

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Tributyltin ion							
% Detected	33.3	0	NA	NA	NA	NA	0
Min. nondetect (µg/kg)	1.6	1.5	NA	NA	NA	NA	1.5
Max. nondetect (µg/kg)	1.7	1.7	NA	NA	NA	NA	1.6
Mean (µg/kg)	--	--	NA	NA	NA	NA	--
Median (µg/kg)	--	--	NA	NA	NA	NA	--
Min. detected (µg/kg)	13	--	NA	NA	NA	NA	--
Max. detected (µg/kg)	13	--	NA	NA	NA	NA	--
Max. detected location	SH-02	--	NA	NA	NA	NA	--
Low molecular weight PAHs							
Number of samples	27	25	17	3	6	0	3
Total LPAHs							
% Detected	66.7	72.0	11.8	0	0	NA	0
Min. nondetect (mg/kg OC)	0.39	0.57	0.43	0.42	0.78	NA	3.1
Max. nondetect (mg/kg OC)	3.9	13	2.3	44	3.5	NA	7.3
Mean (mg/kg OC)	4.3 ^a	2.9 ^a	--	--	--	NA	--
Median (mg/kg OC)	1.1 ^a	1.5 ^a	--	--	--	NA	--
Min. detected (mg/kg OC)	0.38	0.20	1.5	--	--	NA	--
Max. detected (mg/kg OC)	53	16	2.5	--	--	NA	--
Max. detected location	SH-11	SH-18	OB-07	--	--	NA	--
Acenaphthene							
% Detected	11.1	12.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.074	0.12	0.17	0.17	0.32	NA	1.3
Max. nondetect (mg/kg OC)	20	5.3	0.92	18	1.4	NA	2.9
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	0.21	0.24	--	--	--	NA	--
Max. detected (mg/kg OC)	0.53	1.4	--	--	--	NA	--
Max. detected location	SH-02	SH-12	--	--	--	NA	--
Acenaphthylene							
% Detected	18.5	8.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.15	0.12	0.18	0.18	0.34	NA	1.3
Max. nondetect (mg/kg OC)	20	5.6	0.98	19	1.5	NA	3.1
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	0.11	0.21	--	--	--	NA	--
Max. detected (mg/kg OC)	1.3	0.68	--	--	--	NA	--
Max. detected location	SH-02	SH-12	--	--	--	NA	--

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Anthracene							
% Detected	29.6	20.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.14	0.11	0.16	0.16	0.31	NA	1.2
Max. nondetect (mg/kg OC)	1.5	5.0	0.88	17	1.3	NA	2.7
Mean (mg/kg OC)	0.49 ^a	0.39 ^a	--	--	--	NA	--
Median (mg/kg OC)	0.16 ^a	0.20 ^a	--	--	--	NA	--
Min. detected (mg/kg OC)	0.34	0.59	--	--	--	NA	--
Max. detected (mg/kg OC)	5.3	2.2	--	--	--	NA	--
Max. detected location	SH-02	SH-12	--	--	--	NA	--
Fluorene							
% Detected	18.5	12.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.16	0.13	0.19	0.19	0.36	NA	1.4
Max. nondetect (mg/kg OC)	1.5	5.0	1.0	20	1.5	NA	3.2
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	0.14	0.22	--	--	--	NA	--
Max. detected (mg/kg OC)	1.9	1.7	--	--	--	NA	--
Max. detected location	SH-02	SH-18	--	--	--	NA	--
Naphthalene							
% Detected	22.2	28.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.15	0.12	0.18	0.18	0.34	NA	1.3
Max. nondetect (mg/kg OC)	1.7	5.6	0.98	19	1.5	NA	3.1
Mean (mg/kg OC)	0.29 ^a	0.49 ^a	--	--	--	NA	--
Median (mg/kg OC)	0.15 ^a	0.23 ^a	--	--	--	NA	--
Min. detected (mg/kg OC)	0.13	0.35	--	--	--	NA	--
Max. detected (mg/kg OC)	1.9	3.0	--	--	--	NA	--
Max. detected location	SH-11	SH-18	--	--	--	NA	--
Phenanthrene							
% Detected	66.7	72.0	11.8	0	0	NA	0
Min. nondetect (mg/kg OC)	0.16	0.24	0.18	0.18	0.33	NA	1.3
Max. nondetect (mg/kg OC)	1.6	5.4	0.94	18	1.4	NA	3.0
Mean (mg/kg OC)	1.7 ^a	1.9 ^a	--	--	--	NA	--
Median (mg/kg OC)	0.74 ^a	1.0 ^a	--	--	--	NA	--
Min. detected (mg/kg OC)	0.38	0.20	--	--	--	NA	--
Max. detected (mg/kg OC)	15	10	1.5	--	--	NA	--
Max. detected location	SH-02	SH-07	OB-04	--	--	NA	--

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
High molecular weight PAHs							
Number of samples	27	25	17	3	6	0	3
Total HPAHs							
% Detected	88.9	80.0	41.2	66.7	16.7	NA	0
Min. nondetect (mg/kg OC)	1.4	0.57	0.43	1.1	0.78	NA	3.1
Max. nondetect (mg/kg OC)	3.9	13	2.3	1.1	3.5	NA	7.3
Mean (mg/kg OC)	16 ^a	21 ^a	1.7 ^a	--	--	NA	--
Median (mg/kg OC)	9.3 ^a	7.9 ^a	0.56 ^a	--	--	NA	--
Min. detected (mg/kg OC)	1.6	1.3	0.31	0.51	3.0	NA	--
Max. detected (mg/kg OC)	90	181	15	98	3.0	NA	--
Max. detected location	SH-22	SH-07	OB-07	OB-19	HI-03	NA	--
Benzo(a)anthracene							
% Detected	66.7	64.0	11.8	0	0	NA	0
Min. nondetect (mg/kg OC)	0.11	0.13	0.12	0.12	0.23	NA	0.92
Max. nondetect (mg/kg OC)	1.1	3.8	0.67	13	1.0	NA	2.1
Mean (mg/kg OC)	1.4 ^a	1.8 ^a	--	--	--	NA	--
Median (mg/kg OC)	0.82 ^a	0.70 ^a	--	--	--	NA	--
Min. detected (mg/kg OC)	0.54	0.22	0.70	--	--	NA	--
Max. detected (mg/kg OC)	6.9	15	1.8	--	--	NA	--
Max. detected location	SH-02	SH-07	OB-07	--	--	NA	--
Benzo(a)pyrene							
% Detected	66.7	64.0	5.9	33.3	0	NA	0
Min. nondetect (mg/kg OC)	0.16	0.18	0.17	0.17	0.32	NA	1.3
Max. nondetect (mg/kg OC)	1.6	5.3	0.92	0.46	1.4	NA	2.9
Mean (mg/kg OC)	1.5 ^a	2.3 ^a	--	--	--	NA	--
Median (mg/kg OC)	0.89 ^a	0.90 ^a	--	--	--	NA	--
Min. detected (mg/kg OC)	0.54	0.32	1.5	47	--	NA	--
Max. detected (mg/kg OC)	7.3	23	1.5	47	--	NA	--
Max. detected location	SH-02	SH-07	OB-07	OB-19	--	NA	--
Benzo(g,h,i)perylene							
% Detected	48.1	44.0	0	33.3	0	NA	0
Min. nondetect (mg/kg OC)	0.12	0.10	0.14	0.14	0.27	NA	1.0
Max. nondetect (mg/kg OC)	1.3	4.4	0.76	0.38	1.2	NA	2.4
Mean (mg/kg OC)	0.62 ^a	1.4 ^a	--	--	--	NA	--
Median (mg/kg OC)	0.39 ^a	0.29 ^a	--	--	--	NA	--
Min. detected (mg/kg OC)	0.21	0.42	--	51	--	NA	--
Max. detected (mg/kg OC)	2.7	22	--	51	--	NA	--
Max. detected location	SH-02	SH-07	--	OB-19	--	NA	--

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Chrysene							
% Detected	85.2	68.0	29.4	0	16.7	NA	0
Min. nondetect (mg/kg OC)	0.48	0.19	0.14	0.14	0.26	NA	1.0
Max. nondetect (mg/kg OC)	1.3	4.3	0.78	15	1.1	NA	2.4
Mean (mg/kg OC)	2.6 ^a	3.1 ^a	0.37 ^a	--	--	NA	--
Median (mg/kg OC)	1.6 ^a	1.1 ^a	0.21 ^a	--	--	NA	--
Min. detected (mg/kg OC)	0.503	0.32	0.49	--	0.83	NA	--
Max. detected (mg/kg OC)	14	29	2.1	--	0.83	NA	--
Max. detected location	SH-22	SH-07	OB-07	--	HI-03	NA	--
Dibenz(a,h)anthracene							
% Detected	11.1	0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.076	0.12	0.18	0.18	0.34	NA	1.3
Max. nondetect (mg/kg OC)	1.3	5.6	1.0	19	1.5	NA	3.0
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	0.31	--	--	--	--	NA	--
Max. detected (mg/kg OC)	0.57	--	--	--	--	NA	--
Max. detected location	SH-02	--	--	--	--	NA	--
Fluoranthene							
% Detected	88.9	76.0	23.5	33.3	16.7	NA	0
Min. nondetect (mg/kg OC)	0.57	0.22	0.17	0.44	0.31	NA	1.2
Max. nondetect (mg/kg OC)	1.5	5.1	1.4	17	1.4	NA	2.8
Mean (mg/kg OC)	4.3 ^a	5.0 ^a	0.37 ^a	--	--	NA	--
Median (mg/kg OC)	2.3 ^a	2.2 ^a	0.076 ^a	--	--	NA	--
Min. detected (mg/kg OC)	0.54	0.42	0.31	0.23	1.1	NA	--
Max. detected (mg/kg OC)	35	33	3.6	0.23	1.1	NA	--
Max. detected location	SH-22	SH-07	OB-07	OB-18	HI-03	NA	--
Indeno(1,2,3-cd)pyrene							
% Detected	37.0	20.0	5.9	0	0	NA	0
Min. nondetect (mg/kg OC)	0.15	0.12	0.18	0.18	0.34	NA	1.3
Max. nondetect (mg/kg OC)	1.6	5.6	0.97	19	1.5	NA	3.1
Mean (mg/kg OC)	0.45 ^a	0.37 ^a	--	--	--	NA	--
Median (mg/kg OC)	0.28 ^a	0.080 ^a	--	--	--	NA	--
Min. detected (mg/kg OC)	0.22	0.30	1.1	--	--	NA	--
Max. detected (mg/kg OC)	2.4	5.6	1.1	--	--	NA	--
Max. detected location	SH-02	SH-07	OB-02	--	--	NA	--

