrant the accuracy of information supplied by others, or the use of segregated portions of this document.

References

Ecology, 2018, Petroleum Vapor Intrusion (PVI): Updated Screening Levels, Cleanup Levels, and Assessing PVI Threats to Future Buildings; Implementation Memorandum No. 18; Pub. No. 17-09-043 (January 2018), January 10, 2018.

DOF (Dalton Olmsted & Fuglevand, Inc.), 2020, Remedial Investigation Report, Industrial Container Services, WA LLC (Former NW Cooperage Site), Seattle, Washington, Public Review Draft: February 2020 (and appendices).

Attachments

Table 1 – Soil Data Summary – Main Bldg. Area
Table 2 – Groundwater Data Summary – Main Bldg. Area
Figure 1 – Sample Locations – Main Production Area
Figure 2 – Main Building Openings
Figure 3 – West Wall – Outside Main Building (photographs)
Figure 4 – West Wall – Interior Building (photographs)
Figure 5 – South Wall – Outside Main Building (photographs)
Figure 6 – Interior Main Building & Exhaust Fan (East Wall) and South Wall Openings (photographs)
Figure 7 – North Wall & Interior Main Building (photographs)

TABLE 1 - Soil Data Summary - Main Bldg. Area

ICS/NW Cooperage
Seattle, Washington

Location	Spl. Depth (feet)	TPH-G	TPH-D	Benzene	Toluene	Ethyl-benzene	Xylenes	PCE	TCE	cis-1,2-DCE	VC
		(mg/kg)	(mg/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)	(ug/kg)
	SL	30/100(A)	2000	30(A)	7000(A)	6000(A)	9000(A)	50(A)	30(A)	78(B)	1.7(B)
P11	3-4.5	<9	<5.2	2.1	3.5	7.1	10.7	<1.6	<1.6	<1.6	<1.6
P12	3-4.5	23	6.9	35	2.4	7.6	34.4	<1.6	<1.6	<1.6	<1.6
P13	4-6	<80	1600	0.9	6.9	<1.4	2.3	5.1	<1.4	<1.4	<1.4
P14	3-5	10	15	<1.4	1	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4
MW-Ap	9-10	<12	<7	0.7	1.1	<1.2	0.8	<1.2	<1.2	<1.2	<1.2
MW-Bp	9-10	<5.9	<6.3	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2
MW-Cp	9-10	<12	11	<2.0	<2.0	<2	<2.0	<1.2	<2.0	<2.0	<2.0

Notes: (A) - Method A soil cleanup level to protect groundwater (from CLARC 2/2021)
(B) - Method B soil cleanup level to protect groundwater (from CLARC 2/2021) - Method A not available.
SL - Screening level

