APPENDIX B
CSO SOLIDS CHEMISTRY

KING COUNTY SEDIMENT MANAGEMENT PLAN 2018 UPDATE

APPENDIX B:
CSO SOLIDS CHEMISTRY

Prepared for

King County Department of Natural Resources and Parks Sediment Management Program

Sediment Management Plan Update Project

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1 INTRODUCTION

This appendix estimates CSO solids concentrations to evaluate the potential effects of CSO solids deposition (modeled in Appendix A) on chemical concentrations in sediment near CSOs. This appendix presents a method for estimating CSO solids concentrations in low concentration and high concentration CSO basins, compares these concentrations to screening levels (SMS criteria), and establishes threshold deposition rates that could result in screening level exceedances. This information is used for evaluating CSO model results in the main body of this document.

2 CSO SOLIDS CONCENTRATIONS FOR LOW CONCENTRATION AND HIGH CONCENTRATION BASINS

To estimate the effects of the deposition of CSO solids on receiving sediments, available data from sediment trap and solids grab sampling within the combined sewer lines were analyzed to develop characteristic CSO solids concentration profiles. Common chemicals of concern were selected for this analysis based on common benthic SMS exceedances found near both CSOs and stormwater outfalls. Both were selected because CSOs are typically 90% to 95% stormwater. There were between 31 and 85 samples depending on the analyte. All samples were collected by King County from the combined sewer system within individual CSO basins for source characterization and tracing purposes. Due to temporal and spatial variation in chemical concentrations, the small number of samples from any single CSO basin, and the lack of data from many CSO basins, the data were combined into a single dataset to represent the range of expected concentrations of CSO particulates, rather than attempting to assign unique concentrations to each CSO.

Analysis of the CSO solids concentration distributions shows that distributions tend to be bi-modal for some chemicals, indicating that there are CSO basins that tend toward lower concentrations and CSO basins that tend toward higher concentrations for those chemicals. To account for this and to capture a range of concentrations for all the chemicals, two CSO solids profiles were developed. The 25th percentile of all data were used to represent the low end of the range that could be expected from individual basins, and the 75th percentile of all data were used to represent the high end of the range that could be expected from individual basins. Note that basins where the high concentrations of some chemicals were found tended to be sampled more often since that's where source tracing occurred. Therefore, the dataset tends to be biased high for these compounds. However, looking at frequency distributions suggests that using the 25th percentile typically captured the low end of the range that could be expected from individual basins. The CSO solids concentrations for low concentration CSO basins and the high concentration CSO basins are presented in Tables B-1 and B-2, compared to screening levels, as discussed in the next two sections.

3 CSO SOLIDS CONCENTRATIONS COMPARED TO MARINE CRITERIA

Table B-1 presents the CSO solids concentrations for marine benthic SMS chemicals. For this analysis, the CSO solids concentrations were established using dry-weight-based values. Carbon normalized values were also presented, using the average total organic carbon content of all samples of 9%. The solids concentrations were then compared to the lower (SCO) and the higher (CSL) marine benthic criteria. For chemicals with carbon-normalized criteria, solids concentrations were compared to both the carbon normalized criteria and dry-weight-based criteria values (Apparent Effects Thresholds [AETs]).

The results indicate that if just CSO solids would deposit at CSOs (i.e., without the effects of ambient deposition, sediment mixing, or chemical degradation), some marine benthic SMS criteria would be exceeded. At the lower end of the expected range (basins with lower concentrations), 4-methylphenol is predicted to exceed both the CSL and SCO. BEHP is predicted to exceed the CSL and SCO when considering dry-weight-based criteria, but is not predicted to exceed carbon normalized values. Total PCBs are predicted to exceed the SCO only when considering dry-weight-based criteria only.

At the higher end of the expected range (basins with high concentrations), four chemicals are predicted to exceed both the CSL and SCO (2,4-dimethylphenol, 4-methylphenol [p-cresol], BEHP, and mercury). Zinc is predicted to exceed the SCO only. In addition, six organic compounds are predicted to exceed the CSL or SCO when considering dry-weight-based criteria only (chrysene, fluoranthene, phenanthrene, total PCBs, total HPAHs, and total LPAHs).