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Pyrene							
% Detected	88.9	80.0	29.4	33.3	16.7	NA	0
Min. nondetect (mg/kg OC)	0.56	0.22	0.16	0.43	0.31	NA	1.2
Max. nondetect (mg/kg OC)	1.5	5.0	0.88	17	1.3	NA	2.8
Mean (mg/kg OC)	3.6 ^a	4.8 ^a	0.50 ^a	--	--	NA	--
Median (mg/kg OC)	2.2 ^a	2.3 ^a	0.20 ^a	--	--	NA	--
Min. detected (mg/kg OC)	0.54	0.45	0.61	0.27	1.1	NA	--
Max. detected (mg/kg OC)	17	33	3.3	0.27	1.1	NA	--
Max. detected location	SH-22	SH-07	OB-07	OB-18	HI-03	NA	--
Total benzofluoranthenes							
% Detected	70.4	56.0	5.9	0	0	NA	0
Min. nondetect (mg/kg OC)	0.39	0.46	0.43	0.42	0.78	NA	3.1
Max. nondetect (mg/kg OC)	3.9	13	2.3	44	3.5	NA	7.3
Mean (mg/kg OC)	3.1 ^a	3.6 ^a	--	--	--	NA	--
Median (mg/kg OC)	1.9 ^a	1.7 ^a	--	--	--	NA	--
Min. detected (mg/kg OC)	0.44	0.44	2.8	--	--	NA	--
Max. detected (mg/kg OC)	13	22	2.8	--	--	NA	--
Max. detected location	SH-22	SH-07	OB-07	--	--	NA	--
Other SVOCs							
Number of samples	27	25	17	3	6	0	3
Bis(2-ethylhexyl)phthalate							
% Detected	48.1	40.0	17.6	0	0	NA	33.3
Min. nondetect (mg/kg OC)	0.20	0.16	0.31	0.23	0.45	NA	1.9
Max. nondetect (mg/kg OC)	2.2	4.7	1.3	24	1.9	NA	4.0
Mean (mg/kg OC)	0.70 ^a	1.2 ^a	--	--	--	NA	--
Median (mg/kg OC)	0.48 ^a	0.67 ^a	--	--	--	NA	--
Min. detected (mg/kg OC)	0.14	0.44	0.65	--	--	NA	3.9
Max. detected (mg/kg OC)	3.2	13	1.7	--	--	NA	3.9
Max. detected location	SH-10	SH-26	OB-19	--	--	NA	RF-01
Butylbenzylphthalate							
% Detected	3.7	0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.10	0.16	0.24	0.23	0.45	NA	1.7
Max. nondetect (mg/kg OC)	2.2	7.2	1.3	24	1.9	NA	4.0
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	1.0	--	--	--	--	NA	--
Max. detected (mg/kg OC)	1.0	--	--	--	--	NA	--
Max. detected location	SH-03	--	--	--	--	NA	--

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Dibenzofuran							
% Detected	0	12.0	0	0	0	NA	0
Min. nondetect (mg/kg OC)	0.067	0.11	0.16	0.16	0.30	NA	1.2
Max. nondetect (mg/kg OC)	1.4	4.7	0.85	17	1.2	NA	2.7
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	--	0.26	--	--	--	NA	--
Max. detected (mg/kg OC)	--	1.2	--	--	--	NA	--
Max. detected location	--	SH-18	--	--	--	NA	--
4-Methylphenol							
% Detected	33.3	24.0	11.8	0	16.7	NA	0
Min. nondetect (µg/kg)	12	12	12	13	12	NA	12
Max. nondetect (µg/kg)	13	32	13	13	13	NA	13
Mean (µg/kg)	30 ^a	31 ^a	--	--	--	NA	--
Median (µg/kg)	5.1 ^a	2.7 ^a	--	--	--	NA	--
Min. detected (µg/kg)	18	18	43	--	140	NA	--
Max. detected (µg/kg)	410	320	53	--	140	NA	--
Max. detected location	SH-11	SH-11	OB-10	--	HI-06	NA	--
Phenol							
% Detected	22.2	20.0	23.5	33.3	50.0	NA	33.3
Min. nondetect (µg/kg)	13	13	13	13	13	NA	13
Max. nondetect (µg/kg)	14	41	14	14	13	NA	14
Mean (µg/kg)	11 ^a	14 ^a	17 ^a	--	89 ^a	NA	--
Median (µg/kg)	4.2 ^a	10 ^a	2.2 ^a	--	22	NA	--
Min. detected (µg/kg)	16	19	23	21	30	NA	140
Max. detected (µg/kg)	66	47	150	21	290	NA	140
Max. detected location	SH-14	SH-21	OB-01	OB-19	HI-02	NA	RF-03
Polychlorinated biphenyls (PCBs)							
Number of samples	27	25	17	3	6	0	3
Total PCBs							
% Detected	3.7	0	0	0	16.7	NA	0
Min. nondetect (mg/kg OC)	0.036	0.035	0.085	0.084	0.27	NA	0.59
Max. nondetect (mg/kg OC)	0.12	2.5	0.44	9.1	0.61	NA	1.4
Mean (mg/kg OC)	--	--	--	--	--	NA	--
Median (mg/kg OC)	--	--	--	--	--	NA	--
Min. detected (mg/kg OC)	0.62	--	--	--	2.5	NA	--
Max. detected (mg/kg OC)	0.62	--	--	--	2.5	NA	--
Max. detected location	SH-01	--	--	--	HI-06	NA	--

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Chlorinated pesticides							
Number of samples	26	25	17	3	6	0	3
4,4'-DDD							
% Detected	33.3	48.0	11.8	33.3	33.3	NA	33.3
Min. nondetect (µg/kg)	0.14	0.13	0.14	0.14	0.13	NA	0.13
Max. nondetect (µg/kg)	0.27	0.26	0.15	0.15	0.15	NA	0.14
Mean (µg/kg)	0.55 ^a	0.59 ^a	--	--	--	NA	--
Median (µg/kg)	0.17 ^a	0.22 ^a	--	--	--	NA	--
Min. detected (µg/kg)	0.34	0.14	0.31	1.0	0.19	NA	0.15
Max. detected (µg/kg)	2.9	3.6	0.36	1.0	0.33	NA	0.15
Max. detected location	SH-04 /SH-14	SH-21	OB-02	OB-18	HI-07	NA	RF-02
4,4'-DDE							
% Detected	40.7	36.0	11.8	66.7	16.7	NA	0
Min. nondetect (µg/kg)	0.13	0.13	0.13	0.14	0.13	NA	0.13
Max. nondetect (µg/kg)	0.23	0.23	0.16	0.14	0.14	NA	0.14
Mean (µg/kg)	0.57 ^a	0.38 ^a	--	--	--	NA	--
Median (µg/kg)	0.16 ^a	0.17 ^a	--	--	--	NA	--
Min. detected (µg/kg)	0.24	0.14	0.63	0.30	1.2	NA	--
Max. detected (µg/kg)	4.1	1.5	3.1	0.33	1.2	NA	--
Max. detected location	SH-14	SH-01	OB-02	OB-19	HI-07	NA	--
4,4'-DDT							
% Detected	18.5	36.0	35.3	33.3	33.3	NA	33.3
Min. nondetect (µg/kg)	0.14	0.14	0.14	0.15	0.15	NA	0.14
Max. nondetect (µg/kg)	0.23	0.26	0.17	0.15	0.15	NA	0.15
Mean (µg/kg)	--	0.74 ^a	0.80 ^a	--	--	NA	--
Median (µg/kg)	--	0.19 ^a	0.061 ^a	--	--	NA	--
Min. detected (µg/kg)	0.24	0.27	0.31	1.6	0.96	NA	0.57
Max. detected (µg/kg)	4.8	5.8	5.6	1.6	4.5	NA	0.57
Max. detected location	SH-12	SH-14	OB-04	OB-19	HI-04	NA	RF-01
Aldrin							
% Detected	14.8	28.0	0	0	0	NA	0
Min. nondetect (µg/kg)	0.10	0.10	0.21	0.22	0.20	NA	0.20
Max. nondetect (µg/kg)	0.23	0.22	0.25	0.23	0.22	NA	0.22
Mean (µg/kg)	--	0.99 ^a	--	--	--	NA	--
Median (µg/kg)	--	0.058 ^a	--	--	--	NA	--
Min. detected (µg/kg)	0.63	0.15	--	--	--	NA	--
Max. detected (µg/kg)	4.8	19	--	--	--	NA	--
Max. detected location	SH-14	SH-08	--	--	--	NA	--

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
alpha-Chlordane							
% Detected	14.8	36.0	0	33.3	0	NA	66.7
Min. nondetect ($\mu\text{g}/\text{kg}$)	0.11	0.11	0.13	0.13	0.12	NA	0.13
Max. nondetect ($\mu\text{g}/\text{kg}$)	0.23	0.18	0.98	0.14	0.13	NA	0.13
Mean ($\mu\text{g}/\text{kg}$)	--	0.27 ^a	--	--	--	NA	--
Median ($\mu\text{g}/\text{kg}$)	--	0.048 ^a	--	--	--	NA	--
Min. detected ($\mu\text{g}/\text{kg}$)	0.14	0.13	--	0.28	--	NA	0.19
Max. detected ($\mu\text{g}/\text{kg}$)	4.3	2.5	--	0.28	--	NA	0.49
Max. detected location	SH-14	SH-21	--	OB-19	--	NA	RF-01
Dieldrin							
% Detected	18.5	12.0	5.9	0	16.7	NA	0
Min. nondetect ($\mu\text{g}/\text{kg}$)	0.11	0.11	0.11	0.12	0.11	NA	0.11
Max. nondetect ($\mu\text{g}/\text{kg}$)	0.23	0.18	0.13	0.12	0.12	NA	0.12
Mean ($\mu\text{g}/\text{kg}$)	--	--	--	--	--	NA	--
Median ($\mu\text{g}/\text{kg}$)	--	--	--	--	--	NA	--
Min. detected ($\mu\text{g}/\text{kg}$)	0.12	0.18	0.12	--	0.13	NA	--
Max. detected ($\mu\text{g}/\text{kg}$)	3.4	1.9	0.12	--	0.13	NA	--
Max. detected location	SH-14	SH-28	OB-07	--	HI-07	NA	--
gamma-BHC							
% Detected	33.3	28.0	11.8	33.3	16.7	NA	0
Min. nondetect ($\mu\text{g}/\text{kg}$)	0.074	0.074	0.073	0.078	0.071	NA	0.072
Max. nondetect ($\mu\text{g}/\text{kg}$)	0.12	0.12	0.089	0.079	0.077	NA	0.077
Mean ($\mu\text{g}/\text{kg}$)	0.42 ^a	0.24 ^a	--	--	--	NA	--
Median ($\mu\text{g}/\text{kg}$)	0.082 ^a	0.035 ^a	--	--	--	NA	--
Min. detected ($\mu\text{g}/\text{kg}$)	0.29	0.17	0.11	0.34	0.25	NA	--
Max. detected ($\mu\text{g}/\text{kg}$)	4.4	2.8	1.4	0.34	0.25	NA	--
Max. detected location	SH-14	SH-20	OB-05	OB-17	HI-07	NA	--
Heptachlor							
% Detected	14.8	4.0	5.9	0	0	NA	0
Min. nondetect ($\mu\text{g}/\text{kg}$)	0.13	0.13	0.44	0.46	0.42	NA	0.43
Max. nondetect ($\mu\text{g}/\text{kg}$)	0.13	0.12	0.47	0.47	0.46	NA	0.46
Mean ($\mu\text{g}/\text{kg}$)	--	--	--	--	--	NA	--
Median ($\mu\text{g}/\text{kg}$)	--	--	--	--	--	NA	--
Min. detected ($\mu\text{g}/\text{kg}$)	0.19	16	1.1	--	--	NA	--
Max. detected ($\mu\text{g}/\text{kg}$)	5.6	16	1.1	--	--	NA	--
Max. detected location	SH-14	SH-08	OB-09	--	--	NA	--