🟨 - Exceeds screening level

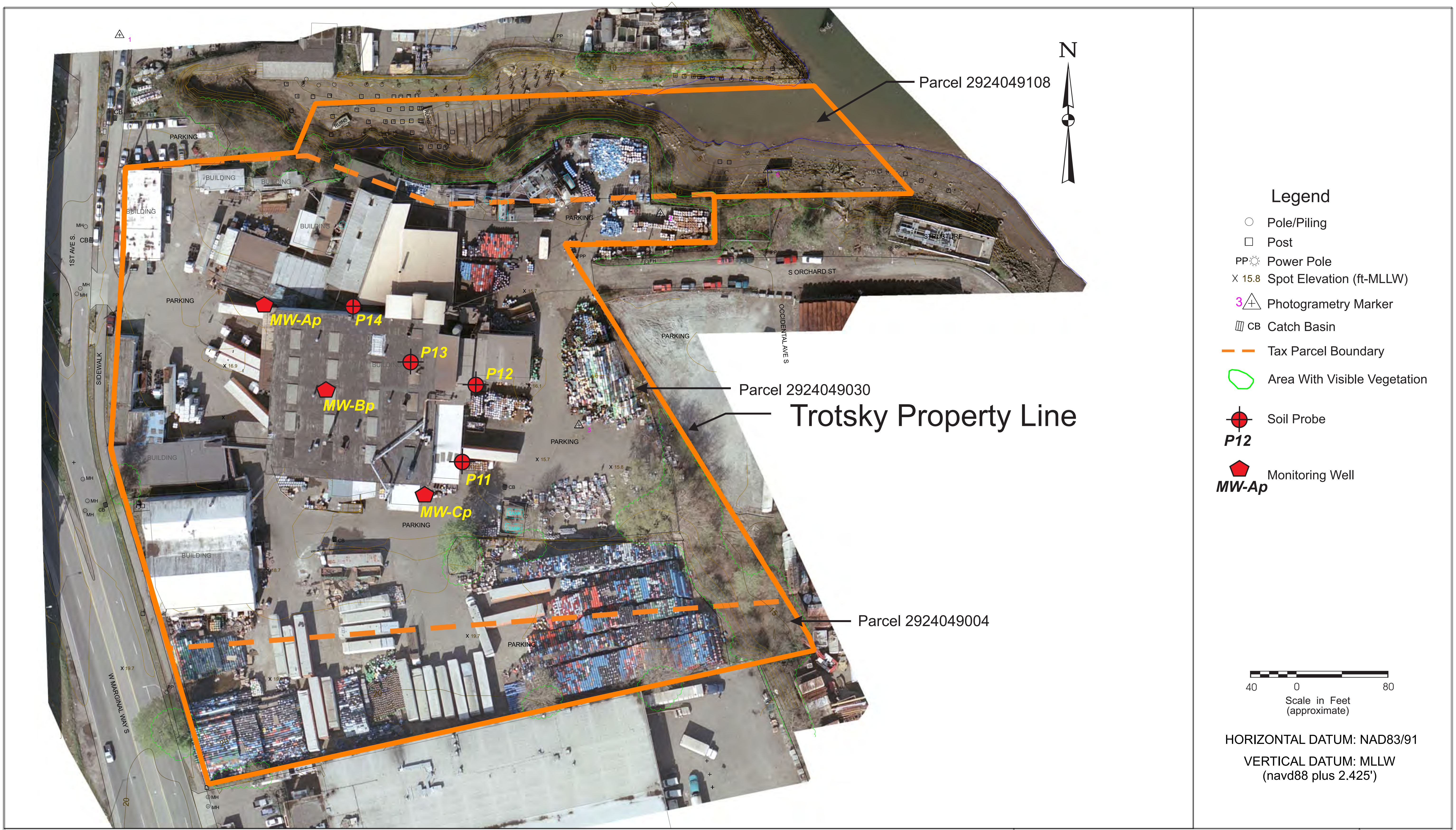
TABLE 2 - Groundwater Data Summary - Main Bldg. Area

ICS/NW Cooperage
Seattle, Washington

Location	No. of Spls.	Spl. Depth (feet)	Constituents	TPH-G	TPH-D	Benzene	Toluene	Ethyl-benzene	Xylenes	PCE	TCE	cis-1,2-DCE	VC
			Units	(mg/l)	(mg/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)
			GW Screening Level(a)	-----	-----	24	34000	6100	710	240	25	----	3.4
P11	1	6-10		<0.25	<0.1	2	1.8	15	5.2	<1	<1	0.65	<1
P12	1	5-9		<0.25	<0.1	48	<1	<1	1.4	<1	<1	<1	0.6
P13	1	10-15		<0.25	0.12	<1	<1	<1	<2	<1	<1	<1	<1
P14	1	10-15		<0.25	<0.1	3.1	7.8	0.72	3	<0.2	0.6	23	2.1
MW-Ap	3	4.5-9.5		-----	-----	0.34(avg)	0.29(avg)	<0.2	1.5(b)	0.95(avg)	<0.22(avg)	0.15(avg)	<0.2
MW-Bp	3	5.5-10.5		-----	-----	<0.2	0.11(avg)	<0.2	0.13(b)	1.3(avg)	<0.2	<0.2	<0.2
MW-Cp	3	3.5-8.5		-----	-----	1.5	1.3(avg)	0.42(avg)	1.5(avg)	<0.2	<0.2	0.11(avg)	<0.2

Notes: (a) - CLARC (2-2021) - Vapor Intrusion Method C
(b) - Highest conc. - detected in one of three samples.

