Appendix K
Water Quality Effects Evaluation

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ABBREVIATIONS

CLARC	Cleanup Levels and Risk Calculation
COC	contaminant of concern
CWA	Clean Water Act
cy/day	cubic yard per day
cy/hour	cubic yard per hour
EPA	U.S. Environmental Protection Agency
LDW	Lower Duwamish Waterway
mg/L	milligram per liter
NTU	nephelometric turbidity unit
PCB	polychlorinated biphenyl
RAL	remedial action level
RD	remedial design
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers
WAC	Washington Administrative Code

1 Introduction

1.1 Background

Dredging of contaminated sediment inherently results in temporary water quality effects during construction. Therefore, significant effort has been made to understand and limit water quality effects during remediation (e.g., *The Four Rs of Environmental Dredging: Resuspension, Release, Residual, and Risk* [USACE 2008]). Moreover, there is an established set of tools commonly used to analyze potential water quality effects during dredging operations and typical approaches employed for managing those potential effects.

Remedial activities in the Lower Duwamish Waterway (LDW) upper reach are anticipated to consist of mechanical dredging of contaminated sediment, which will be placed into and dewatered on a haul barge. Barge dewatering generates dredge return water (i.e., dredging return water that is made up of free water captured by the dredging bucket and placed into the barge or porewater generated from dewatering of the sediment stockpile on the barge). This dredge return water typically is discharged back to the receiving waters within the dredging work zone after suspended solids are filtered out of the dredge return water.

This appendix provides a screening-level evaluation of predicted water quality effects during both remedial dredging and barge dewatering to help inform the development of water management requirements in the specifications and a Water Quality Monitoring Plan as part of the Construction Quality Assurance Plan during Pre-Final (90%) Remedial Design (RD). The results of this appendix can be considered by the U.S. Environmental Protection Agency (EPA) to inform the detailed water quality monitoring requirements in EPA's Clean Water Act (CWA) Section 404 ARAR Memorandum.

1.2 Water Quality Criteria

The LDW upper reach RD is required to substantively comply with applicable federal and Washington State water quality criteria, as noted in the Intermediate (60%) RD *Basis of Design Report* Section 3.2.

EPA will determine specific compliance criteria, measurement methods, mixing zones, and other conditions in the CWA Section 404 ARAR Memorandum. The *Record of Decision* (EPA 2014) states that the LDW is considered marine water under the state's water quality standards regulation because it meets the salinity threshold described in Washington Administrative Code (WAC) 173-201A-260(3)(e) and that salinity measurements show tidal conditions exist beyond the turning basin. The *Record of Decision* also states that the LDW is not specifically noted in WAC 173-201A-610 and 612, Table 612, but is a continuation of Elliott Bay for the purposes of applying marine criteria. Based on the beneficial use classification of the LDW as "excellent quality" to support salmonid migration and rearing, the compliance criteria for conventional parameters will likely be the "excellent quality" Washington State Surface Water Quality Standards for marine waters (WAC 173-201A-210). The Water Quality Monitoring Plan will develop specific monitoring methods to be used during construction, in alignment with that certification.

For the purposes of this appendix, turbidity water quality standards for the project are based on WAC 173-201A-210(1)(e) for waters designated as "excellent" marine quality. The turbidity criterion is to not exceed 5 nephelometric turbidity units (NTU) above background (or 10% above background if background is 50 NTU or higher) at the edge of the designated area of mixing during construction activities. For estuarine waters in Washington State, the standard point of compliance for a temporary area of mixing is identified as 150 feet from the activity causing the disturbance. However, sediment remediation projects often request an area of mixing larger than the point of compliance, in part because it is not safe or sometimes physically possible to sample that close to the working equipment. The proposed area of mixing is described in the Water Quality Monitoring Plan detailed outline (Attachment F-1 to Appendix F) and based on a variety of considerations. For this analysis, the water quality effects evaluation calculated all predicted concentrations and comparisons to water quality criteria using a value of 150 feet.

Acute and chronic criteria for protection of aquatic life in marine water were selected as the water quality standards for contaminants in sediment that could enter the water column due to sediment suspension during dredging or dredging return water from a barge. Applicable water quality criteria are provided in Table K-1 as obtained from Ecology's Cleanup Levels and Risk Calculation (CLARC)[1] database based on the minimum federal standards (40 Code of Federal Regulations 131.45) and state standards (173-201A WAC) for protection of aquatic life in marine water. Per WAC 173-201A-240, marine water quality criteria are expressed as the dissolved fraction for metals except mercury, which is expressed as total recoverable fraction for the chronic criteria, and polychlorinated biphenyls (PCBs) which are expressed as the total recoverable fraction for both acute and chronic criteria. Criteria are averaged over a specific time frame (i.e., a 1-hour average for the acute criterion, a 4-day average for the chronic criterion, and a 24-hour average for total PCBs for both acute and chronic).