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Petroleum Hydrocarbons							
Number of samples	5	2	3	0	0	0	3
Motor oil							
% Detected	20.0	50.0	0	NA	NA	NA	0
Min. nondetect (mg/kg)	160	150	150	NA	NA	NA	130
Max. nondetect (mg/kg)	360	150	270	NA	NA	NA	150
Mean (mg/kg)	--	--	--	NA	NA	NA	--
Median (mg/kg)	--	--	--	NA	NA	NA	--
Min. detected (mg/kg)	220		--	NA	NA	NA	--
Max. detected (mg/kg)	220	270	--	NA	NA	NA	--
Max. detected location	SH-05	SH-02	--	NA	NA	NA	--
Dioxin/Furans							
Number of samples	27	9	17	5	6	0	3
Total Dioxin (TEQ)							
% Detected	100	100	100	100	100	NA	100
Min. nondetect (ng/kg)	--	--	--	--	--	NA	--
Max. nondetect (ng/kg)	--	--	--	--	--	NA	--
Mean (ng/kg)	42.8	198	32.1	97.8	5.42	NA	0.482
Median (ng/kg)	35.5	16.2	33.0	82.0	2.95	NA	0.508
Min. detected (ng/kg)	1.00	2.68	4.44	52.4	1.77	NA	0.245
Max. detected (ng/kg)	175	902	54.4	180	13.0	NA	0.692
Max. detected location	SH-03	SH-10	OB-12	OB-06	HI-03	NA	RF-01
Resin Acids							
Number of samples	13	11	9	3	2	0	3
Total resin acids							
% Detected	100	90.9	100	100	100	NA	66.7
Min. nondetect (µg/kg)	--	98	--	--	--	NA	98
Max. nondetect (µg/kg)	--	98	--	--	--	NA	98
Mean (µg/kg)	3,300	17,000 ^a	1,500	4,500	--	NA	--
Median (µg/kg)	2,500	2,100	1,200	3,000	--	NA	--
Min. detected (µg/kg)	270	130	740	1,700	1,400	NA	120
Max. detected (µg/kg)	9,000	68,000	3,200	8,900	2,800	NA	730
Max. detected location	SH-24	SH-21	OB-02	OB-19	HI-04	NA	RF-02

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
12-Chlorodehydroabietic acid							
% Detected	7.7	0	0	0	0	NA	0
Min. nondetect (µg/kg)	96	97	97	97	98	NA	98
Max. nondetect (µg/kg)	300	480	300	300	98	NA	99
Mean (µg/kg)	--	--	--	--	--	NA	--
Median (µg/kg)	--	--	--	--	--	NA	--
Min. detected (µg/kg)	130	--	--	--	--	NA	--
Max. detected (µg/kg)	130	--	--	--	--	NA	--
Max. detected location	SH-19	--	--	--	--	NA	--
Abietic acid							
% Detected	92.3	81.8	77.8	100	0	NA	33.3
Min. nondetect (µg/kg)	96	98	99	--	98	NA	98
Max. nondetect (µg/kg)	96	98	100	--	98	NA	99
Mean (µg/kg)	1,200 ^a	9,000 ^a	350 ^a	2,700	--	NA	--
Median (µg/kg)	840	1,600	200 ^a	1,700	--	NA	--
Min. detected (µg/kg)	120	230	120	610	--	NA	730
Max. detected (µg/kg)	3,300	38,000	920	5,900	--	NA	730
Max. detected location	SH-22	SH-21	OB-17	OB-19	--	NA	RF-02
Dehydroabietic acid							
% Detected	84.6	90.9	55.6	100	0	NA	0
Min. nondetect (µg/kg)	96	98	99	--	98	NA	98
Max. nondetect (µg/kg)	98	98	100	--	98	NA	99
Mean (µg/kg)	1,400 ^a	4,300 ^a	260 ^a	1,200	--	NA	--
Median (µg/kg)	840 ^a	530	170 ^a	1,000	--	NA	--
Min. detected (µg/kg)	120	110	170	530	--	NA	--
Max. detected (µg/kg)	4,200	22,000	710	2,000	--	NA	--
Max. detected location	SH-24	SH-21	OB-17	OB-19	--	NA	--
Isopimaric acid							
% Detected	53.8	63.6	11.1	100	0	NA	0
Min. nondetect (µg/kg)	96	97	99	--	98	NA	98
Max. nondetect (µg/kg)	300	99	300	--	98	NA	99
Mean (µg/kg)	190 ^a	1,200 ^a	--	420	--	NA	--
Median (µg/kg)	120 ^a	230 ^a	--	290	--	NA	--
Min. detected (µg/kg)	100	120	170	110	--	NA	--
Max. detected (µg/kg)	540	3,700	170	870	--	NA	--
Max. detected location	SH-22	SH-21	OB-17	OB-19	--	NA	--

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Linolenic acid							
% Detected	46.2	18.2	11.1	0	100	NA	0
Min. nondetect (µg/kg)	96	97	97	97	--	NA	98
Max. nondetect (µg/kg)	300	300	300	300	--	NA	99
Mean (µg/kg)	160 ^a	--	--	--	--	NA	--
Median (µg/kg)	150 ^a	--	--	--	--	NA	--
Min. detected (µg/kg)	160	150	100	--		NA	--
Max. detected (µg/kg)	290	1,000	100	--	290	NA	--
Max. detected location	SH-30	SH-21	OB-02	--	HI-04	NA	--
Neoabietic acid							
% Detected	0	18.2	0	0	0	NA	0
Min. nondetect (µg/kg)	96	97	97	97	98	NA	98
Max. nondetect (µg/kg)	300	480	300	300	98	NA	99
Mean (µg/kg)	--	--	--	--	--	NA	--
Median (µg/kg)	--	--	--	--	--	NA	--
Min. detected (µg/kg)	--	280	--	--	--	NA	--
Max. detected (µg/kg)	--	550	--	--	--	NA	--
Max. detected location	--	SH-18	--	--	--	NA	--
Oleic acid							
% Detected	92.3	36.4	77.8	0	100	NA	33.3
Min. nondetect (µg/kg)	300	97	97	97	--	NA	98
Max. nondetect (µg/kg)	300	480	300	300	--	NA	98
Mean (µg/kg)	320 ^a	150 ^a	980 ^a	--	--	NA	--
Median (µg/kg)	300 U	74 ^a	880 ^a	--	--	NA	--
Min. detected (µg/kg)	150	140	610	--	1,300	NA	120
Max. detected (µg/kg)	650	820	1,800	--	2,500	NA	120
Max. detected location	SH-24	SH-21	OB-02	--	HI-04	NA	RF-01
Palustric acid							
% Detected	0	27.3	0	0	0	NA	0
Min. nondetect (µg/kg)	96	97	97	97	98	NA	98
Max. nondetect (µg/kg)	300	290	300	300	98	NA	99
Mean (µg/kg)	--	330 ^a	--	--	--	NA	--
Median (µg/kg)	--	250 ^a	--	--	--	NA	--
Min. detected (µg/kg)	--	530	--	--	--	NA	--
Max. detected (µg/kg)	--	920	--	--	--	NA	--
Max. detected location	--	SH-18	--	--	--	NA	--

Table 4-1 (continued). Summary statistics for Oakland Bay study sample results.

Parameter Group	Shelton Harbor		Oakland Bay		Hammersley Inlet		Reference Stations
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
Pimaric acid							
% Detected	0	9.1	11.1	0	0	NA	0
Min. nondetect (µg/kg)	96	97	97	97	98	NA	98
Max. nondetect (µg/kg)	300	480	300	300	98	NA	99
Mean (µg/kg)	--	--	--	--	--	NA	--
Median (µg/kg)	--	--	--	--	--	NA	--
Min. detected (µg/kg)	--	220	99	--	--	NA	--
Max. detected (µg/kg)	--	220	99	--	--	NA	--
Max. detected location	--	SH-21	OB-17	--	--	NA	--
Retene							
% Detected	69.2	81.8	0	100	NA	NA	0
Min. nondetect (µg/kg)	8.7	20	19	--	NA	NA	20
Max. nondetect (µg/kg)	20	20	20	--	NA	NA	20
Mean (µg/kg)	160 ^a	4,100 ^a	--	210	NA	NA	--
Median (µg/kg)	28 ^a	50 ^a	--	160	NA	NA	--
Min. detected (µg/kg)	10	15	--	48	NA	NA	--
Max. detected (µg/kg)	900	21,000	--	430	NA	NA	--
Max. detected location	SH-19	SH-21	--	OB-17	NA	NA	--
Sandaracopimaric acid							
% Detected	7.7	27.3	0	0	0	NA	0
Min. nondetect (µg/kg)	96	97	97	97	110	NA	98
Max. nondetect (µg/kg)	300	480	300	300	160	NA	99
Mean (µg/kg)	--	310 ^a	--	--	--	NA	--
Median (µg/kg)	--	170 ^a	--	--	--	NA	--
Min. detected (µg/kg)	1,300	570	--	--	--	NA	--
Max. detected (µg/kg)	1,300	1,300	--	--	--	NA	--
Max. detected location	SH-21	SH-21	--	--	--	NA	--

NA Not analyzed.