🟨 - Exceeds groundwater vapor intrusion screening level



HORIZONTAL DATUM: NAD83/91

VERTICAL DATUM: MLLW
(navd88 plus 2.425')

Notes:

1) Property Survey by Continental Survey Co. (12-15-09)
2) Topography by David C. Smith Associates (flown 3-18-10 @ 1412 PDT)

Air Photograph - March 18, 2010

Ref: ICS-NW Cooperage Photo Topo Vapor.cdr

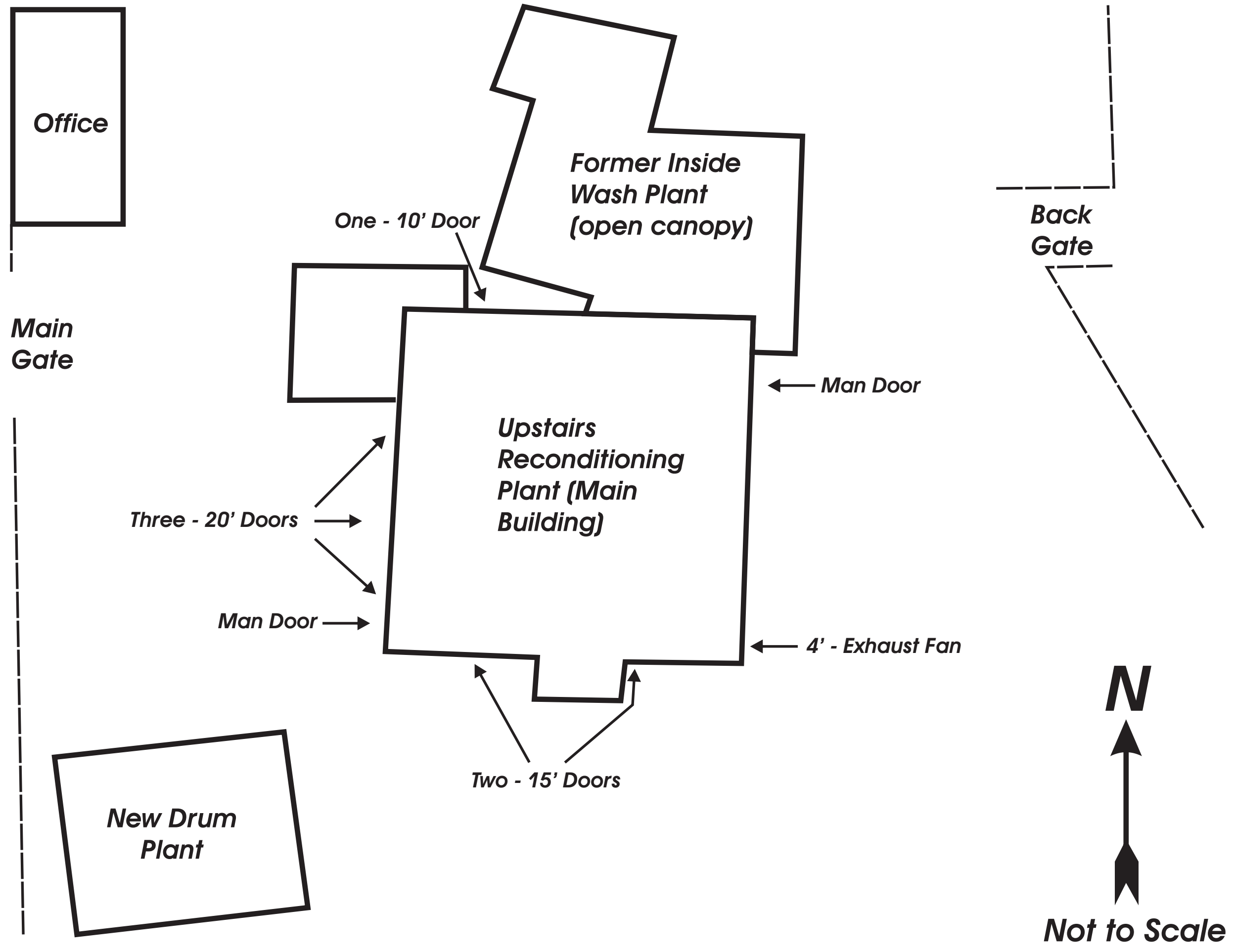
ICS/NW Cooperage Site

Sample Locations
Main Production Building

SUM-008-03FS ***Oct. 2021***

Dalton, Olmsted & Fuglevand, Inc.

FIGURE
1



ICS/NW Cooperage
Seattle, Washington

Main Building Openings

SUM-008-03FS **FIGURE 2** Oct. 2021

Dalton, Olmsted & Fuglevand, Inc.