Table B-1 CSO Solids Concentrations Compared to Marine SMS Criteria

	SMS Criteria								CSO Solids Concentrations								Exceedance Factors (CSO Concentration/SMS Criteria)							
									Low Concentration CSO Basin Profile				High Concentration CSO Basin Profile				Low Concentration CSO Basin Profile				High Concentration CSO Basin Profile			
	SCO		LAET		CSL		2LAET		Dry Weight		OC Norm		Dry Weight		OC Norm		SCO		CSL		SCO		CSL	
Parameter	Value	Unit	Value	Unit	Value	Unit	Value	Unit	Value	Unit	Value	Unit	Value	Unit	Value	Unit	SCO	LAET	CSL	2LAET	SCO	LAET	CSL	2LAET
1,2,4-Trichlorobenzene	0.8	mg/kg-OC	31	ug/kg	1.8	mg/kg-OC	51	ug/kg	0.010	ug/Kg	0.00011	mg/kg-OC	0.152	ug/Kg	0.00166	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1,2-Dichlorobenzene	2.3	mg/kg-OC	35	ug/kg	2.3	mg/kg-OC	50	ug/kg	0.071	ug/Kg	0.00078	mg/kg-OC	1.360	ug/Kg	0.01483	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1,4-Dichlorobenzene	3.1	mg/kg-OC	110	ug/kg	9.0	mg/kg-OC	110	ug/kg	2.0	ug/Kg	0.022	mg/kg-OC	506.0	ug/Kg	5.518	mg/kg-OC	0.0	0.0	0.0	0.0	1.8	4.6	0.6	4.6
2,4-Dimethylphenol	29	ug/kg	29	ug/kg	29	ug/kg	29	ug/kg	0.082	ug/Kg			1.370	ug/Kg			0.0	--	0.0	--	0.0	--	0.0	--
2-Methylnaphthalene	38	mg/kg-OC	670	ug/kg	64	mg/kg-OC	670	ug/kg	4.1	ug/Kg	0.044	mg/kg-OC	260.0	ug/Kg	2.835	mg/kg-OC	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.4
2-Methylphenol (o-Cresol)	63	ug/kg	63	ug/kg	63	ug/kg	63	ug/kg	0.13	ug/Kg			1.43	ug/Kg			0.0	--	0.0	--	0.0	--	0.0	--
4-Methylphenol (p-Cresol)	670	ug/kg	670	ug/kg	670	ug/kg	670	ug/kg	5,050	ug/Kg			79,000	ug/Kg			7.5	--	7.5	--	118	--	118	--
Acenaphthene	16	mg/kg-OC	500	ug/kg	57	mg/kg-OC	500	ug/kg	0.89	ug/Kg	0.010	mg/kg-OC	4.60	ug/Kg	0.050	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acenaphthylene	66	mg/kg-OC	1,300	ug/kg	66	mg/kg-OC	1,300	ug/kg	0.16	ug/Kg	0.0017	mg/kg-OC	1.54	ug/Kg	0.0168	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anthracene	220	mg/kg-OC	960	ug/kg	1,200	mg/kg-OC	960	ug/kg	1.4	ug/Kg	0.015	mg/kg-OC	113.0	ug/Kg	1.232	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
Arsenic	57	mg/kg	57	mg/kg	93	mg/kg	93	mg/kg	5.3	mg/Kg			8.5	mg/Kg			0.1	--	0.1	--	0.1	--	0.1	--
Benzo(a)anthracene	110	mg/kg-OC	1,300	ug/kg	270	mg/kg-OC	1,600	ug/kg	267	ug/Kg	2.9	mg/kg-OC	1,050	ug/Kg	11.5	mg/kg-OC	0.0	0.2	0.0	0.2	0.1	0.8	0.0	0.7
Benzo(a)pyrene	99	mg/kg-OC	1,600	ug/kg	210	mg/kg-OC	1,600	ug/kg	197	ug/Kg	2.1	mg/kg-OC	968	ug/Kg	10.6	mg/kg-OC	0.0	0.1	0.0	0.1	0.1	0.6	0.1	0.6
Benzo(g,h,i)perylene	31	mg/kg-OC	670	ug/kg	78	mg/kg-OC	720	ug/kg	98	ug/Kg	1.1	mg/kg-OC	452	ug/Kg	4.9	mg/kg-OC	0.0	0.1	0.0	0.1	0.2	0.7	0.1	0.6
Benzoic Acid	650	ug/kg	650	ug/kg	650	ug/kg	650	ug/kg	13	ug/Kg			482	ug/Kg			0.0	--	0.0	--	0.7	--	0.7	--
Benzyl Alcohol	57	ug/kg	57	ug/kg	73	ug/kg	73	ug/kg	0.25	ug/Kg			3.98	ug/Kg			0.0	--	0.0	--	0.1	--	0.1	--
Bis(2-Ethylhexyl)Phthalate	47	mg/kg-OC	1,300	ug/kg	78	mg/kg-OC	3,100	ug/kg	3,640	ug/Kg	40	mg/kg-OC	20,600	ug/Kg	225	mg/kg-OC	0.8	2.8	0.5	1.2	4.8	15.8	2.9	6.6
Cadmium	5.1	mg/kg	5.1	mg/kg	6.7	mg/kg	6.7	mg/kg	0.87	mg/Kg			2.74	mg/Kg			0.2	--	0.1	--	0.5	--	0.4	--
Chromium	260	mg/kg	260	mg/kg	270	mg/kg	270	mg/kg	39	mg/Kg			63	mg/Kg			0.1	--	0.1	--	0.2	--	0.2	--
Chrysene	110	mg/kg-OC	1,400	ug/kg	460	mg/kg-OC	2,800	ug/kg	349	ug/Kg	3.8	mg/kg-OC	1,470	ug/Kg	16.0	mg/kg-OC	0.0	0.2	0.0	0.1	0.1	1.1	0.0	0.5
Copper	390	mg/kg	390	mg/kg	390	mg/kg	390	mg/kg	152	mg/Kg			210	mg/Kg			0.4	--	0.4	--	0.5	--	0.5	--