OC organic carbon (normalized)

mg/kg milligram per kilogram

µg/kg microgram per kilogram

-- Not able to calculate.

^a Values are estimated using regression on ordered statistics (ROS).

Diesel- and gasoline-range petroleum hydrocarbons and guaiacols (associated with wood waste) are not included on this table because there were no detections of those chemicals.

Table 4-2. Reference sediment associated with Oakland Bay study sediment samples.

Sample	Total Fines (percent)	Organic Carbon (percent)	Associated Reference Sediment Sample			
			Amphipod	Larval	Polychaete	Microtox ^a
REF-1	81.2	0.639	NA	NA	NA	NA
REF-2	51.5	0.589	NA	NA	NA	NA
REF-3	13.1	0.273	NA	NA	NA	NA
SH-01	27.8	1.59	Ref-3	Ref-3	Ref-2 ^b	Control ^c
SH-02	59.7	2.46	Ref-2	Ref-3 ^b	Ref-2	Control ^c
SH-03	66.2	3.8	Ref-2	Ref-3 ^b	Ref-2	Control ^c
SH-04	76	4.13	Ref-1	Ref-3 ^b	Ref-1	Control ^c
SH-05	29	3.2	Ref-3	Ref-3	Ref-3	Control ^c
SH-07	34.2	1.59	Ref-2	Ref-2	Ref-2	Control ^c
SH-09	32.4	2.17	Ref-2	Ref-3 ^b	Ref-2	Control ^c
SH-10	15	2.03	Ref-3	Ref-3	Ref-2 ^b	Ref-3
SH-11	63.4	2.32	Ref-2	Ref-2	Ref-2	Control ^c
SH-12	57.6	4.79	Ref-2	Ref-2	Ref-2	Control ^c
SH-13	65.3	11	Ref-2	Ref-2	Ref-2	Control ^c
SH-14	51.7	3.1	Ref-2	Ref-3 ^b	Ref-2	Control ^c
SH-15	4.6	0.542	Ref-3	Ref-3	Ref-3	Ref-3
SH-16	2.2	0.511	Ref-3	Ref-3	Ref-3	Ref-3
SH-18	85	4.79	Ref-1	Ref-1	Ref-1	Ref-1
SH-19	67.3	4.44	Ref-1 ^d	Ref-3 ^b	Ref-1 ^d	Control ^c
SH-20	77.2	5.15	Ref-1	Ref-3 ^b	Ref-1	Ref-1
SH-21	76.2	5.59	Ref-1	Ref-3 ^b	Ref-1	Ref-1
SH-22	36.8	5.77	Ref-2	Ref-3 ^b	Ref-2	Ref-3
SH-23	64.8	3.33	Ref-2	Ref-3 ^b	Ref-2	Control ^c
SH-24	42	4.97	Ref-2	Ref-3 ^b	Ref-2	Control ^c
SH-25	49.6	2.6	Ref-2	Ref-2	Ref-2	Control ^c
SH-26	12.8	1.92	Ref-3	Ref-3	Ref-3	Control ^c
SH-27	21.6	1.38	Ref-3	Ref-3	Ref-3	Ref-3
SH-28	24.1	1.24	Ref-3	Ref-3	Ref-2 ^b	Control ^c
SH-29	4.1	0.594	Ref-3	Ref-3	Ref-3	Ref-3
SH-30	31.2	1.99	Ref-3	Ref-3	Ref-3	Ref-3
OB-01	11.9	0.878	Ref-3	Ref-3	Ref-2 ^b	Ref-3
OB-02	31.1	1.4	Ref-3	Ref-3	Ref-2 ^b	Control ^c
OB-03	69.5	2.79	Ref-2	Ref-3 ^b	Ref-1	Control ^c

Table 4-2 (continued). Reference sediment associated with Oakland Bay study sediment samples.

Sample	Total Fines (percent)	Organic Carbon (percent)	Associated Reference Sediment Sample			
			Amphipod	Larval	Polychaete	Microtox ^a
OB-04	42.6	3.45	Ref-2	Ref-2	Ref-2	Control ^c
OB-05	71.6	2.35	Ref-1	Ref-1	Ref-1	Ref-1
OB-06	96.9	4.68	Ref-1	Ref-1	Ref-1	Ref-1
OB-07	16.9	0.995	Ref-3	Ref-3	Ref-3	Ref-3
OB-08	87.4	1.36	Ref-1	Ref-1	Ref-1	Ref-1
OB-09	87.8	2.69	Ref-1	Ref-1	Ref-1	Ref-1
OB-10	84.2	2.62	Ref-1	Ref-1	Ref-1	Ref-1
OB-11	44.1	2.32	Ref-2	Ref-2	Ref-2	Ref-1
OB-12	91.6	2.26	Ref-1	Ref-1	Ref-1	Ref-1
OB-13	66.2	3.53	Ref-2	Ref-2	Ref-2	Control ^c
OB-14	24.5	1.71	Ref-3	Ref-3	Ref-2 ^b	Control ^c
OB-17	21.2	2.39	Ref-3	Ref-3	Ref-2 ^b	Control ^c
OB-18	82.6	2.86	Ref-1	Ref-1	Ref-1	Ref-1
OB-19	92	2.6	Ref-1	Ref-1	Ref-1	Ref-1
HI-02	6	0.571	Ref-3	Ref-3	Ref-2 ^b	Ref-3
HI-03	13.7	1.45	Ref-3	Ref-3	Ref-3	Ref-3
HI-04	4.3	0.625	Ref-3	Ref-3	Ref-2 ^b	Ref-3
HI-05	6.9	0.799	Ref-3	Ref-3	Ref-3	Control ^c
HI-06	16.7	2.43	Ref-3	Ref-3	Ref-2 ^b	Ref-3
HI-07	6.8	0.68	Ref-3	Ref-3	Ref-2 ^b	Control ^c

^a Microtox analyses were performed before grain size analysis conducted by the laboratory; therefore, selection of appropriate reference sediment was based on field wet sieving results.

^b The appropriate reference sample failed toxicity test criteria. As an alternative, the test sediment was compared to a reference sample passing toxicity test criteria with the next closest matching grain size in the test batch.

^c Microtox analyses were performed with only one reference sample per analytical batch. In this case, the reference sample failed toxicity test criteria. As an alternate, the test sediment was compared to the laboratory control sample, as no other reference sample was available for comparison in the test batch.

^d The total fines for this sample were near the breakpoint between using reference REF-1 or REF-2. The test sediment was compared to the second closest match of grain size (within 1 percent difference of the closest matching grain size) because the test failed criteria when using the alternate reference sample.

The reference sediment samples were collected with high, medium, and low fines content. Sediment samples were then compared to the reference sediment with comparable fines content. Ecology's Sediment Sampling and Analysis Plan Appendix (Ecology 2008) directs that test sediment percent fines should be within 20 percent of the selected reference sediment. Percent fines of the reference sediments were 81.2 percent (REF-1), 51.5 percent (REF-2), and 13.1 percent (REF-3); adding the 20 percent measure resulted in overlapping comparison ranges of 0 – 33.1 percent, 31.5 – 71.5 percent, and 61.2 – 100 percent fines. In order to select one reference sample for comparison for each sample location, the midway point between each measured grain size range was selected as the 'cutoff' point. Test sediments with less than 32.3 percent fines were compared to reference sediment REF-3, those with percent fines between 32.3 and 66.35 percent were compared to reference sediment REF-2, and test sediments with greater than 66.35 percent fines were compared to reference sediment REF-1. In those cases where test sediment percent fines were very close to the reference sample cutoff points (SH-03, SH-09, SH-12, SH-19, OB-13), the percent fines of the sample was compared to the reference sample closer in grain size. Percent fines for each sample, and the reference used for comparison in each bioassay test, are shown in Table 4–2.

The reference sample with the closest matching percent fines content was *not* selected for comparison to the surface sediment samples when:

- The closest matching reference sample failed toxicity test criteria – two or three of the reference samples were included with each test batch, and as an alternative, the test sediment was compared to a reference sample passing toxicity test criteria with the next closest matching grain size in the test batch. (refer to Section 4.5.2).
- Microtox analyses were performed with only one reference sample per analytical batch – if the reference sample failed toxicity test criteria, the test sediment was compared to the laboratory control sample, as no other reference sample was available for comparison in the test batch.

Table 4-3 includes the list of organisms used in each of the toxicity tests, and each primary test endpoint. A summary of SQS and CSL results for all toxicity tests is presented in Table 4-4. As shown in Table 4-4, 25 of the 50 samples met SQS and CSL criteria, nine samples exceeded SQS criteria, and 16 samples exceeded CSL criteria, based on all four toxicity tests. The acute larval test had the most failures (14 CSL and seven SQS), the chronic polychaete test had seven SQS failures, and the acute amphipod and chronic Microtox test each had one SQS failure. The bioassay laboratory report is provided in Appendix H.

4.4 Radiology

Sediment cores OB-15, OB-16, and SH-17 were subjected to radioisotope analysis to determine historical patterns of sedimentation and accumulation in Oakland Bay and Shelton Harbor.

Table 4-3. SMS biological effect criteria and applicability.

Biological Test	Sediment Quality Standards	Cleanup Screening Levels	Species	Primary Endpoint(s)
Amphipod Mortality	The test sediment has a higher (statistically significantly, t-test, $P \leq 0.05$) mean mortality than the reference sediment, and the test sediment mean mortality is more than 25% on an absolute basis.	The test sediment has a significantly higher (t-test, $P \leq 0.05$) mean mortality than the reference sediment, and the test sediment mean mortality is more than 30% greater, on an absolute basis, than the reference sediment mean mortality.	<i>Ampelisca abdita</i> <i>Eohaustorius estuaries</i>	Mortality
Larval Development	The test sediment has a mean survivorship of normal larvae that is significantly less (t-test, $P \leq 0.1$) than the mean normal survivorship in the reference sediment, and the mean normal survivorship in the test sediment is less than 85% of the mean normal survivorship in the reference sediment.	The test sediment has a mean survivorship of normal larvae that is significantly less (t-test, $P \leq 0.1$) than the mean normal survivorship in the reference sediment, and the mean normal survivorship in the test sediment is less than 70% of the mean normal survivorship in the reference sediment.	<i>Mytilus</i> sp.	Abnormality Mortality
Juvenile Polychaete Growth	The mean individual growth rate of polychaetes in the test sediment is less than 70% of the mean individual growth rate of the polychaetes in the reference sediment, and the test sediment mean individual growth rate is statistically different (t-test, $P \leq 0.05$) from the reference sediment mean individual growth rate.	The mean individual growth rate of polychaetes in the test sediment is less than 50% of the mean individual growth rate of the polychaetes in the reference sediment, and the test sediment mean individual growth rate is statistically different (t-test, $P \leq 0.05$) from the reference sediment mean individual growth rate.	<i>Neanthes arenaceodentata</i>	Biomass
Microtox (porewater) bioluminescence	The mean light output of the highest concentration of the test sediment is less than 80 % of the mean light output of the reference sediment, and the two means are statistically different (t-test, $P \leq 0.05$).	Not Applicable	<i>Vibrio fischeri</i>	Luminescence

Table 4-4. Summary of Oakland Bay study toxicity testing results compared to SMS criteria.