Ref: Wall Opening Locations.cdr

Fig. 3a - Three 20' Loading Doors (view to east - 10-2021 #1322)

Fig. 3b - 20' Doors and Man-Door - SW Bldg. Corner (view to south-east (10-2021 #1323)

ICS/NW Cooperage
Seattle, Washington

West Wall
Outside Main Building

SUM-008-03FS **FIGURE 3** Oct. 2021
Dalton, Olmsted & Fuglevand, Inc.

Ref: Plate 1 Oct. 2021.cdr

Fig. 4a - 20’ Loading Door - West Wall (view to west - 10-2021 #1342)

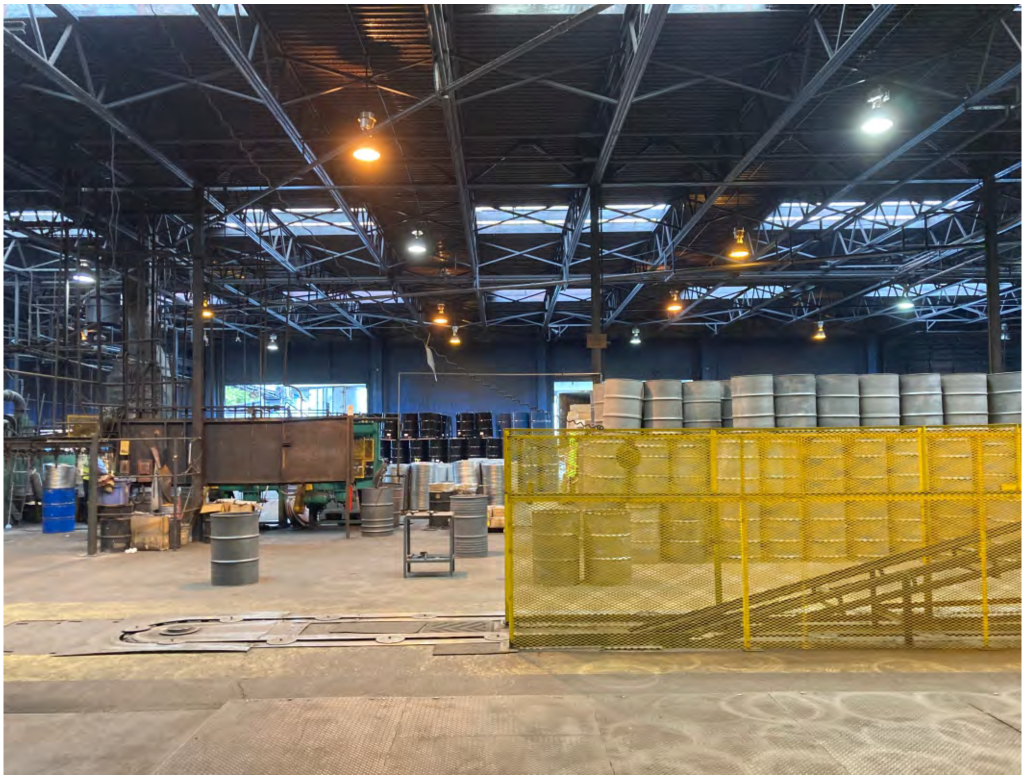


Fig. 4b - 20’ Doors West Wall + Interior (view to west (10-2021 #1350)

ICS/NW Cooperage
Seattle, Washington

West Wall
Interior Building

SUM-008-03FS **FIGURE 4** Oct. 2021
Dalton, Olmsted & Fuglevand, Inc.

Ref: Plate 2 Oct. 2021.cdr

Fig. 5a - West 15’ Door in South Wall (view to northeast (10-2021 #1325)

Fig. 5b - East 15’ Door in South Wall (view to northeast (10-2021 #1327)

ICS/NW Cooperage
Seattle, Washington

South Wall - Outside Main Building

SUM-008-03FS **FIGURE 5** Oct. 2021
Dalton, Olmsted & Fuglevand, Inc.

Ref: Plate 3 Oct. 2021.cdr

Fig. 6a - Exhaust Fan Southeast Corner of East Wall (view generally southeast (10-2021 #1348)

Fig. 6b - 15’ Doors in South Wall view to southeast (10-2021 #1328)

ICS/NW Cooperage
Seattle, Washington

Interior Main Building & Exhaust Fan (East Wall) and South Wall Openings

SUM-008-03FS **FIGURE 6** Oct. 2021
Dalton, Olmsted & Fuglevand, Inc.