Dibenzo(a,h)anthracene	12	mg/kg-OC	230	ug/kg	33	mg/kg-OC	230	ug/kg	1.1	ug/Kg	0.012	mg/kg-OC	6.4	ug/Kg	0.069	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dibenzofuran	15	mg/kg-OC	540	ug/kg	58	mg/kg-OC	540	ug/kg	0.88	ug/Kg	0.010	mg/kg-OC	4.33	ug/Kg	0.047	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diethyl Phthalate	61	mg/kg-OC	200	ug/kg	110	mg/kg-OC	1,200	ug/kg	0.31	ug/Kg	0.0034	mg/kg-OC	3.03	ug/Kg	0.0330	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dimethyl Phthalate	53	mg/kg-OC	71	ug/kg	53	mg/kg-OC	160	ug/kg	0.26	ug/Kg	0.0028	mg/kg-OC	3.19	ug/Kg	0.0348	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Di-N-Butyl Phthalate	220	mg/kg-OC	1,400	ug/kg	1,700	mg/kg-OC	1,400	ug/kg	2.2	ug/Kg	0.024	mg/kg-OC	63.4	ug/Kg	0.691	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Di-N-Octyl Phthalate	58	mg/kg-OC	6,200	ug/kg	4,500	mg/kg-OC	6,200	ug/kg	0.57	ug/Kg	0.0062	mg/kg-OC	1,540	ug/Kg	16.7939	mg/kg-OC	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.2
Fluoranthene	160	mg/kg-OC	1,700	ug/kg	1,200	mg/kg-OC	2,500	ug/kg	709	ug/Kg	7.7	mg/kg-OC	1,780	ug/Kg	19.4	mg/kg-OC	0.0	0.4	0.0	0.3	0.1	1.0	0.0	0.7
Fluorene	23	mg/kg-OC	540	ug/kg	79	mg/kg-OC	540	ug/kg	1.4	ug/Kg	0.015	mg/kg-OC	65.6	ug/Kg	0.715	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
Hexachlorobenzene	0.38	mg/kg-OC	22	ug/kg	2.30	mg/kg-OC	70	ug/kg	0.016	ug/Kg	0.00017	mg/kg-OC	0.143	ug/Kg	0.00156	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hexachlorobutadiene (Hexachloro-1,3-butadiene)	3.9	mg/kg-OC	11	ug/kg	6.2	mg/kg-OC	120	ug/kg	0.035	ug/Kg	0.00038	mg/kg-OC	0.699	ug/Kg	0.00762	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Indeno(1,2,3-c,d)pyrene	34	mg/kg-OC	600	ug/kg	88	mg/kg-OC	690	ug/kg	6.4	ug/Kg	0.069	mg/kg-OC	456.0	ug/Kg	4.973	mg/kg-OC	0.0	0.0	0.0	0.0	0.1	0.8	0.1	0.7
Lead	450	mg/kg	450	mg/kg	530	mg/kg	530	mg/kg	88	mg/Kg			160	mg/Kg			0.2	--	0.2	--	0.4	--	0.3	--
Mercury	0.41	mg/kg	0.41	mg/kg	0.59	mg/kg	0.59	mg/kg	0.25	mg/Kg			0.94	mg/Kg			0.6	--	0.4	--	2.3	--	1.6	--
Naphthalene	99	mg/kg-OC	2,100	ug/kg	170	mg/kg-OC	2,100	ug/kg	0.18	ug/Kg	0.0020	mg/kg-OC	99.00	ug/Kg	1.0796	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N-Nitrosodiphenylamine	11	mg/kg-OC	28	ug/kg	11	mg/kg-OC	40	ug/kg	0.30	ug/Kg	0.0033	mg/kg-OC	3.45	ug/Kg	0.0376	mg/kg-OC	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
Pentachlorophenol	360	ug/kg	360	ug/kg	690	ug/kg	690	ug/kg	1.1	ug/Kg			20.4	ug/Kg			0.0	--	0.0	--	0.1	--	0.0	--
Phenanthrene	100	mg/kg-OC	1,500	ug/kg	480	mg/kg-OC	1,500	ug/kg	323	ug/Kg	3.5	mg/kg-OC	1,600	ug/Kg	17.4	mg/kg-OC	0.0	0.2	0.0	0.2	0.2	1.1	0.0	1.1
Phenol	420	ug/kg	420	ug/kg	1,200	ug/kg	1,200	ug/kg	0.78	ug/Kg			9.20	ug/Kg			0.0	--	0.0	--	0.0	--	0.0	--
Pyrene	1,000	mg/kg-OC	2,600	ug/kg	1,400	mg/kg-OC	3,300	ug/kg	830	ug/Kg	9.1	mg/kg-OC	2,460	ug/Kg	26.8	mg/kg-OC	0.0	0.3	0.0	0.3	0.0	0.9	0.0	0.7
Silver	6.1	mg/kg	6.1	mg/kg	6.1	mg/kg	6.1	mg/kg	2.0	mg/Kg			3.7	mg/Kg			0.3	--	0.3	--	0.6	--	0.6	--
Total PCB Aroclors (SMS Marine 2013)	12	mg/kg-OC	130	ug/kg	65	mg/kg-OC	1,000	ug/kg	181	ug/Kg	2.0	mg/kg-OC	526	ug/Kg	5.7	mg/kg-OC	0.2	1.4	0.0	0.2	0.5	4.0	0.1	0.5
Total HPAH (SMS)	960	mg/kg-OC	12,000	ug/kg	5,300	mg/kg-OC	17,000	ug/kg	4,680	ug/Kg	51	mg/kg-OC	12,500	ug/Kg	136	mg/kg-OC	0.1	0.4	0.0	0.3	0.1	1.0	0.0	0.7
Total LPAH (SMS)	370	mg/kg-OC	5,200	ug/kg	780	mg/kg-OC	5,200	ug/kg	461	ug/Kg	5.0	mg/kg-OC	5,580	ug/Kg	60.9	mg/kg-OC	0.0	0.1	0.0	0.1	0.2	1.1	0.1	1.1
Zinc	410	mg/kg	410	mg/kg	960	mg/kg	960	mg/kg	347	mg/Kg			756	mg/Kg			0.8	--	0.4	--	1.8	--	0.8	--