Station	Amphipod (<i>A. abdita</i> or <i>E. estuarius</i>)	Larval (<i>Mytilus</i> sp.)	Polychaete (<i>N. arenaceodentata</i>)	Microtox		Overall Station Status
	Absolute Mortality (percent)	Normal Survivorship Relative to Reference	MIG Relative to Reference	Sample Mean of Initial Light Output (percent)		
				5 min	15 min	SQS or CSL ^b
SH-01	10	0.94	0.739 ^a	100	96	Pass
SH-02	6	0.49 ^a	0.926	101	98	CSL
SH-03	14	0.49 ^a	0.831	96	92	CSL
SH-04	9	0.63 ^a	0.928	100	97	CSL
SH-05	15	0.26	0.704	106	100	CSL
SH-07	5	0.67	0.880	95	86	CSL
SH-09	12	1.01 ^a	0.901	101	98	Pass
SH-10	7	1.07	0.744 ^a	103	98	Pass
SH-11	7	1.16	1.020	100	96	Pass
SH-12	11	1.01	1.014	95	86	Pass
SH-13	8	1.12	0.639	94	87	SQS
SH-14	18	0.80 ^a	0.833	103	103	SQS
SH-15	3	1.22	0.928	101	97	Pass
SH-16	2	1.12	0.690	101	93	Pass
SH-18	10	0.85	0.755	100	95	Pass
SH-19	15	0.58 ^a	0.654	102	97	CSL
SH-20	10	1.04 ^a	0.920	102	94	Pass
SH-21	14	0.53 ^a	0.714	102	94	CSL
SH-22	10	0.63 ^a	0.643	110	104	CSL
SH-23	18	0.86 ^a	0.727	103	101	Pass
SH-24	18	0.47 ^a	0.785	98	95	CSL
SH-25	21	1.08	0.914	103	100	Pass
SH-26	13	0.83	0.631	100	94	SQS
SH-27	8	1.25	0.780	100	96	Pass
SH-28	6	0.99	0.691 ^a	101	97	SQS
SH-29	4	1.29	0.814	106	106	Pass
SH-30	9	0.91	1.002	106	100	Pass
OB-01	11	1.11	0.817 ^a	98	93	Pass
OB-02	21	1.05	0.771 ^a	102	98	Pass
OB-03	29	0.99 ^a	0.588	103	101	SQS
OB-04	5	0.76	1.167	97	90	SQS
OB-05	9	0.74	0.595	43	35	CSL
OB-06	14	0.68	0.724	104	95	CSL
OB-07	14	1.04	0.734	104	101	Pass

Table 4-4 (continued). Summary of Oakland Bay study toxicity testing results compared to SMS criteria.

Station	Amphipod (<i>A. abdita</i> or <i>E. estuarius</i>)	Larval (<i>Mytilus</i> sp.)	Polychaete (<i>N. arenaceodentata</i>)	Microtox		Overall Station Status
	Absolute Mortality (percent)	Normal Survivorship Relative to Reference	MIG Relative to Reference	Sample Mean of Initial Light Output (percent)		
				5 min	15 min	SQS or CSL ^b
OB-08	8	0.93	0.748	101	92	Pass
OB-09	10	0.79	0.820	99	95	SQS
OB-10	6	0.54	0.919	103	97	CSL
OB-11	11	1.17	0.785	94	89	Pass
OB-12	21	0.84	0.771	101	92	SQS
OB-13	10	0.69	0.681	92	86	CSL
OB-14	10	0.65	0.782 ^a	95	90	CSL
OB-17	10	0.96	1.008 ^a	96	91	Pass
OB-18	12	0.56	0.770	104	96	CSL
OB-19	8	0.55	0.917	100	95	CSL
HI-02	4	1.11	0.625 ^a	107	111	SQS
HI-03	17	1.04	1.028	108	105	Pass
HI-04	2	1.06	1.062 ^a	115	121	Pass
HI-05	1	1.32	0.837	99	94	Pass
HI-06	7	0.97	0.822 ^a	104	109	Pass
HI-07	2	1.26	0.941 ^a	97	96	Pass

^a Bioassays must be run with reference sediments that are well-matched to the test sediments for grain size. In this case, the appropriate reference sample failed toxicity test criteria. As an alternative, the test sediment was compared to a reference sample passing toxicity test criteria with the next closest matching grain size in the test batch. In the case of the larval test, two of the three reference sediments for Batch 1 did not meet the test criteria; therefore, all bioassays from Batch 1 of the larval test were compared with Reference 3.

^b SQS or CSL station exceedance. A station with two or more SQS exceedances is assigned a CSL exceedance under the Sediment Management Standards (WAC 173-204-520(1)(d) and (3)(d)).

Bold indicates SQS failure.

Bold underline indicates CSL failure.

MIG mean individual growth.

min minute.

Lead-210 measurements are routinely employed to date recent marine sediments. The technique works by examining change in the relative presence of lead-210 with depth. Lead-210 is created when lead at the earth's surface is bombarded by radiation from space (cosmogenic). Lead-210 in the sediment ceases to be created once it is buried during the sedimentation process. Lead-210, created when the sediment was exposed on the surface to cosmogenic radiation, decays at a known rate. By measuring the amount of lead-210 throughout the sediment cores, it can be determined how long it has been since that particular sediment was buried. The sedimentation rate can be estimated by examining the trend in reduction of lead-210 with depth below the seabed.

Deposition of cesium-137 began in 1946 as a result of thermonuclear activities worldwide. The deepest trace of its presence in a core defines a timeframe benchmark to compare with lead-210 findings. An estimated sediment deposition rate is assumed and core sections on either side of the estimated 1946 surface are analyzed. When results of the deeper sample indicate no cesium-137 and the next shallower core section selection indicates cesium presence, then the 1946 benchmark depth is bracketed. Lead-210 analysis is performed first to help identify the appropriate depth; however, selecting the optimal core sections can be difficult. Both elements are primarily associated with fine-grained sediments, not with sand and gravels.

All of the cores exhibited expected trends of lead-210, decreasing with depth (Figure 4-4); however, not all presented clear transition breakpoints useful for interpretation.

Core OB-15 indicated a clearly defined lead-210 starting layer and gradual increase in radioactivity moving upward; OB-16 presented a less clear trend. It required three cesium-137 core section samples in the OB-15 core and five core section samples in the OB-16 core to adequately define the 1946 benchmark.

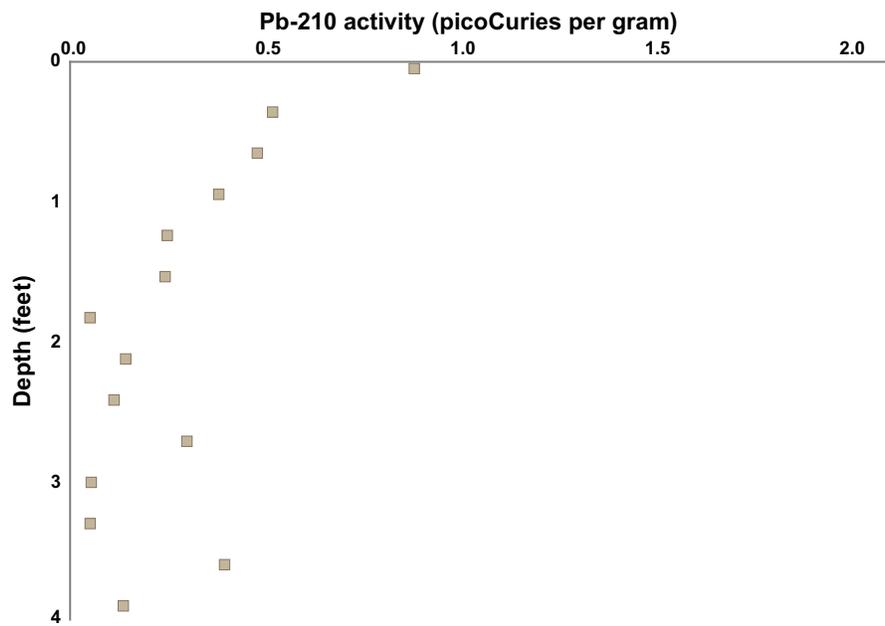
Due to the sand and gravel content of core SH-17, lead-210 was difficult to interpret. Based on the poor preliminary lead-210 results, it was decided to not analyze core SH-17 for cesium-137, but to evaluate the other cores in more detail. The presence of extensive gravel throughout the SH-17 core appeared to result from Goldsborough Creek deposits associated with channelization of the creek by man. This alternative timeframe benchmark provided a non-radiological means of dating the sediment.

Analytical results for all the radioisotope cores are presented in Appendix I.