Ref: Plate 4 Oct. 2021.cdr

Fig. 7a - 10' Door in North Wall (view to east -10-2021 #1339)

Fig. 7b - General View of Building Interior (10-2021 #1345)

ICS/NW Cooperage
Seattle, Washington

North Wall & Interior
Main Building

SUM-008-03FS **FIGURE 7** Oct. 2021
Dalton, Olmsted & Fuglevand, Inc.

Ref: Plate 5 Oct. 2021.cdr

APPENDIX F
LEGAL OPINION
STABILITY OF NORTH EMBAYMENT SHORELINE

FEASIBILITY STUDY REPORT
ICS/NWC RI/FS
SEATTLE, WASHINGTON

Dalton, Olmsted & Fuglevand, Inc.

APPENDIX F

1st Ave. LLC, the Current Owner of the Douglas Property Has the Legal Obligation to Prevent Collapse of the Ecology Block Wall and Shoreline

Submitted by Ralph H. Palumbo
Arete Law Group
Attorneys for the Herman Trotsky Estate

The current Douglas Property, which is owned by 7100 1st Ave. S. Seattle LLC ("1st Ave. LLC"), was originally part of a turning basin with approximately the same elevation as the Industrial Container Services, WA, LLC's ("ICS") (formerly known as the Northwest Cooperage Inc. ("NWC") portion of the ICS/NWC-Douglas embayment intertidal areas (the "Embayment Area"). Later, the Uplands Area of the Douglas Property was created on the north side of the Embayment Area by filling behind an ecology block wall and other training walls. The ecology block wall stands in an approximately vertical position and has an unknown foundation.

The Conceptual Embayment Remedy proposes to excavate contaminated sediments in the Embayment Area. The sediments would be dewatered and stabilized as needed. Excavated/dredged sediment would be disposed off-site; sediment with PCB concentrations equal to or greater than 50 ppm would be disposed in a TSCA permitted (Subtitle C) landfill while remaining sediment would be disposed in a Subtitle D landfill. *See* Feasibility Study Report, Section 7.3. Sediment removal depths in the Embayment Area of 2-Foot (EB-1), 2- to 3-Foot (EB-2) and 2- to 5-Foot (EB-3) are evaluated in the Feasibility Study Report. *Id.* at Section 7.4.2. Using the simplified ranking system (Table 10-1, Feasibility Study Report), EB-3 ranks highest, and is the ICS/NWC Preferred Remedy. *Id.* at Sections 10.1 & 11.1. After sediment removal, an engineered cap (two to five feet thick) will be installed to meet pre-construction grades in areas where sediments are removed, and appropriate vegetation to enhance habitat will be planted on the Embayment bottom and side slopes.

It is likely removal of 2-Foot to 5-Foot of contaminated sediments in the Embayment Area at the foot of the Douglas Property Uplands Area ecology block wall and other portions of the steep Douglas shoreline, including PCB contaminated sediments located on land owned by 1st Ave. LLC, will cause the ecology block wall/steep shoreline to fail (collapse). Feasibility Study Report, Section 8.6. Failure of the ecology block wall/steep shoreline would result in soils collapsing into the Embayment Area, resulting in loss of a portion of the Douglas Property Uplands Area and burial of contaminated sediments in the Embayment Area.

To prevent failure of the ecology block wall/steep shoreline, a structural sheet pile wall (the "North Sheet Pile Wall") would be installed along the north embayment shoreline. The structural wall is needed to support the existing ecology block wall and embayment slopes while excavation and capping of contaminated sediments are performed. Preliminary geotechnical and structural analyses indicate the sheets need to be driven to a depth of approximately 42 feet below the top of slope.

1st Ave. LLC's Obligation to Prevent Collapse of the Ecology Block Wall and Shoreline. 1st Ave. LLC, as the current owner of the Douglas Property, has a legal obligation to prevent collapse of the existing ecology block wall and embayment slopes while excavation and capping of contaminated sediments proceed, either by paying the cost to construct the North Sheet Pile Wall or by some other means.