1.3 Objectives of Effects Evaluation

The objectives of this water quality effects evaluation are as follows:

1. Estimate the predicted total and dissolved contaminant of concern (COC) concentrations that may be mobilized into the water column during dredging at the edge of the area of mixing during construction (Section 3).

[1] The CLARC is a database maintained by Ecology that compiles both Washington State and federal cleanup levels for media and contaminants.

2. Estimate the predicted total and dissolved COC concentrations that may be discharged to waters within the construction work zone during barge dewatering and transported to the edge of the area of mixing (Section 4).

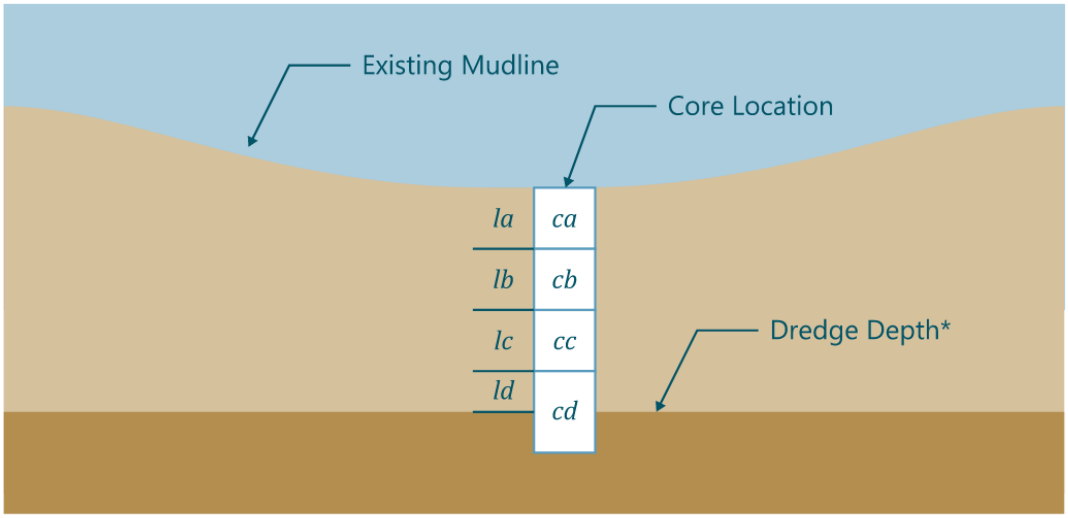
Section 2 summarizes the contaminant input parameters used in both analyses.

2 Contaminant Input Parameters

The chemical concentrations in dredged sediment are a key input to the water quality evaluation. Two different contaminant concentrations in sediment were evaluated for each modeled contaminant. A high concentration was calculated to represent a maximum concentration that may be dredged for comparison to acute water quality criteria. An area-wide representative concentration was calculated to represent an average concentration that will be dredged for comparison to chronic water quality criteria (Table K-2). These concentration calculations are discussed in this section.

Core samples in the *Pre-Design Investigation Data Evaluation Report* (Anchor QEA and Windward 2022) design dataset were used to estimate contaminant concentrations in dredged sediment. Because dredging inherently mixes sediment, the vertically weighted average concentration in each core (excluding cores without contamination) was calculated. This approach results in a conservatively high average concentration. The dredge depth of each core was estimated based on the maximum depth of contamination for each core, plus 1 foot of overdredging (i.e., if depth of contamination is 4 feet, the total dredge depth is 5 feet). Then the vertically weighted average concentration was calculated for each core by calculating the sum of each core interval's chemical concentration multiplied by the length of that core interval for every analyzed core interval, divided by the total length of all analyzed core intervals for each individual core (Figure K-1).

Figure K-1
Calculation of Vertically Weighted Average Concentration



$$Cavg = \frac{(la)(ca)+(lb)(cb)+(lc)(cc)+(ld)(cd)}{la+lb+lc+ld}$$

Where:

cx	*= concentration in core interval "x"*
lx	*= length of core interval "x" included in vertically weighted average*
Cavg	*= vertically weighted average*

Note*: Dredge depth was estimated based on the maximum depth of contamination for each core, plus 1-ft of overdredge

After the vertically weighted average concentration for every core within remedial action level (RAL) exceedance areas was determined, a maximum and an average concentration were calculated to be used to compare against acute and chronic water quality criteria. The maximum concentration was the highest individual core result (i.e., highest vertically weighted average concentration of all RAL exceedance area cores), and this maximum concentration was compared against acute criteria. The average concentration represents the averaging of all RAL exceedance area cores and was compared against chronic criteria.