Notes:

Shaded = exceedance factor > 1

-- = AET comparison not applicable because the SCO and CSL criteria are dry weight-based.

2LAET = second lowest apparent effects threshold
µg/kg = microgram per kilogram
CSL = Cleanup Screening Level
CSO = combined sewer overflow
HPAH = high-molecular-weight polycyclic aromatic hydrocarbon
LAET = lowest apparent effects threshold
LPAH = low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg = milligram per kilogram
OC = organic carbon
PAH = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SCO = Sediment Cleanup Objective
SMS = Sediment Management Standards

Table B-2

CSO Solids Concentrations Compared to Freshwater SMS Criteria

Parameter	SMS Criteria				CSO Solids Concentrations				Exceedance Factors (CSO Concentration/SMS Criteria)			
					Low Concentration CSO Basin Profile		High Concentration CSO Basin Profile		Low Concentration CSO Basin Profile		High Concentration CSO Basin Profile	
	SCO		CSL		Dry Weight		Dry Weight					
	Value	Unit	Value	Unit	Value	Unit	Value	Unit	SCO	CSL	SCO	CSL
4-Methylphenol (p-Cresol)	260	ug/kg	2,000	ug/kg	5,050	ug/Kg	79,000	ug/Kg	19	2.5	304	40
Arsenic	14	mg/kg	120	mg/kg	5.3	mg/Kg	8.5	mg/Kg	0.4	0.0	0.6	0.1
Benzoic Acid	2,900	ug/kg	3,800	ug/kg	13	ug/Kg	482	ug/Kg	0.0	0.0	0.2	0.1
Bis(2-Ethylhexyl)Phthalate	500	ug/kg	22,000	ug/kg	3,640	ug/Kg	20,600	ug/Kg	7.3	0.2	41	0.9
Cadmium	2.1	mg/kg	5.4	mg/kg	0.87	mg/Kg	2.7	mg/Kg	0.4	0.2	1.3	0.5
Carbazole	900	ug/kg	1,100	ug/kg	1.3	ug/Kg	21	ug/Kg	0.0	0.0	0.0	0.0
Chromium	72	mg/kg	88	mg/kg	39	mg/Kg	63	mg/Kg	0.5	0.4	0.9	0.7
Copper	400	mg/kg	1,200	mg/kg	152	mg/Kg	210	mg/Kg	0.4	0.1	0.5	0.2
Dibenzofuran	200	ug/kg	680	ug/kg	0.88	ug/Kg	4.3	ug/Kg	0.0	0.0	0.0	0.0
Di-N-Butyl Phthalate	380	ug/kg	1,000	ug/kg	2.2	ug/Kg	63	ug/Kg	0.0	0.0	0.2	0.1
Di-N-Octyl Phthalate	39	ug/kg	1,100	ug/kg	0.57	ug/Kg	1,540	ug/Kg	0.0	0.0	39	1.4
Lead	360	mg/kg	1,300	mg/kg	88	mg/Kg	160	mg/Kg	0.2	0.1	0.4	0.1
Mercury	0.7	mg/kg	0.8	mg/kg	0.25	mg/Kg	0.94	mg/Kg	0.4	0.3	1.4	1.2
Nickel	26	mg/kg	110	mg/kg	34	mg/Kg	58	mg/Kg	1.3	0.3	2.2	0.5
Pentachlorophenol	1,200	ug/kg	1,200	ug/kg	1.1	ug/Kg	20	ug/Kg	0.0	0.0	0.0	0.0
Phenol	120	ug/kg	210	ug/kg	0.78	ug/Kg	9.2	ug/Kg	0.0	0.0	0.1	0.0
Selenium	11	mg/kg	20	mg/kg	0.0088	mg/Kg	0.0090	mg/Kg	0.0	0.0	0.0	0.0
Silver	0.6	mg/kg	1.7	mg/kg	2.0	mg/Kg	3.7	mg/Kg	3.5	1.2	6.4	2.1
Total PAHs	17,000	µg/kg	30,000	µg/kg	5,141	µg/kg	18,080	µg/kg	0.3	0.2	1.1	0.6
Total PCB Aroclors (SMS Freshwater 2013)	110	µg/kg	2,500	µg/kg	181	ug/Kg	526	ug/Kg	1.6	0.1	4.8	0.2
Zinc	3,200	mg/kg	4,200	mg/kg	347	mg/Kg	756	mg/Kg	0.1	0.1	0.2	0.2

Notes:

Shaded = exceedance factor > 1

µg/kg = microgram per kilogram
CSL = Cleanup Screening Level
CSO = combined sewer overflow
mg/kg = milligram per kilogram
PAH = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SCO = Sediment Cleanup Objective
SMS = Sediment Management Standards

Note that carbon normalized criteria are less likely to result in exceedances, therefore sediment samples that are carbon normalized are less likely to result in exceedances. Marine sediment samples are carbon-normalize when organic carbon content is between 0.5% and 3.5% (Ecology 2105), which is typical of sediment near CSOs.