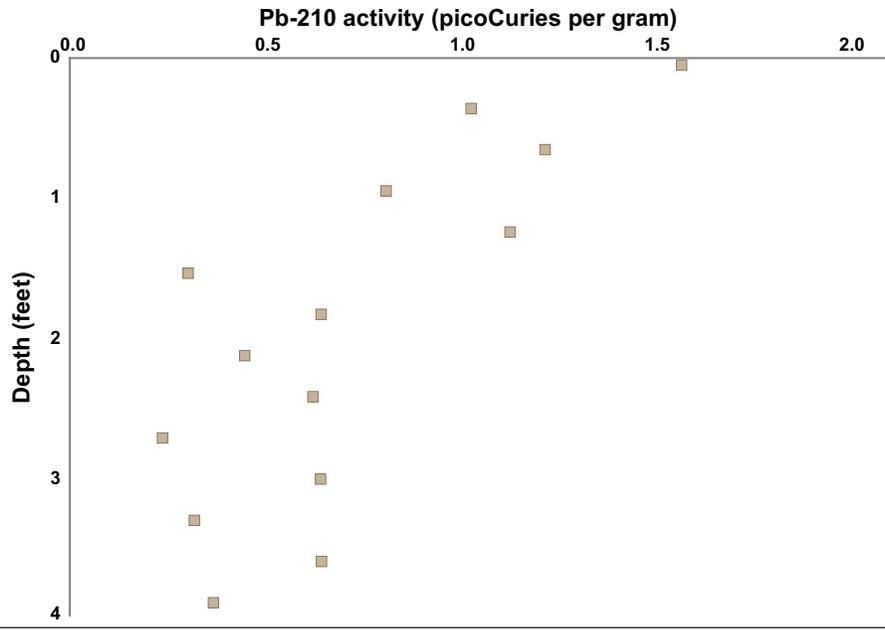
4.5 Data Validation

A QA1 data review was performed for all chemical, toxicity, and radiology data collected for this project. A QA1 data review evaluates field collection and handling, completeness, data presentation, detection limits, and the acceptability of test results for method blanks, certified reference materials, analytical replicates, matrix spikes, and surrogate recoveries. A QA1 review for bioassay data covers similar field and reporting elements and evaluates the acceptability of test results for positive controls, negative controls, reference sediment, replicates, and

Sample location
SH-17



Sample location
OB-15



Sample location
OB-16

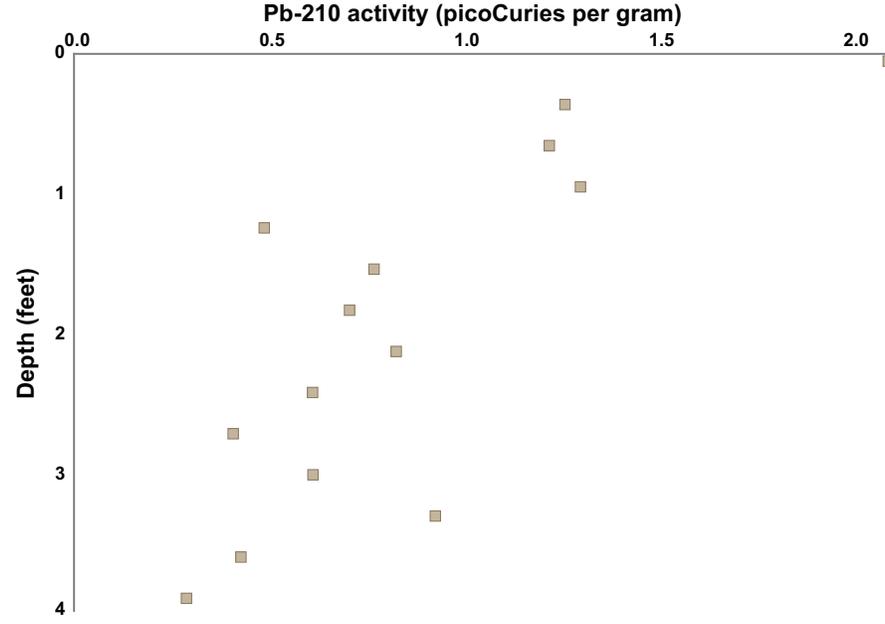


Figure 4-4. Lead-210 core profiles in Shelton Harbor and Oakland Bay.

experimental conditions (e.g. temperature, salinity, pH, dissolved oxygen). The QA1 data reviews were performed based on data quality objectives outlined in the project *Sampling and Analysis Plan* (Herrera 2008); completed QA1 memoranda are provided in Appendix J. In general, chemistry data met project criteria and are considered acceptable for use. Approximately 450 of 15,000 chemistry results (3 percent) were qualified due to holding time, precision, or accuracy criteria failures; no data were rejected. A summary of data quality issues encountered is provided for chemical, toxicity, and radiology data in the following sections.

4.5.1 Chemical Data Validation

All chemistry data are considered acceptable for use as intended, with the minor qualifications described below:

- Low matrix spike recoveries – several total sulfide results were qualified as estimated or estimated detection limit values due to low matrix spike recoveries.
- Laboratory duplicate criteria exceedances – the total sulfide result for sample OB-12-WC-12 and total mercury result for sample SH-21-WS-00 were qualified as estimated.
- Low matrix spike recovery values and laboratory duplicate criteria exceedances – all PCB and pesticide compounds for sample SH-21-WS-00 were qualified as estimated or estimated detection limit.
- Holding time exceedances – several samples analyzed for pesticides and PCBs were qualified as estimated or estimated detection limit.
- Primary and confirmation column criteria exceedances – several PCB and pesticide compound results were qualified as estimated.
- Method blank criteria exceedance – bis(2ethylhexyl) phthalate (BEHP) results were qualified as estimated or nondetected.
- Internal standard criteria exceedance – several SVOCs for sample SH-21-WS-12 were qualified as estimated detection limit values.
- High surrogate recoveries – several resin acid compound results for sample SH-12-WC-12 were qualified as estimated.
- Low laboratory control sample recoveries – several neoabietic acid results were qualified as estimated or estimated detection limit values.

4.5.2 Toxicity Data Validation

One or more reference sediment samples (REF-1, REF-2, REF-3) failed toxicity analysis criteria for the larval development, juvenile polychaete growth test, or Microtox test. In these cases, test

sediment was compared to the next closest passing reference sediment sample with respect to grain size, or to the control sample in the case of the Microtox test. No other data quality issues were identified for the toxicity analyses and no data were qualified.

4.5.2.1 *Bioassay Water Quality Results*

Water quality test condition protocols and summary of daily measurements are presented in Table 4–5. The temperature, salinity, dissolved oxygen, and pH were all within control limits and acceptable ranges throughout the tests, with minor exceptions for the amphipod mortality, larval development, and juvenile polychaete growth test, as described below:

- Temperature dropped below control limits for the juvenile polychaete growth bioassays, and rose above the control limits for the amphipod mortality bioassay and for one batch for the juvenile polychaete growth bioassay
- Salinity rose above control limits for one of the amphipod mortality bioassays and the juvenile polychaete growth bioassays
- Dissolved oxygen dropped below control limits for the juvenile polychaete growth bioassays.

These water quality deviations are not believed to have had significant effects on the test results.

The water quality measurements (interstitial and overlying) for ammonia and sulfides are presented in Table 4–6. The total ammonia and sulfide concentrations were all below levels of potential concern in bioassay test results (DMMP 2002; DMMP 2004), with the exception described below:

- The initial interstitial sulfide concentration for sample OB-10-SS-00 (18 milligram per liter [mg/L]) exceeded the level of potential concern (3.4 mg/L) for the juvenile polychaete bioassay; however, sample OB-10-SS-00 passed the toxicity test criteria.
- Based on the water quality measurements, there do not appear to be any adverse effects on test organisms due to laboratory test conditions.

4.5.2.2 *Negative Control and Reference Sediment Performance Results*

Reference sediments are used in comparison with test sediments for interpreting bioassay results. Three reference locations from Carr Inlet were sampled for comparison to the test sediments collected from Oakland Bay. Carr Inlet is recognized as a suitable reference area for the collection of sediments for interpreting bioassay results.

Table 4-5. Water quality test results compared to test control limits, Oakland Bay study.

Test (test species)	Control Limits/Test Results	Temperature	Salinity	Dissolved Oxygen	pH ^a
Amphipod Mortality (<i>A. abdita</i>)	Control Limits	20 ± 1°C	28 ± 2 ppt	≥5.0 mg/L	7.3 – 8.3
	Test Results ^b	19.4 to 23.8 °C	27 – 35 ppt	6.6-8.7 mg/L	7.6 – 8.8
Amphipod Mortality (<i>E. estuarius</i>)	Control Limits	15 ± 1°C	28 ± 2 ppt	≥5.0 mg/L	7.3 – 8.3
	Test Results ^b	15.0 to 16.9 °C	28 – 30 ppt	6.4-9.7 mg/L	7.4 – 8.5
Larval Development (<i>Mytilus</i> sp.)	Control Limits	16 ± 1°C	28 ± 1 ppt	≥4.8 mg/L	7.3 – 8.3
	Batch 1 Test Results ^b	15.1 to 16.5 °C	28 ppt	5.2 – 9.7 mg/L	7.3 – 8.0
	Batch 2 Test Results ^b	15.2 to 16.6 °C	27 – 28 ppt	6.0 – 8.8 mg/L	7.5 – 8.2
Juvenile Polychaete Growth (<i>N. arenaceodentata</i>)	Control Limits	20 ± 1°C	28 ± 2 ppt	≥6.0 mg/L	7.0 – 9.0
	Batch 1 Test Results ^b	16.9 to 20.7 °C	27 – 32 ppt	2.9 – 10.7 mg/L	7.1 – 8.8
	Batch 2 Test Results ^b	18.4 – 23.0 °C	28 – 32 ppt	3.6 – 14.2 mg/L	7.6 – 8.9
Microtox Bioluminescence (<i>V. fischeri</i>)	NA ^c	15 °C ^d	20 ± 2 ppt ^e	50 – 100% saturation ^f	7.9 – 8.2

^a pH is required for water quality monitoring, but does not have explicit control limits.

^b Water quality test results are for reference and test sediment parameters only; does not include negative control results.

^c Water quality is not monitored, but the 100 percent porewater extract of the sediment sample is adjusted for temperature, pH, dissolved oxygen, and salinity.

^d Temperature is maintained at 15°C in an incubator during testing.

^e Same as interstitial.

^f Continuous aeration is required by the method, so DO concentration is not a cause of concern.

°C degrees Celcius

mg/L milligrams per liter

ppt parts per thousand

NA not applicable

Source: Ecology (2003)

Table 4-6. Water quality measurements of total ammonia and sulfides, Oakland Bay study.

Test (test species)	Batch	Ammonia (interstitial) (mg/L)	Ammonia (overlying) (mg/L)	Sulfides (interstitial) (mg/L)	Sulfides (overlying) (mg/L)
Amphipod Mortality (<i>A. abdita</i>)	1	<0.5– 8.34	<0.5– 2.32	0 – 0.241	0 – 0.150
Amphipod Mortality (<i>E. estuarius</i>)	1	<0.5– 8.79	<0.5– 1.89	0.019 – 0.797	0 – 0.032
Larval Development (<i>Mytilus</i> sp.)	1	NA	<0.5 - 0.541	NA	0 – 0.570
	2	NA	<0.5	NA	0.002 – 0.124
Juvenile Polychaete Growth (<i>N. arenaceodentata</i>)	1	<0.5 – 5.03	<0.5 – 0.745	0.006 – 0.392	0 – 0.026
	2	<0.5 – 8.92	<0.5 – 2.88	0 – 18	0 – 0.055
Microtox Bioluminescence (<i>V. fischeri</i>)	1-14	NA	2.7 – 45.6	NA	NA

mg/L milligrams per liter

NA not applicable

The performance results of the negative control and reference sediments for each bioassay are presented in Table 4-7. The negative control performance standards were met for all four bioassays; therefore, test results for amphipod mortality, larval development, juvenile polychaete, and Microtox should be considered valid for the purpose of SMS confirmatory biological tests. Reference sediments did not meet certain performance criteria, as described below:

- Reference samples REF-01-SS-00 and REF-02-SS-00 did not meet the performance criteria in Batch 1 for the larval development bioassay.
- Reference sample REF-03-SS-00 did not meet the performance criteria in Batch 1 for the juvenile polychaete growth bioassay.
- Reference sample REF-02-SS-00 did not meet the performance criteria in any of the six batches analyzed for Microtox.
- Reference sample REF-03-SS-00 did not meet the performance criteria in one of the five batches analyzed for Microtox.