The partitioning coefficients for modeled contaminants are also a key input for the water quality effects evaluation. Partitioning coefficients can vary widely depending on geochemical conditions and contaminant characteristics (e.g., mixture of PCBs). For simplicity, the partitioning coefficients were pulled from the values in the CLARC database (Table K-1). The PCBs partitioning coefficient was calculated based on the organic-carbon-based partitioning coefficient times average percent of organic carbon in the cores.

3 Potential Water Quality Effects During Dredging

3.1 Predicted Water Quality Effects Using the DREDGE Model

3.1.1 Model Description

The U.S. Army Corps of Engineers (USACE) developed the DREDGE Model (Hayes and Je 2000) to help predict contaminant concentrations within the water column that result from dredging operations. The model steps are as follows:

1. The model first estimates the mass rate at which sediments become suspended into the water column during mechanical dredging operations, based on the dredging production rate and the percent loss of material during dredging, which are supplied by the user.
2. Next, the model estimates the transport of the total suspended solids (TSS) plume from the dredging area due to lateral diffusion, transport by ambient water currents, and settlement of suspended solids. This calculation predicts the TSS concentration with distance from the dredging area.
3. Finally, the model estimates the total and dissolved contaminant concentrations in the water column based on contaminant concentrations in the predicted TSS and equilibrium partitioning theory. The model conservatively assumes that partitioning is instantaneous in the water column and that solids-phase concentrations and dissolved-phase concentrations are in equilibrium.

An additional evaluation check was performed using just the third step in the DREDGE Model, to back-calculate the TSS concentration that would be predicted to result in a water quality exceedance based on partitioning assumptions.

3.1.2 Model Input Parameters

Table K-3 presents the model input parameters selected for the evaluations and the rationale for each parameter. The DREDGE Model inputs consist of dredge characteristics and transport parameters. The general approach was to use reasonable conservative assumptions (i.e., assumptions that result in higher concentrations) to account for uncertainty.

The dredging production rate was assumed to be 180 cubic yards per hour (cy/hour) for the acute (1-hour average) evaluation, 1,000 cubic yards per day (cy/day) for the chronic (4-day average), and 1,000 cy/day for the total PCBs acute and chronic (24-hour average) evaluation. Dredging is not a continuous operation because the contractor will not work 24 hours a day (e.g., a typical 10-hour workday involves 6 to 8 hours of active dredging), and there is significant downtime in a typical workday for moving and setting up the dredge plant and equipment maintenance. These are considered reasonable maximum average production rates for calculating the average conditions over the time frames of interest.

Three percent of the dredged material volume was assumed to be suspended into the water column during dredging, which is high compared to previous studies (e.g., Anchor QEA 2003). The DREDGE Model assumes that suspended solids loading is evenly distributed throughout the water column during the raising of the dredge bucket.

Suspended solids transport lateral diffusion coefficients were established based on discussions with USACE (Schroeder 2019; Table K-3). The site-specific settling rates in the model were determined based on sediment grain sizes and densities. The mean settling velocity is a conservative representation of the TSS (i.e., fine fraction) and was therefore estimated based on the Stokes' law settling velocity of a particle size of 37 micrometers, representative of the median of the fine fraction of dredged material.

The ambient river flow and tidal velocities within LDW vary; however, a speed of 1 foot per second was used for modeling and is considered representative of moderate flow in the LDW. Dredging was not assumed to occur during high-flow storm events because dredging contractors may not be able to safely operate during high-flow events.

3.1.3 Model Results

Table K-4 presents the model results for the acute water quality evaluation (1-hour average; 180 cy/hour). The DREDGE Model predicted a TSS concentration of 15.6 mg/L at 150 feet from the work zone. The resulting predicted total and dissolved concentrations for COCs did not exceed acute water quality criteria.

Table K-5 presents the model results for the chronic water quality criteria (4-day average; 1,000 cy/day). The DREDGE Model predicted an effective average TSS concentration of 3.6 milligrams per liter (mg/L) at 150 feet from the work zone. This is the predicted average TSS concentration averaged over a 4-day period; TSS concentrations at 150 feet would be higher during active dredging. All predicted dissolved COC concentrations were below marine chronic water quality criteria.