4 CSO SIGNATURE CONCENTRATIONS COMPARED TO FRESHWATER CRITERIA

Table B-2 presents the CSO signature concentrations for freshwater benthic SMS chemicals. All freshwater criteria are dry-weight-based values. The results indicate that if just CSO solids would deposit at CSOs (i.e., without the effects of ambient deposition, sediment mixing, or degradation), some freshwater benthic SMS criteria would be exceeded. At the lower end of the expected range (basins with low concentrations), 4-methylphenol and silver are predicted to exceed both the CSL and SCO, and BEHP, nickel, and total PCBs are predicted to exceed the SCO. These chemicals are also predicted to exceed the same standards in basins at the higher end of the expected range (high concentration basins), and in addition, di-n-octyl phthalate and mercury are predicted to exceed the CSL, and cadmium and total PAHs are predicted to exceed the SCO.

5 AMBIENT DEPOSITION RATES AND CONCENTRATIONS

As discussed above, comparing CSO solids concentrations to SMS criteria does not account for ambient sedimentation, sediment mixing, or degradation, yet sediment near outfalls also reflects the effects of these processes. In particular, as CSO particulates settle near outfalls, they mix with other sources of sedimentation. For this analysis, the ambient deposition rate was estimated for marine CSOs and for freshwater CSOs to more appropriately estimate the effect of CSO solids on receiving sediments.

5.1 Ambient Deposition Rates

Ambient deposition varies by location; however, as a reasonable working assumption, the same ambient deposition rate was used for all marine CSOs and a different rate for all freshwater CSOs. Marine outfalls were estimated to have an ambient deposition rate of 0.56 cm/year based on information in Elliott Bay shoreline areas using several methods, including stable lead and contaminant marker profiling in sediment cores (Romberg et al.

1987), along with monitoring the rate of accumulation of recent sediments on top of the 1990 Denny Way cap (Romberg and Wilson 1989; King County 2005). Excluding pre-cap cores collected adjacent to the former shoreline outfall with locally elevated historical deposition rates related to raw sewage discharges, the average net sedimentation rate calculated from these measurements along the Elliott bay shoreline near Denny Way is approximately 0.56 ±0.13 cm/year. Similar net sedimentation rates have been reported in other areas of Elliott Bay (CH2M Hill 2005; King County 2010, Anchor QEA and Herrera 2017), corroborating these data. The Denny Way sedimentation rate, of 0.56 cm/year, was applied to all other marine CSOs.

Freshwater CSOs were estimated to have an ambient deposition rate of 0.3 cm/year based on a review of available literature documenting ambient sedimentation rates for Lake Washington and Lake Union (Ecology, 2001; Barnes et al. 1979).

5.2 Ambient Deposition Concentrations

Ambient deposition will have its own chemical profile depending on the location and source of ambient sedimentation. A range of potential ambient deposition concentrations was used for this analysis.

For the low end of the range, ambient deposition concentrations will be equivalent to the natural background concentrations in Puget Sound. Natural background concentrations from the Sediment Cleanup Users Manual II (SCUM II) were used when available (Ecology 2015). Table B-3 presents the natural background concentrations used for this analysis. For organic compounds without established natural background concentrations in SCUM II, the ambient deposition concentration from the high end of the range was used, as described in the following paragraph. Therefore, those compounds only appear in Table B-4a or B-4b.

Table B-3
Puget Sound Natural Background Concentrations

Chemical	Unit	Natural Background
Total PCBs	ug/kg	3.5
Arsenic	mg/kg	11
Cadmium	mg/kg	0.8
Chromium	mg/kg	62
Copper	mg/kg	45
Lead	mg/kg	21
Mercury	mg/kg	0.2
Nickel	mg/kg	50
Silver	mg/kg	0.24
Zinc	mg/kg	93

Source: https://fortress.wa.gov/ecy/publications/documents/1209057.pdf Table 10-1

Table B-4a
Average Inner Elliott Bay Concentrations

Chemical	Unit	Average
1,4-Dichlorobenzene	ug/Kg	10
4-Methylphenol (p-Cresol)	ug/Kg	65
Bis(2-Ethylhexyl)Phthalate	ug/Kg	83
Chrysene	ug/Kg	130
Fluoranthene	ug/Kg	210
Mercury	mg/Kg	0.23
Phenanthrene	ug/Kg	150
Total PCB Aroclors	ug/kg	61
Total HPAH	ug/kg	1,300
Total LPAH	ug/kg	510
Zinc	ug/Kg	65

Source: Average of available EIM data within Inner Elliott Bay within the last 10 years.

Table B-4b
Central Lake Washington Concentrations

Chemical	Unit	Average
4-Methylphenol (p-Cresol)	ug/kg	72
Bis(2-Ethylhexyl)Phthalate	ug/kg	150
Cadmium	mg/kg	1.8
Di-N-Octyl Phthalate	ug/kg	27
Mercury	mg/kg	0.41
Nickel	mg/kg	61
Silver	mg/kg	1.4
Total PAHs	ug/kg	1,400
Total PCB Aroclors	ug/kg	73

Source: Lake Washington Location KCM-0826 (Average of 2008, 2009, and 2010 data)

For the high end of the range, ambient deposition concentrations will be equivalent to more highly urbanized waterways with multiple diffuse sources. For marine CSOs, the high end of ambient deposition was determined based on the average of inner Elliott Bay samples collected within the last 10 years that are not within 1,000 feet of the Seattle shoreline or existing cleanup sites. For freshwater CSOs, the high end of ambient deposition was determined based on the average of three samples in the center of Lake Washington (station KCM-0826 sampled in 2008, 2009, and 2010). Tables B-4a and B-4b present the high end of ambient concentrations used for this analysis.