Table 4-7. Performance standards and results for negative controls and reference sediments, Oakland Bay study.

Test (test species)	Performance Standard	Negative Control		Performance Standard	Reference Sediment	
		Batch 1	Batch 2		Batch 1	Batch 2
Amphipod Mortality (<i>A. abdita</i>)	$M_C \leq 10\%$	9%	NA	$M_R < 25\%$	REF-01: 15% REF-02: 13%	NA
Amphipod Mortality (<i>E. estuarius</i>)	$M_C \leq 10\%$	1%	NA	$M_R < 25\%$	REF-02: 15% REF-03: 13%	NA
Larval Development (<i>Mytilus</i> sp.)	$N_C \div I \geq 0.70$	0.84	1.03	$N_R \div N_C \geq 65\%$	REF-01: 51.2% REF-02: 45.0% REF-03: 70.2%	REF-01: 85.6% REF-02: 65.7% REF-03: 78.6%
Juvenile Polychaete Growth (<i>N. arenaceodentata</i>)	$M_C \leq 10\%$ $MIG_C > 0.38^a$	0.0% 0.563	0.0% 0.414	MIG_R / MIG_C <80%	REF-01: 91.7% REF-02: 96.3% REF-03: 65.9%	REF-01: 136% REF-02: 106% REF-03: 95.2%
Microtox Bioluminescence (<i>V. fischeri</i>)	$M_C > 80\%^b$	83-102% ^c	NA	$M_R > 80\%^b$	REF-01: 92-102% ^c REF-02: 49-65% ^c REF-03: 66-100% ^c	NA

Bold font indicates performance criteria not met.

^a Target MIG_C is 0.72 mg/individual/day; the test is considered as failed if the Control MIG is less than 0.38 mg/individual/day.

^b Percent mean light output of final control or reference relative to initial control or reference.

^c The bioassays were performed in several batches; reference sediment results are provided as a range.

M mean mortality

N mean normal development survival in seawater control

NA not applicable

I initial count

MIG mean individual growth rate (mg/individual/day)

Subscripts: R = reference; C = negative control

Because of these reference sample failures, all samples analyzed in Batch 1 for the larval development bioassay were compared to reference sample REF-03-SS-00; all samples analyzed in Batch 1 for the juvenile polychaete growth bioassay were compared to reference samples REF-01-SS-00 or REF-02-SS-00 (Michelsen and Shaw 1996). For Microtox bioassays, samples were compared to control samples if reference samples failed performance criteria.

4.5.2.3 Positive Control Results

Bioassay reference toxicant test results are provided in Table 4-8. The median lethal concentration (LC50) values for all the bioassays fell within the acceptable range of mean +/- two standard deviations for historical reference toxicant data generated by the laboratory. The reference toxicant results indicate the test organisms appeared to be sufficiently sensitive for demonstrating a toxic response and sufficiently robust for laboratory testing. The reference control charts, with both current and running means and standard deviation, are provided in Appendix H.

Table 4-8. Bioassay reference toxicant results, Oakland Bay study.

Test (test species)	Reference Toxicant	Endpoint	Test Batch	LC50	Laboratory Historical Range (mean +/- 2SD)
Amphipod Mortality (<i>A. abdita</i>)	Cadmium chloride	96-hour survival	1	0.32 mg/L	0.135 – 1.14 mg/L
Amphipod Mortality (<i>E. estuaries</i>)	Cadmium chloride	96-hour survival	1	13.4 mg/L	4.0 – 12.2 mg/L
Larval Development (<i>Mytilus</i> sp.)	Copper chloride	normality	1 2	7.4 µg/L 8.3 µg/L	3.4 – 18.7 µg/L 3.5 – 18.0 µg/L
Juvenile Polychaete Growth (<i>N. arenaceodentata</i>)	Cadmium chloride	96-hour survival	1 2	6.8 mg/L 8.0 mg/L	2.4 – 16.9 mg/L
Microtox Bioluminescence (<i>V. fischeri</i>)	Phenol	luminescence	1-14	23.8 – 59.0 mg/L	20.7 – 68.7 mg/L

mg/L milligrams per liter
 µg/L microgram per liter
 LC50 median lethal concentration
 SD standard deviation

4.5.3 Radiology Data Validation

No data quality issues were identified for the radiological analyses and no data were qualified.

5.0 Evaluation of Study Area Conditions

This section presents an evaluation of study area conditions based on data presented in Section 4, including descriptions of general geomorphologic processes (provided in Appendix E). Comparisons to other historical information are provided in Section 7.

The geomorphic assessment was based on information associated with area-wide data gathering (i.e., geologic process evaluation and geophysics) and location-specific sources (i.e., sediment core lithology and radioisotope dating). Location-specific data can define conditions related to current and historical activities conducted at that position in the bay, but can also be used to support development of a model that may indicate conditions reflecting broader bay-wide processes. In this study, geophysical survey results were derived from a series of transects, determined in the field based on site conditions and the features to be interpreted by the specific survey type. Later, sediment cores were collected and interpreted for lithology at a single point in space.

The results of both techniques were compared and data from the core samples evaluated within the context of the overall site model (discussed further in Section 5.2.3). This may have resulted in conflicts on a small scale (e.g., where sediment layer thickness associated with wood, defined by the geophysical survey, did not exactly correspond to visible wood volume at a particular core location). To obtain more precise measures of wood waste characteristics both laterally and vertically over small spaces, a more detailed data gathering study would be required in the area of concern. The results of this bay-wide study provide adequate information to focus further efforts.

5.1 Bathymetry

Oakland Bay is an embayment at the southwestern end of Puget Sound. Like the rest of Puget Sound, Oakland Bay was glaciated and carved out during the last ice age. Central Oakland Bay and Hammersley Inlet are most probably the remnants of a subglacial channel formed during glacial retreat, but still reflecting the original shape; the bay has been filled with sediment eroded from the surrounding landscape. A majority of sediment input to the study area comes from creeks located in Shelton Harbor, in Chapman Cove, at Bayshore Point, and at the head of the bay (Goldsborough Creek represents two thirds of the total sediment input to Oakland Bay). Creek deltas are shallow areas influenced by drainage from upland areas and small local waves, and are dominated by flood discharges with high sand content. The heavy sand is deposited near the creek mouths, while muddy sediment (silt and clay) remains suspended and is transported into deeper water.

Oakland Bay water depths vary from 15 feet (4.6 meters) to 80 feet (26.2 meters) below MLLW during high tide. A deep hole covering 1,000 feet by 500 feet (300 meters by 150 meters) varies in depth from 45 to 80 feet (14 to 24 meters) at the transition of Oakland Bay to Hammersley Inlet (Figure 4-1). A relict channel, maintained by modern tidal flow and up to 50 feet

(15 meters) deep, stretches north from this hole, past the eastern boundary of Shelton Harbor and along the western edge of lower Oakland Bay. Shallow tidal flats up to 10 feet (3 meters) deep at high tide dominate most of the southeast shoreline of Oakland Bay, Chapman Cove, and the head of the bay. Much of northern and western Shelton Harbor is dominated by shallow areas resulting from creek deltas that can vary up to 15 feet (4.6 meters) deep, depending on tide conditions. The remainder of Shelton Harbor is deeper and has been dredged to a depth of approximately 10 to 15 feet (3 to 4.5 meters) below MLLW.

The relict channel is no longer apparent in Chapman Cove and north of Bayshore Point, as it has been filled with sediment. Eroded sediment from the surrounding landscape is also reflective of glaciation, being comprised of glacial till (varying from silt to gravel and cobble), outwash sand, and glacial lacustrine silt and clay. Hardpoint bedrock outcroppings are common at the interface between Hammersley Inlet and Oakland Bay. This is evident in the subbottom profiles generated by the geophysical survey (Appendix E, Figure 4). The hardpoints at the interface of Oakland Bay and Hammersley Inlet effectively constrict tidal flow through a narrow and deep subglacial channel.

Past work describing geologic and hydrographic conditions in Oakland Bay indicates a low energy, tidally influenced estuary that occupies a drowned drainage network. The extreme tide range in Oakland Bay ensures strong near-bed flood currents, little ebb tide flushing (mostly surficial water), and a high retention rate of local sediment inputs (Albertson 2004). Fresh water that enters the bay from creeks is less dense than marine salt water. During tidal cycles, fresh and marine waters mix; however, the fresh water tends not to mix deeply. As a consequence, the fine grain and colloidal sediment fractions (a small mass fraction of the total sediment load) entrained in the fresh water move out of the bay near the surface. This means that although there are local high velocity tidal currents at the junction between Oakland Bay and Hammersley Inlet, most sediment that originates in Oakland Bay remains there.

The dense seawater delivered to the bay likely flows along the deep channel bottom, as evidenced by the orientation of the marine bedforms at its south end (Appendix E, Bedform 1 in Figure 4). The steeper slopes on the ‘downstream’ side of the rippled bedform feature indicate water flow into Oakland Bay from Hammersley Inlet at depth. Shallow-water marine bedforms (Bedform 2, Appendix E, Figure 4) oriented toward Hammersley Inlet also confirm that less dense, less saline flow is occurring out of Oakland Bay at shallower depths (Albertson 2004). No other bedforms were found in the study area.

5.2 Sediment and Wood Waste Distribution

Vashon recessional outwash and proglacial stratified sand and gravel with variable amounts of silt were deposited as glacial ice receded across the area. These deposits extend northeast of Shelton along the western shoreline, continuing to the north end of Oakland Bay as the ground surface. Beneath this layer, glacial till was deposited by glacier ice along Shelton Harbor to the north and south; it is composed of a highly compacted mixture of clay, silt, sand, and gravel. Below the till, Vashon advance outwash consists of layers of sand and gravel and lacustrine clay,

silt, and sand deposited in front of the advancing glacier. The advance outwash is commonly exposed where topography is steep and the overlying till has been removed by erosion. It is found along the northwest shoreline of the bay, on the shoreline and slopes to the north of Chapman Cove, and on either side of the shoreline where the bay becomes Hammersley Inlet. Pre-Vashon gravel deposits have been cemented and are well compacted. They are found on steep slopes between the till and recessional deposits, particularly to the north and south of the fill material in Shelton Harbor and along the eastern slopes of Oakland Bay. Typically, the unconsolidated deposits are underlain by volcanic basalt bedrock in this area.