In summary, based on site-specific model inputs to the DREDGE Model, no acute or chronic water quality exceedances are predicted for COCs at the point of compliance of 150 feet from the dredging activity.

3.2 Turbidity Criteria and Total Suspended Solids Threshold Concentrations

The preceding section showed that water quality criteria exceedances are not predicted at the point of compliance during dredging operations, based on dredging operational characteristics and modeled hydrodynamic conditions. This section summarizes an additional evaluation performed to illustrate how turbidity monitoring is considered to be appropriate to monitor and identify potential water quality criteria exceedances in real time during dredging. The following subsection (3.2.1) discusses the relationship between turbidity and TSS, which is important for linking the real-time turbidity monitoring with potential water quality effects; however, while turbidity provides important real-time information on water quality, a confirmed turbidity exceedance may trigger a request from EPA for chemical analysis for relevant COCs to determine if an exceedance of water quality criteria has occurred. The next subsection (3.2.2) discusses a back-calculation method to predict concentrations of TSS that would need to be observed at the point of compliance from dredging operations that potentially could result in acute or chronic water quality criteria exceedances. Together, these evaluations demonstrate that real-time turbidity measurements are considered to be an appropriate method to monitor for potential water quality exceedances due to dredging operations.

3.2.1 Turbidity and Total Suspended Solids

Turbidity is a water quality parameter that refers to how clear the water is. TSS are physical particles in the water (e.g., sediment), and turbidity is the effect on light caused by those particles and anything else that affects light. Therefore, there is not a constant relationship between turbidity and TSS, but they are related. The greater the amount of TSS in the water, the murkier it appears and the higher the measured turbidity. However, turbidity is also caused by discoloration of the water affecting light transmission through the water; therefore, the relationship between turbidity and TSS can fluctuate at any site. Because turbidity is generally correlated with TSS and provides real-time feedback about water quality during dredging operations, it is commonly used as the primary tool to assess whether significant resuspension is occurring during dredging operations.

Turbidity is commonly used to assess water quality effects during dredging, with a criterion established relative to ambient background concentrations to assess the contributory effect of dredging on turbidity (e.g., 5 NTU above background, or 10% above background when background turbidity >50 NTU). Turbidity measurements provide real-time information about the potential effects to water quality due to dredging and therefore can provide near real-time feedback to the contractor. Although TSS is used in predictive modeling, real-time measurements of TSS during dredging are not possible (i.e., TSS requires laboratory analysis). As such, turbidity, which has a relationship to TSS, is recommended for real-time measurements of water quality during dredging.

Based on literature (Thackston and Palermo 2000; Anchor QEA 2003) and Anchor QEA's, experience at other remedial dredging sites, the turbidity to TSS relationship ranges from approximately 1 NTU = 0.5 mg/L TSS to 1 NTU = 4 mg/L TSS, with 1 NTU = 2 mg/L TSS considered to be a reasonable relationship. Specific turbidity criteria to be recommended for the LDW upper reach will be described in the Water Quality Monitoring Plan during Pre-Final (90%) RD.

3.2.2 Chemical Concentrations and Total Suspended Solids

The partitioning component of the DREDGE Model was used to back-calculate the concentrations of TSS that would result in acute or chronic water quality criteria. Table K-6 presents the TSS concentrations at the 150-foot point of compliance that would exceed acute and chronic water quality criteria based on the maximum and the mean concentrations in cores. The lowest TSS concentration that could result in an acute water criteria exceedance was for copper. The copper acute water quality criterion of 4.8 micrograms per liter was predicted to be exceeded at 21 mg/L TSS above the background TSS at the 150-foot compliance point. Because 1 NTU equates to approximately 0.5 to 4 mg/L TSS, the compliance criterion of 5 NTU above background would be predicted to equate to an approximate TSS concentration of 2.5 to 20 mg/L above background, which is lower than the predicted concentration required to exceed the copper acute criteria. Because all other COCs are predicted to require a much higher TSS concentration than copper to potentially exceed acute criteria at the point of compliance, this evaluation shows there is low risk of exceeding the acute criteria at the point of compliance under any dredging scenarios.

The lowest TSS concentration that exceeded chronic water criteria was for total PCBs. The chronic water quality criterion of 0.030 microgram per liter was predicted to be exceeded at 43 mg/L TSS above the background TSS, indicating that the long-term average TSS concentration should be maintained below 43 mg/L above background. Again, considering a typical turbidity to TSS conversion of 1 NTU = 0.5 to 4 mg/L TSS, the project compliance criterion of 5 NTU above background would be predicted to equate to an approximate TSS concentration of 2.5 to 20 mg/L above background, which is also protective of chronic water quality criteria.