The applicable legal rule is as follows. “All landowners have an absolute right to lateral support: ‘to have the soil in its natural condition supported by the soil of adjoining land in its natural conditions.’ … The law imposes on all owners a duty not to interfere with the lateral support their land provides to neighboring lands. The duty is an affirmative obligation - a duty to maintain - in cases involving retaining walls. When a wall on one owner's land supports the soil of another's, courts hold that the owner has "the obligation to maintain the wall to support the [neighbor's] land." The owner is liable if, even while behaving reasonably, he or she fails to maintain the retaining wall whose conditions deteriorate, thereby causing the neighboring land to subside. *See* 2014 Duke Law Journal article, THE DUTY TO MAINTAIN, 64 Duke L.J. 437, 473-475. “The duty to maintain retaining walls is a duty attached to the ownership of the property on which the wall is situated, that is, it runs with the land. Not only is the owner who built the wall responsible for its maintenance, but so too are successors. An owner is subject to a duty to maintain the support provided by his or her land to neighboring soil as that support existed at the time he or she assumed ownership.” *Id.*

Courts across the United States have uniformly held that an owner who raises his land above the level of the adjoining land must build a retaining wall or other structure if necessary to keep the soil within the owner's property. Conversely, the owner of the lower land has no duty to provide support for the adjoining land that has been raised above its natural level. *See*, e.g., *Scott v. West*, 219 Tex. App. LEXUS 5614 (July 3, 2019); *Tortolano v. Di Filippo*, 115 R.I. 496, 349 A.2d 48, 51 (R.I. 1975) (holding that a court may require"[a]n owner who alters the grade of his land to a level above his neighbor's" to build a retaining wall on his property because the owner who raises his land "is under a duty to keep the fill used from falling or sliding onto the adjoining parcel," and explaining that "[t]he underlying rationale of this rule is that a landowner who fills his lot above the level of the lot of an adjoining landowner has no right to lateral support from the latter and the latter cannot be compelled to contribute to the cost of a retaining wall"); *Carpentier v. Ellis*, 489 S.W.2d 388, 390 (Tex. App. 1972) (holding that, if a landowner adds fill to the land, an adjoining landowner has no obligation to provide support beyond that which would have been required without the alterations); *Sime v. Jensen*, 213 Minn. 476, 7 N.W.2d 325, 327-28 (Minn. 1942) (holding that because an owner who raises his land above the level of adjoining land has no right of lateral support from the adjoining land for the now elevated soil and is also under the duty to keep the fill soil off adjoining land, a landowner who raises the grade of his lot must build a retaining wall or other structure if necessary to keep the soil within the owner's property, and the plaintiff in the case was guilty of nuisance and trespass for failing to keep his soil off the defendant's land); *Kennedy v. Rosecrans Gardens, Inc.*, 114 Cal. App. 2d 87, 249 P.2d 593, 594-95 (Cal. Dist. Ct. App. 1952) (holding that when defendant landowner raised the grade of its land, causing earth and water to be deposited on its adjoining neighbor's now lower elevated land, the defendant committed trespass, and the plaintiff was entitled to damages or injunctive relief because the harmful results were not trivial); *Abrey v. City of Detroit*, 127 Mich. 374, 86 N.W. 785, 786 (Mich. 1901) (holding "[w]hen one places a bank on his own land above his neighbor's, he is bound to erect a retaining wall or structure sufficient to keep the dirt from encroaching upon his neighbor's land"); 1 Am. Jur. 2d Adjoining Landowners § 45 ("[t]he right of an adjoining property owner to lateral support exists only so far as to require support for his land in its natural state from his neighbor's land in its natural state" and that land has no right of lateral support "where the natural condition thereof has been altered through man's activities.”)

The natural state of the Douglas Property was riverbed at the same elevation the ICS/NWC portion of the Embayment Area. Before the Douglas Property was filled to create the Douglas Property Uplands Area, excavation of contaminated soils in the ICS/NWC portion of the Embayment Area would not have adversely impacted the adjoining Douglas Property portion of the Embayment Areas. Conversely, having artificially raised the level of the Douglas Property portion of the Embayment Area and built the ecology block retaining wall to create the existing Douglas Property Uplands Area, 1st Ave., LLC has an obligation to maintain or replace the ecology block retaining wall so excavation and capping of contaminated sediments in the Embayment Area can be performed – both on the ICS/NWC portion of the Embayment Area and and 1st Ave. LLC’s portion of the Embayment Area.