6 THRESHOLD CSO DEPOSITION RATES

Section 6 uses the information presented in Sections 1–5 (CSO solids concentrations, the ambient deposition rates, and ambient solids concentrations) to calculate CSO deposition rates above which sediments are predicted to exceed SMS criteria. This information is used for interpreting the CSO deposition rate predictions from Appendix A modelling.

6.1 Threshold CSO Deposition Rate Calculation

In order to determine if the combination of CSO and ambient deposition has the potential to exceed SMS criteria near a CSO, a mass-balance calculation was performed to calculate the threshold CSO deposition rate that is predicted to result in an exceedance in the sediment bed. Equation 1 describes that the net sedimentation and resulting sediment concentrations are assumed to be composed of two parts, CSO solids and ambient solids:

$$DsCs = DcCc + DaCa \tag{1}$$

where:

Ds	=	net sediment deposition rate at a location
Cs	=	average sediment concentration in depositing solids in a location (expressed as an exceedance factor), which is assumed to be equal to the bedded sediment concentration
Dc	=	*deposition rate in CSO solids*
Cc	=	concentration in CSO solids (expressed as an exceedance factor)
Da	=	deposition rate in ambient solids
Ca	=	concentration in ambient solids (expressed as an exceedance factor)

The equation is based on the mass balance of net incoming solids assumed to be a mixture from two sources: CSO solids and ambient deposition. Therefore, assuming all solids have the same density, the following is also true:

$$Ds = Dc + Da \tag{2}$$

For this analysis, we are interested in the CSO solids deposition rate (Dc), where the bedded sediment concentration is equal to the standard (i.e., Cs = 1). Equation 2 is substituted into Equation 1 to remove Ds from the equation, Cs is set equal to 1:

$$(Dc + Da) * 1 = DcCc + DaCa \tag{3}$$

The resulting equation is solved for Dc:

$$Dc = \frac{(CaDa - Da)}{(1 - Cc)} \tag{4}$$

In Equation 4, Dc is the deposition rate in CSO solids that would result in an exceedance factor of 1.0 in net incoming sediment (considering both CSO solids and ambient solids). Deposition rates greater than Dc would exceed SMS criteria in the location, and deposition rates less than Dc would pass SMS criteria.

The following assumptions were part of this calculation:

1. Bedded sediment equals the concentration in net incoming sediment, so there is no impact from pre-existing bedded sediment. Bedded sediment is in equilibrium with net incoming sediment.
2. Ambient deposition rate is constant, regardless of CSO solid deposition rate.
3. There is no chemical degradation.
4. CSO solids and ambient solids have the same density.

Tables B-5 through B-8 show the CSO deposition rates (Dc) that are predicted to result in exceedances for chemicals with CSO solids concentrations greater than criteria. Chemicals with higher exceedance factors have lower threshold deposition rates, because it takes less CSO deposition to result in an exceedance. Chemicals with lower exceedance factors have higher threshold deposition rates because it takes more CSO deposition to result in an exceedance. In addition, the high ambient concentration estimates have been paired with the high concentration basin estimates, to further reduce the threshold deposition rates for this bounding analysis. Conversely, the low ambient concentration estimates have been paired with the low concentration basin estimates, to further increase the threshold deposition rates for this analysis.

Table B-5
Marine CSO Threshold Deposition Rates

Chemical	CSO Deposition Rate Above Which SMS Criteria are Exceeded Considering Ambient Deposition (cm/yr)			
	SCO		CSL	
	Possible Exceedance	Predicted Exceedance	Possible Exceedance	Predicted Exceedance
1,4-Dichlorobenzene	0.14	--	0.14	--
4-Methylphenol (p-Cresol)	0.0043	0.077	0.0043	0.077
Bis(2-Ethylhexyl)Phthalate	0.035	0.29	0.10	3.1
Chrysene	10	--	--	--
Fluoranthene	10	--	--	--
Mercury	0.19	--	0.58	--
Phenanthrene	7.6	--	7.6	--
Total PCB Aroclors	0.10	1.4	--	--
Total HPAH (SMS) (U = 0)	12	--	--	--
Total LPAH (SMS) (U = 0)	6.9	--	6.9	--
Zinc	0.56	--	--	--

Notes:

1. Rates calculated with an estimated ambient deposition rate of 0.56 cm/yr.
2. High end estimate (Predicted Exceedance) is for CSO particulate concentration representative of low-concentration basins, and ambient deposition concentration from Puget Sound natural background.
3. Low end estimate (Possible Exceedance) is for CSO particulate concentration representative of high-concentration basins, and ambient deposition concentrations from inner Elliott Bay.
4. 4-Methylphenol (p-Cresol) and 1,4,- dichlorobenzene exceedances are transient in sediment because the chemicals degrade rapidly.

-- = not applicable (CSO particulate does not exceed criteria)

cm/yr = centimeter per year

CSL = Cleanup Screening Level

CSO = combined sewer overflow

HPAH = high-molecular-weight polycyclic aromatic hydrocarbon

LPAH = low-molecular-weight polycyclic aromatic hydrocarbon

PCB = polychlorinated biphenyl

SCO = Sediment Cleanup Objective

SMS = Sediment Management Standards

Table B-6a

Marine Sediment CSL Threshold Deposition Rates

CSO Deposition Rate (cm/yr)			Possible Exceedance	Predicted Exceedance
0	to	0.10	None	None
0.10	to	0.58	BEHP	None
0.58	to	3.1	BEHP, mercury	None
3.1	to	6.9	BEHP, mercury	BEHP
6.9	and above		Additional analytes	BEHP