4 Potential Effects During Barge Dewatering and Dredge Return Water Discharge

Dredging return water is typically discharged from the barge to the dredging work zone after filtration to remove suspended solids. The dredge return water is one of the many processes during dredging that contributes to overall effects on the water column. This section provides a screening-level assessment of the incremental contribution of the return water to ambient chemical concentrations in the water column.

4.1 Model Description

The effects of barge dewatering dredge return water were estimated using the procedure in *Evaluation of Dredged Material Proposed for Discharge in Water of the U.S. – Testing Manual, Appendix C* (USACE 1998). The following steps were performed:

- The average concentration in sediment cores and the chronic water criteria were used because sediment mixes in the barge, and barge dredge return water discharge can take place throughout the day (even when dredging is not being performed).
- The dissolved contaminant concentrations in porewater were calculated by partitioning theory.
- Sediment porewater was assumed to mix on the barge with free water captured by the dredging buckets during dredging.
- The barge dredge return water was assumed to discharge continuously into the dredging work zone.
- The dissolved concentration and discharge rate of barge dredge return water were compared to water quality criteria to calculate a required dilution factor to meet water quality criteria. The dilution factor is calculated using the following EFQUAL equation (USACE 1991):

$$dilution\ factor = \frac{(concentration\ in\ the\ dredge\ return\ water\ discharge) - (water\ quality\ standard)}{water\ quality\ standard}$$

- The dilution factor is the ratio of surface water to dredge return water that needs to be mixed together to meet the water quality criteria. This dilution factor is used to determine the quantity of water that must be diluted with dredge return water and the distance of mixing to meet the water quality criteria in the next step.
- Finally, a distance of mixing was calculated based on the approach described in *Evaluation of Dredged Material Proposed for Discharge in Water of the U.S. – Testing Manual, Appendix C*

(USACE 1998) that achieves the chronic water quality criteria. This distance was compared to the typical point of compliance of 150 feet for in-water construction activities.

4.2 Model Input Parameters

Table K-7 presents the model input parameters selected for the evaluation and the rationale for each parameter. The model assumptions are similar to the DREDGE Model. The production rate was assumed to be 1,000 cy/day of in situ dredged sediment, consistent with a comparison to chronic criteria (4-day average). The proportion of free water compared to the in situ volume of sediment is 43%, calculated by assuming a bucket fill factor of 70%, and a conservatively high assumption of bucket free water at 30% of the bucket volume placed on the barge (i.e., 30% / 70% = 43%). This assumption results in a free water volume of 430 cy/day. The volume of free water is then assumed to discharge continuously from the barge (i.e., 430 cy/day = 228 liters per minute). The dissolved concentration in barge dredge return water is calculated based on porewater concentrations for each chemical (based on partitioning). The volume of sediment porewater is assumed to fully mix with the volume of free water, which results in conservatively higher barge dredge return water concentrations.

The turbulent dissipation parameter was assumed to be 0.005 based on the recommendations in *Evaluation of Dredged Material Proposed for Discharge in Water of the U.S. – Testing Manual, Appendix C* (USACE 1998). A depth of mixing was assumed to be 3 meters, which conservatively assumes that mixing does not occur in the entire water column, and the ambient water velocity was assumed to be 1 foot per second.

4.3 Model Results

Table K-8 presents the results of the barge dredge return water discharge evaluation. The largest required mixing zone of 60 feet was calculated to achieve chronic water quality criteria for copper. All other COCs meet chronic criteria closer than 60 feet to the barge discharge. Based on this evaluation, water quality criteria for COCs are predicted to be met at the point of compliance 150 feet from the work zone for barge dredge return water discharge.

5 Summary and Conclusions

Screening-level site-specific water quality modeling predicts there is unlikely to be water quality criteria exceedances for COCs due to suspension of sediment during dredging operations, or from barge dredge return water discharge of dissolved concentrations. Based on this water quality assessment, it is unlikely there will be a chronic exceedance when the barge dredge return water discharge is combined with water quality effects associated with dredging. Monitoring for turbidity at 150 feet or the closest safe distance from dredging and barge discharge is expected to provide real-time feedback of water quality conditions during dredging and provide a mechanism for corrective action(s) should excessive sediment suspension be observed. Further, the turbidity compliance criterion (5 NTU above background, or 10% above background when background turbidity >50 NTU) is predicted to result in COC concentrations less than marine water quality criteria and supports the use of turbidity as the primary evaluation metric. The proposed water quality criteria, area of mixing (and point of compliance), and procedures for water quality monitoring, reporting, and potential contingency response actions (i.e., procedures to follow in the case of a water quality exceedance) will be described in the Water Quality Monitoring Plan to be developed during Pre-Final (90%) RD.

The results of this appendix can be considered by EPA to inform the detailed water quality monitoring requirements in EPA's CWA Section 404 ARAR Memorandum. Actual water quality monitoring, as defined in the Water Quality Monitoring Plan, will be conducted during remedial actions, and the contractor will be required to modify operations to remain in compliance with the requirements outlined in EPA's CWA Section 404 ARAR Memorandum.

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Tables

Table K-1

Water Quality Criteria and Partitioning Coefficients from the CLARC Database

Chemical	Marine Acute (µg/L)	Marine Chronic (µg/L)	Kd (L/kg)	Koc (L/kg)
Arsenic	69	36	29	
Cadmium	33	7.9	6.7	
Chromium VI	1,100	50	19	
Copper	4.8	3.1	22	
Lead	140	5.6	10,000	
Mercury	1.8	0.025	52	
Nickel	74	8.2	65	
PCBs	10	0.030		78,100
Silver	1.9		8.3	
Zinc	90	81	62	

Notes:

Blank cells = not applicable

1. Values from Ecology's CLARC database.
2. COCs selected based on COCs in the Design Dataset with Water Quality Criteria.
3. Water Quality Criteria are the lowest of Federal (40 CFR 131.45) and Washington State Standards (173-201A WAC) for protection of aquatic life.
4. Acute and chronic criteria for metals (except mercury) are based on the dissolved fraction.
5. The chronic criterion for mercury is based on total recoverable and the acute criterion is based on the dissolved fraction (WAC 173-201A-240).
6. Criteria for total PCBs are based on total recoverable fraction (WAC 173-201A-240).

µg/L: microgram per liter

CFR: Code of Federal Regulations

CLARC: Cleanup Levels and Risk Calculation

COC: contaminant of concern

L/kg: liter per kilogram

PCB: polychlorinated biphenyl

WAC: Washington Administrative Code

Table K-2
Summary Chemical Concentrations for Water Quality Evaluations

Chemical	Unit	Maximum of Cores	Mean of Cores
Arsenic	mg/kg	662	18
Cadmium	mg/kg	6.0	0.61
Chromium	mg/kg	188	29
Copper	mg/kg	228	46
Lead	mg/kg	844	47
Mercury	mg/kg	0.58	0.17
Silver	mg/kg	1.1	0.29
Zinc	mg/kg	1,790	113
PCBs	µg/kg	6,680	738

Notes:

1. Core statistics based on the Design Dataset samples within the dredge prism.
2. Each core concentration is the vertically weighted average concentration of core samples within the dredge prism.
3. The preliminary dredging depth for this analysis is based on the depth of benthic SCO exceedances (e.g., 12 mg/kg OC for Total PCBs) plus 1 foot of overdredging.

µg/microgram per kilogram

mg/kg: milligram per kilogram

OC: organic carbon

PCB: polychlorinated biphenyl

SCO: sediment cleanup objective

Table K-3
DREDGE Model Input Parameters

Parameter	Value	Unit	Rationale
Dredge Characteristics			
Production Rate	180 cy/hour (acute); 1000 cy/day (chronic)	varies	Based on dredging project experience within the LDW. 180 cy/hour represents a maximum 1-hour dredge rate for comparison to acute criteria. 1000 cy/day represents an average 4-day dredge rate for comparison to chronic criteria.
In Situ Dry Density	919	kg/m^3	Calculated based on an average total solids of 59% assuming a particle density of 2.60 (specific gravity).
Source Strength (Percent Loss from Dredge Bucket)	3	percent	1% typical of environmental bucket. 3% is a conservative estimate (higher TSS).
Transport Characteristics			
Lateral Diffusion Coefficient	10,000	cm^2/s	Reasonable based on personal communication with Paul Schroeder, USACE (December 3, 2019) for LDW and laterally bounded waterways.
Settling Velocity	0.00077	m/s	Calculated based on Stokes' Law assuming 37 µm particle size (half of the 74 µm upper threshold of fine-grained material).
Water Depth	5	m	Within the range of LDW water depth during construction.
Ambient Water Velocity	1	ft/s	Flow changes with river stage and tidal conditions. 1 ft/sec was selected as a reasonable minimum average flow velocity over time. Higher flow velocities reduce predicted TSS due to dilution effects.
Particle Size (Diameter)	37	µm	Particle size is used to calculate the settling velocity (median of fines fraction).
Specific Gravity of Sediment Particles	2.6	unitless	The average specific gravity from design dataset samples is 2.6, with a range between 2.3 and 2.66.