Table B-6b

Marine Sediment SCO Threshold Deposition Rates

CSO Deposition Rate (cm/yr)			Possible Exceedance	Predicted Exceedance
0	to	0.035	None	None
0.035	to	0.10	BEHP	None
0.10	to	0.19	BEHP, PCBs	None
0.19	to	0.29	BEHP, PCBs, mercury	None
0.29	to	0.56	BEHP, PCBs, mercury	BEHP
0.56	to	1.4	BEHP, PCBs, mercury, zinc	BEHP
1.4	to	6.9	BEHP, PCBs, mercury, zinc	BEHP, PCBs
6.9	and above		Additional analytes	BEHP, PCBs

Note:
4-Methylphenol (p-Cresol) and 1,4,- dichlorobenzene exceedances are transient in sediment because the chemicals degrade rapidly. These chemicals are not included in this analysis.

Table B-7
Freshwater CSO Deposition Rates

Chemical	CSO Deposition Rate Above Which SMS Criteria are Exceeded Considering Ambient Deposition (cm/yr)			
	SCO		CSL	
	Possible Exceedance	Predicted Exceedance	Possible Exceedance	Predicted Exceedance
4-Methylphenol (p-Cresol)	0.00072	0.012	0.00072	0.19
Bis(2-Ethylhexyl)Phthalate	0.0052	0.033	--	--
Cadmium	0.14	--	--	--
Di-N-Octyl Phthalate	0.0024	--	0.73	--
Mercury	0.27	--	0.86	--
Nickel	Exceeds	Exceeds	--	--
Silver	Exceeds	0.069	0.046	1.5
Total PAHs	4.3	--	--	--
Total PCB Aroclors	0.027	0.45	--	--

Notes:
1. Rates calculated with an estimated ambient deposition rate of 0.3 cm/yr.
2. High end estimate (Predicted Exceedance) is for CSO particulate concentration representative of low-concentration basins, and ambient deposition concentration from Puget Sound natural background.
3. Low end estimate (Possible Exceedance) is for CSO particulate concentration representative of high-concentration basins, and ambient deposition concentrations from the center of Lake Washington.
4. 4-Methylphenol (p-Cresol) exceedances are not found in sediment because contaminant degrades rapidly.

-- = not applicable (CSO particulate does not exceed criteria)
cm/yr = centimeter per year
CSL = Cleanup Screening Level
CSO = combined sewer overflow
Exceeds = SMS criteria exceeded regardless of deposition rate
PAH = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SCO = Sediment Cleanup Objective
SMS = Sediment Management Standards

Table B-8a
Freshwater Sediment CSL Threshold Deposition Rates

CSO Deposition Rate (cm/yr)			Possible Exceedance	Predicted Exceedance
0	to	0.046	None	None
0.046	to	0.73	Silver	None
0.73	to	0.86	Silver, di-n-octyl phthalate	None
0.86	to	1.5	Silver, di-n-octyl phthalate, mercury	None
1.5	to	6.9	Silver, di-n-octyl phthalate, mercury	Silver
6.9	and above		Additional analytes	Silver

Table B-8b
Freshwater Sediment SCO Threshold Deposition Rates

CSO Deposition Rate (cm/yr)			Possible Exceedance	Predicted Exceedance
0	to	0.0024	Nickel, silver	Nickel
0.0024	to	0.0052	Nickel, silver, di-n-octyl phthalate	Nickel
0.0052	to	0.027	Nickel, silver, di-n-octyl phthalate, BEHP	Nickel
0.027	to	0.033	Nickel, silver, di-n-octyl phthalate, BEHP, PCBs	Nickel
0.033	to	0.069	Nickel, silver, di-n-octyl phthalate, BEHP, PCBs	Nickel, BEHP
0.069	to	0.14	Nickel, silver, di-n-octyl phthalate, BEHP, PCBs	Nickel, BEHP, silver
0.14	to	0.27	Nickel, silver, di-n-octyl phthalate, BEHP, PCBs, cadmium	Nickel, BEHP, silver
0.27	to	0.45	Nickel, silver, di-n-octyl phthalate, BEHP, PCBs, cadmium, mercury	Nickel, BEHP, silver
0.45	to	4.3	Nickel, silver, di-n-octyl phthalate, BEHP, PCBs, cadmium, mercury	Nickel, BEHP, silver, PCBs
4.3	and above		Additional analytes	Nickel, BEHP, silver, PCBs

Note:
4-Methylphenol (p-Cresol) exceedances are not found in sediment because contaminant degrades rapidly and not included

6.2 Comparison to Marine Criteria

For marine criteria, dry-weight-based AET values were used as the basis of the calculation instead of carbon-normalized values because they result in higher exceedance factors and therefore provide a more conservative (i.e., worst-case) result. As shown in Table B-5, 4-methylphenol (p-cresol) and 1,4-dichlorobenzene have high SMS exceedance factors in CSO solids and resulting low threshold deposition rates; however, both these compounds tend to have transitory effects in sediment because of relatively fast degradation rates in aquatic environments. Both are not widely observed in CSO receiving sediment samples exceeding criteria. They also vary temporally where they are observed with only occasional exceedances of criteria. For these reasons, these two chemicals are not identified as key chemicals for this analysis. The next highest exceedance factors in CSO solids and resulting lowest threshold deposition rates were for BEHP, PCBs, mercury, and zinc. These chemicals are identified as key chemicals for this analysis.