Notes:

µm: micrometer

cm^2/s: square centimeter per second

cy: cubic yard

ft/s: foot per second

kg/m^3: kilogram per cubic meter

LDW: Lower Duwamish Waterway

m: meter

m/s: meter per second

TSS: total suspended solids

USACE: U.S. Army Corps of Engineers

Table K-4
DREDGE Model Output Compared to Marine Acute Water Quality Criteria

Chemical	Marine Acute Criteria (µg/L)	Maximum of Cores (mg/kg)	Concentration at 150 Feet (µg/L)
Arsenic	69	662	10
Cadmium	33	6.0	0.093
Chromium VI	1,100	188	2.9
Copper	4.8	228	3.5
Lead	140	844	11
Mercury	1.8	0.58	0.0090
PCBs	10	6.7	0.0027
Silver	1.9	1.1	0.017
Zinc	90	1,790	28

Notes:

1. DREDGE model predicted an effective average TSS concentration of 15.6 mg/L at the 150-foot point of compliance.
2. TSS value represents the average over a 1-hour period for acute criteria, except for PCBs, for which DREDGE model predicted an effective average TSS concentration of 3.6 mg/L at the 150-foot point of compliance, representing the average over a 24-hour period for both acute and chronic criteria (WAC 173-201A-240).
3. Water Quality Criteria are the lowest of Federal (40 CFR 131.45) and Washington State Standards (173-201A WAC) for protection of aquatic life.
4. Maximum of Cores refers to the maximum vertically-weighted average concentration among cores in the dredge prism.
5. Total chromium concentrations are compared to chromium VI water quality criteria.
6. Criteria for metals are based on the dissolved fraction.
7. Acute criteria for total PCBs are based on total recoverable fraction (WAC 173-201A-240).

µg/L: microgram per liter
CFR: Code of Federal Regulations
mg/kg: milligram per kilogram
mg/L: milligram per liter
PCB: polychlorinated biphenyl
TSS: total suspended solids
WAC: Washington Administrative Code

Table K-5
DREDGE Model Output Compared to Chronic Water Quality Criteria

Chemical	Marine Chronic Criteria (µg/L)	Mean of Cores (mg/kg)	Concentration at 150 Feet (µg/L)
Arsenic	36	18	0.066
Cadmium	7.9	0.61	0.0022
Chromium VI	50	29	0.10
Copper	3.1	46	0.17
Lead	5.6	47	0.16
Mercury	0.025	0.17	0.00062
PCBs	0.030	0.74	0.0027
Silver		0.29	0.0011
Zinc	81	113	0.41

Notes:

Blank cells = not applicable

1. DREDGE model predicted an effective average TSS concentration of 3.6 mg/L at the 150-foot point of compliance.
2. TSS value represents the average over a 4-day period for chronic criteria, except for PCBs, for which the TSS value represents the average over a 24-hour period for both acute and chronic criteria (WAC 173-201A-240).
3. Water Quality Criteria are the lowest of Federal (40 CFR 131.45) and Washington State Standards (173-201A WAC) for protection of aquatic life.
4. Mean of Cores refers to the average of the vertically-weighted average concentration among cores in the dredge prism.
5. Total chromium concentrations are compared to chromium VI water quality criteria.
6. Criteria for metals (except mercury) are based on the dissolved fraction.
7. Chronic criteria for mercury and total PCBs are based on total recoverable fraction (WAC 173-201A-240).

µg/L: microgram per liter

CFR: Code of Federal Regulations

mg/kg: milligram per kilogram

mg/L: milligram per liter

PCB: polychlorinated biphenyl

TSS: total suspended solids

WAC: Washington Administrative Code

Table K-6
Average TSS Threshold Concentrations that Exceed Water Quality Criteria

Chemical	Marine Acute Criteria (µg/L)	Marine Chronic Criteria (µg/L)	Maximum of Cores (mg/kg)	Mean of Cores (mg/kg)	TSS Equivalent to the Marine Acute Criteria Based on the Maximum of Cores (mg/L)	TSS Equivalent to the Marine Chronic Criteria Based on the Mean of Cores (mg/L)
Arsenic	69	36	662	18	105	>1000
Cadmium	33	7.9	6.0	0.61	>1000	>1000
Chromium VI	1,100	50	188	29	>1000	>1000
Copper	4.8	3.1	228	46	21	67
Lead	140	5.6	844	47	>1000	>1000
Mercury	1.8	0.025	0.58	0.17	>1000	145
PCBs	10	0.030	6.7	0.74	>1000	41
Silver	1.9		1.1	0.29	>1000	
Zinc	90	81	1,790	113	50	756

Notes:

Blank cells = not applicable

1. Contaminant partitioning is used to back-calculate the TSS that results in exceedances of dissolved criteria (except for mercury and PCBs, which are described below). Criteria are applicable at the 150-foot point of compliance.
2. Maximum sediment concentrations are based on the maximum vertically-weighted average core concentrations in cores from the Design Dataset and are coupled with acute criteri
3. Mean sediment concentrations are based on the mean vertically-weighted average core concentrations in cores from the Design Dataset and are coupled with chronic criteria.
4. Acute criteria for total PCBs are based on total recoverable fraction (WAC 173-201A-240).
5. Chronic criteria for mercury and total PCBs are based on total recoverable fraction (WAC 173-201A-240).

µg/L: microgram per liter

mg/kg: milligram per kilogram

mg/L: milligram per liter

PCB: polychlorinated biphenyl

TSS: total suspended solids

WAC: Washington Administrative Code

Table K-7
Barge Effluent Model Input Parameters

Parameter	Value	Unit	Rationale
Dredge Characteristics			
Production Rate	1000	cy/day	Based on dredging project experience within the LDW. 1000 cy/day represents an average 4-day dredge rate for comparison to chronic criteria.
In Situ Dry Density	919	kg/m^3	Calculated based on an average total solids of 59% assuming a particle density of 2.60 (specific gravity).
Proportion of Free Water to In Situ Volume of Sediment	43%	percent	Assuming a 70% bucket fill factor and the other 30% of the bucket is made up of free water. (30% / 70% = 43%)
Barge Water Effluent Discharge Rate	228	L/min	Equivalent to 430 cy/day free water discharged continuously.
Transport Characteristics			
Assumed Turbulent Dissipation Parameter	0.005	unitless	Recommended in USACE (1998) for estuary system.
Depth of Mixing	3	m	Discharge is assumed to mix to a depth of 3 meters.
Ambient Water Velocity	1	ft/s	Flow changes with river stage and tidal conditions. 1 ft/s was selected as a reasonable minimum average flow velocity over a tidal cycle. Higher flow velocities reduce predicted TSS due to dilution effects.
Specific Gravity of Sediment Particles	2.6	unitless	Reasonable specific gravity for LDW sediments.

Notes:

1. Dissolved chemical concentrations are calculated based on porewater concentrations for each chemical (based on partitioning). The volume of porewater is then assumed to mix with the volume of free water.

cy: cubic yard

ft/s: foot per second

kg/m^3: kilogram per cubic meter

LDW: Lower Duwamish Waterway

L/min: liter per minute

m: meter

USACE: U.S. Army Corps of Engineers

Table K-8
Barge Effluent Area of Mixing Calculation

Chemical	Marine Chronic Criteria (µg/L)	Sediment Concentration (mg/kg)	Dissolved Concentration in Effluent (µg/L)	Dilution Factor	Area of Mixing (feet)
Arsenic	36	18	364	9.1	4.7
Cadmium	7.9	0.61	47	4.9	3.1
Chromium VI	50	29	858	16	6.9
Copper	3.1	46	1,201	387	57
Lead	5.6	47	2.8		
Mercury	0.025	0.17	1.9	77	19
PCBs	0.030	0.74	0.36	11	5.3
Silver		0.29	19		
Zinc	81	113	1,074	12	5.7

Notes:

1. Sediment concentrations are based on the mean vertically-weighted average core concentrations in cores from the Design Dataset coupled with chronic criteria.
2. Dissolved chemical concentrations are calculated based on porewater concentrations for each chemical (based on partitioning). The volume of porewater is then assumed to mix with the volume of free water.
3. The dilution factor is the ratio of surface water to dredge return water that needs to be mixed in order to achieve water quality criteria, and is calculated using the EFQUAL equation (USACE 1991).
4. Area of mixing based on the Dilution Volume Method for CDF Effluent Discharges in USACE, 1998. Evaluation of Dredged Material Proposed for Discharge in Water of the U.S. – Testing Manual, Appendix C.
5. The dredge return water discharge rate based on the rate of dredging and the volume of free water is 228 L/min.

µg/L: microgram per liter

L/min: liter per minute

mg/kg: milligram per kilogram