Table B-6 summarizes the predicted exceedance threshold CSO deposition rates for these chemicals. The results indicate that only a few chemicals potentially result in SCO or CSL exceedances. For BEHP, the CSO deposition rate that could result in an exceedance is relatively low, due to the widespread distribution of the contaminant in CSO basins. CSL criteria are predicted to be exceeded at 3.1 cm/year in low concentration basins (for BEHP), and could be exceeded with as little as 0.1 cm/year in high concentration basins (for BEHP). SCO criteria are predicted to be exceeded at 0.29 cm/year (for BEHP), and could be exceeded with as little as 0.035 cm/year (for BEHP), depending on CSO and ambient sediment conditions. The low concentration basins have higher threshold sedimentation rates because more CSO solids would be required to result in an exceedance; conversely, high concentration basins have lower threshold sedimentation rates because less CSO solid would be required to result in an exceedance.

Other contaminants (mercury, PCBs, and zinc) that are relatively widespread are more likely than other contaminants to have possible exceedances, however, these are not predicted to exceed the SCO or CSL except at high CSO deposition rates.

6.3 Comparison to Freshwater Criteria

For freshwater criteria, the possible sediment exceedances from the deposition of CSO solids are shown in Table B-7. Similar to marine sediments, 4-methylphenol (p-cresol) is not considered a key benthic risk driver in CSO receiving sediments for this analysis. The next highest exceedance factors in CSO solids and resulting lowest threshold deposition rates were for nickel, silver, di-N-octyl phthalate, BEHP, PCBs, cadmium, and mercury. These chemicals are identified as key chemicals for this analysis.

Table B-8 summarizes the predicted exceedance threshold CSO deposition rates for these chemicals. The results indicate that several chemicals potentially result in SCO or CSL exceedances. For silver, CSO deposition rate that could result in an exceedance is relatively low, due to the widespread distribution of the contaminant in CSO basins. CSL criteria are predicted to be exceeded at 1.5 cm/year in low concentration basins (for silver), and could be exceeded with as little as 0.05 cm/year in high concentration basins (for silver). In addition, SCO criteria are predicted to be exceeded for nickel based on elevated ambient concentrations only, even at Puget Sound natural background concentrations. Similarly, silver is predicted to exceed the SCO based on ambient deposition only, based on central Lake Washington concentrations. In addition, phthalates (BEHP and di-n-octyl phthalate) have potential or predicted exceedances of the SCO at low CSO deposition rates.

Other contaminants (mercury, PCBs, and cadmium) that are relatively widespread are more likely than other contaminants to have possible exceedances; however, these are not predicted to exceed the SCO or CSL except at relatively high CSO deposition rates.

6.4 CSO Threshold Deposition Rates and Clusters of Concern

Under the SMS, a cluster of potential concern is identified if the average of three proximal exceedance locations exceed the CSL. Sampling locations are typically a minimum 70 feet apart from one another, so a cluster of potential concern is created by exceeding the CSL in an area of about 5,000 square feet, or by having one location that is several times greater than the CSL, thus increasing the average to above the CSL.

The modeling results indicate that in marine sediments, for the contaminant that is most likely to exceed the CSL (BEHP), CSO deposition rates higher than 3.1 cm/year are predicted to create a cluster of potential concern, and CSO deposition rates as low as 0.10 cm/year has some potential to result in a cluster of potential concern, depending on individual CSO concentrations. See Table B-6a for all potential and predicted CSL exceedances. In freshwater sediments, for the contaminant that is most likely to exceed the CSL (silver), modeling results indicate that CSO deposition rates higher than 1.5 cm/year are predicted to create a cluster of potential concern, and CSO deposition rates as low as 0.05 cm/year has some potential to result in a cluster of potential concern, depending on individual CSO concentrations. See Table B-8a for all potential and predicted CSL exceedances.

The results of this model can also be used to evaluate recontamination potential. CSOs that are predicted to exceed the lower of the deposition rates may need further source characterization to determine potential for recontamination resulting in a cluster of potential concern.

Given the variation in CSO discharges and receiving water conditions, sediment conditions, and the number of assumptions that go into this analysis, the following general threshold CSO deposition rates were established for interpretation. The CSO deposition rate of greater than 0.10 cm/year was established as warranting further investigation with a potential for creating a cluster of potential concern. The CSO deposition rate of greater than 1.0 cm/year was established as being more likely to result in a cluster of potential concern (with deposition rates of 3.2 cm/year and 1.5 cm/year being predicted to create a cluster of potential concern for marine and freshwater CSOs respectively). These orders of magnitude deposition rates are used as a rule of thumb for interpreting the model results in the main body of this SMP update and provide a screening tool as a modeling line of evidence.

7 SUMMARY AND CONCLUSIONS

To link the effects of CSO solids deposition (modeled in Appendix A) to the chemical concentrations in bedded sediment, CSO solid concentrations were estimated from available CSO solids data. Based on the distributions of chemical concentrations, a range of chemical concentrations were then established to represent both the low and high end of the range that could be expected from individual CSO basins. Finally, threshold CSO deposition rates were calculated that are predicted to result in a cluster of potential concern (assuming low end concentrations) and that could possibly result in a cluster of potential concern (assuming high end concentrations). Due to the high variability in CSO solids concentrations and CSO sediment conditions, general threshold depositions rates were established to help interpret the model results. The CSO deposition rate of 0.10 cm/year was established as warranting further investigation and possibly creating a cluster of potential concern. The CSO deposition rate of 1.0 cm/year was established as being more likely to result in a cluster of potential concern.

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