5.2.1 Sediment Lithology

With core penetration of 12 feet (3.6 meters) or less, none of the glacial till or glaciofluvial units discussed above were found in the sediments (although till may have been encountered at SH-25, causing core refusal – low tide observations indicated a rock shelf extending from the shore). Eroded material from the glacial units was found in sediment cores collected throughout the study area, including alluvial deposits of sand and gravel found overlying fine-grained marine deposits consisting of silty clay and clayey silt.

Twenty-seven cores were collected from Shelton Harbor, with the following sediment grain size characteristics:

<u>Grain Size</u>	<u>Number of Samples</u>
Primarily coarse	6
Transition from coarse to fine from top to bottom	2
Transition from fine to coarse from top to bottom	4
Primarily fine	15

Cores with coarse sediment throughout were collected from the Goldsborough and Shelton Creek deltas. Before human development, the creeks feeding Shelton Harbor were not channelized, instead depositing most of their sand and gravel much further to the west as they meandered slowly through a complex network of channels on the delta (now the downtown area). Since being channelized, they now deliver sand and gravel rapidly to the middle of the harbor.

The two cores exhibiting a coarse-to-fine transition from top to bottom were found in the north and east portions of the harbor directly impacted by the creeks. Upward grain-size coarsening in the cores indicates recent delivery of sand and gravel overlying a heterogeneous sub-layer with some fine grain material present.

All samples collected from the south side of the harbor were composed either entirely of fine-grain material or material grading from fine to coarse downward. Before human development, significant amounts of sand and gravel were likely deposited along the southern shore of Shelton Harbor from erosion of adjacent bluffs. With human development, the base of the bluff has been

protected with fill and rock revetments and creek discharge limited to the north side of the harbor. The loss of generally coarse sediment input, along with fine material re-suspended from nearby dredging operations, has resulted in the upward fining pattern observed in these cores.

Nineteen cores were collected from Oakland Bay, with the following sediment grain size characteristics:

<u>Grain Size</u>	<u>Number of Samples</u>
Primarily coarse	2
Transition from coarse to fine from top to bottom	0
Transition from fine to coarse from top to bottom	1
Primarily fine	16

One core with coarse sediment throughout was collected east of Bayshore Point from a deep hole maintained by intermittent intense flow. This area collects large amounts of shells from the surrounding area at the north end of the bay. The shells are trapped because they are transported to the area via bedload (transport that occurs near the bed), but cannot escape out of the hole. Fine-grain material is not deposited because the currents in the area are too strong to allow deposition. The other coarse sediment core was collected from the shoreline just north of the marina, adjacent to historical bulk fuel facilities. This sample was collected from the steep side slope of the deep trough seen in the bathymetric map (Figure 4-1).

The one core with a fine-to-coarse transition from top to bottom was located at the mouth of the creeks at the head of the bay. The fine-to-coarse transition here is similar to the creek deltas in Shelton Harbor and likely has a similar origin (i.e., confinement of streamflow from development).

Most cores collected from Oakland Bay consisted of fine-grain sediments throughout, indicating long-term deposition, distant from energetic sources (creeks) where coarse-grain sediment deposits first.

Six cores were collected from Hammersley Inlet, with the following sediment grain size characteristics:

<u>Grain Size</u>	<u>Number of Samples</u>
Primarily coarse	3
Transition from coarse to fine from top to bottom	1
Transition from fine to coarse from top to bottom	1
Primarily fine	1

Coarse grain material was noted in five of the samples, located both along the sides of the deep trough and in the middle of the channel. The one core exhibiting primarily fine-grained sediment was collected from the depositional flat located south of Eagle Point.

The distribution of sediment provides clues to the direction of sediment transport in the study area. Sediment varies from coarse to fine along the direction of transport. Coarse material is found at the creek deltas that surround Oakland Bay and in Hammersley Inlet. While there are pockets of sediment accumulation in Hammersley Inlet and the smaller embayments, for the most part, sediment varies from coarse to fine moving from the source to final destination in deeper portions of the bay. Thus, the broad distribution of predominantly fine material across Oakland Bay indicates that this area is far from sediment sources and represents the final place of deposition within the study area.

Review of sediment core logs across most of Oakland Bay indicates a general pattern of coarser clayey silt found in the top 2 feet (0.6 meter), transitioning to finer silty clay below (the 2-foot transition depth varies up to a foot (0.3 meter) in either direction at a few locations). Those cores that do not exhibit this pattern were collected adjacent to shorelines or alluvial fans. Hammersley Inlet and Shelton Harbor sampling stations did not follow this pattern, reflecting areas of relatively high hydraulic energy (i.e., alluvial fans and scoured beds). Much of the harbor exhibited clayey silt starting at depths ranging from 1 to 3 feet (0.3 to 1.0 meter), overlain by coarser material (usually containing sand).

5.2.2 Sediment Accumulation Rates

Three sediment cores from Shelton Harbor and Oakland Bay (SH-17, OB-15, and OB-16) were sampled for the presence and concentrations of lead-210 and cesium-137 to estimate sediment accumulation rates. Detailed analysis provided in Appendix E). SH-17 was collected on the Goldsborough Creek delta, OB-15 was collected in the middle of Oakland Bay, and OB-16 was collected near the Johns Creek delta, south of Bayshore Point (Figures 3-2 and 3-3).

Core SH-17, collected on the edge of the Goldsborough Creek delta, included large quantities of sand and gravel associated with relatively recent sediment input from the creek. As a result, the core did not contain a significant amount of lead-210 typically associated with older, fine-grained sediments (see Section 4.1.2.3). The lack of fine-grained sediments at this location made precise determination of sediment age impossible. However, the presence of gravel in the core provided independent geomorphic evidence of an average accumulation rate of approximately 0.39 in/year (1 cm/year) at this location (based on the assumption that the deepest gravel, at 4 feet [1.2 meter], was deposited after the onset of major development, around 1900).

Core OB-15, collected from the middle of Oakland Bay indicated a sediment accumulation rate of between 0.11 and 0.20 inch/year (0.27 and 0.51 cm/year) based on cesium-137 presence at 6.8 in (17 cm) and absence at 12.8 in (32 cm). The lead-210 results independently support this conclusion because background levels of lead-210 are achieved at 18.8 in (47 cm) depth.

Core OB-16, collected from the north end of the main portion of Oakland Bay provided a less clear-cut picture of sediment accumulation. The lead-210 results suggest an accumulation rate of approximately 0.10 in/year (0.25 cm/year). The cesium-137 measurements constrain the accumulation rate to greater than 0.26 in/year (0.66 cm/year). While there is a possibility that the discrepancy between the lead-210 and cesium-137 measurements could be explained by disturbance of the seabed between 1946 and 1985 or so (e.g., by shellfish management activities), it is also possible that the low lead-210 concentrations in older sediments were too close to the detection limit for an accurate accumulation rate determination. Even though these results represent a disturbed site, they are generally consistent with the results seen at the other core locations.

The three sediment cores collected for radioisotope analyses represent the fringe of substantial creek sediment input to Shelton Harbor (SH-17), relatively undisturbed central Oakland Bay (OB-15), and an area of transition between disturbed and undisturbed portions of Oakland Bay (OB-16). Together, the radioisotope analytical results and core lithologies indicate that sediment accumulation rates vary across the Oakland Bay system, between 0.10 and 0.20 inches/year (0.25 and 0.51 cm/year) in central Oakland Bay, and possibly exceeding 0.40 inches/year (1 cm/year) in areas of preferential sediment accumulation (i.e., near creek deltas).

A geomorphic analysis of the Oakland Bay system performed before radiological core testing estimated sediment accumulation rates based on sediment input analysis and modeling, with an average accumulation rate determined as 0.23 in/year (0.57 cm/year) across the study area (Appendix E). This is close to the measured range of 0.10 and 0.20 in/year (0.25 to 0.51 cm/year) based on the radioisotope analysis. The rate of fine grain sediment accumulation within central Oakland Bay does not appear to reflect only inputs from adjacent creeks and shorelines.

The only other sources of sediment in the system can be attributed primarily to the creeks in Shelton Harbor and, to a lesser extent, Hammersley Inlet. Since Shelton Harbor exceeds the average accumulation rate estimated from the sediment input analysis (i.e., approximately 0.4 in/year [1 cm/year]) and areas far from sediment sources achieve somewhere between 50 and 90 percent of the anticipated accumulation rate, it appears that sediment accumulates in Oakland Bay. These conclusions are consistent with other qualitative evidence of high near-bed water flow and associated sediment transport artifacts (e.g., bedforms oriented into the bay and hydrographic modeling discussed in Appendix E).

Geophysical survey data identified a broadly distributed, recently deposited surface layer generally extending 1 to 3 feet (0.3 to 1 meter) deep. The transition between recent and older sediment layers was discernable in core logs, characterized by less dense clayey silt on top of denser silty clay in non-alluvial areas. This less dense surface layer coincides with increased human activities that have resulted in higher sediment delivery rates through increased upland erosion, channelization of Shelton Harbor creeks, and the introduction of wood waste (channelization of the creeks has resulted in increased hydraulic forces that transport fine grain material further into the bay). The addition of wood waste also has contributed to lower overall sediment density. It is possible that this transition also could be corroborated using radiological data; however, analysis of many more core sections would have been required, and a higher clay content throughout.

5.2.3 Wood Waste Distribution

Evidence of wood was found in 80 percent of all sample locations and was observed at all depths sampled. Percentage of wood presence visually estimated from cores is shown in Figures 5-1 and 5-2.

The geophysical survey data represented in Figures 4-2 and 4-3 depict the thickness of recent deposition indicated by acoustic tomography. The map is based on a network of survey transects, with no modification to fit data to core log observations at individual sampling stations. Evidence of wood waste found in cores penetrating recent deposits across the study area supports the strength of the geophysical evidence. Because uncompacted wood does not transmit sound well, sediments containing wood produce a distinct signature characteristic of low acoustic reflectivity. In this study, the slow sound speed associated with wood-containing sediments helped to enhance the contrast with older, more consolidated wood-free sediments beneath, where the sound speed was much faster. The relatively higher wood content found in recent sediment deposits is an artifact of increased wood processing that began in the late 1880s.

Shelton Harbor geophysical survey results presented in Figure 4-3 proved to be of marginal use. Approximately one-half of the harbor could not be reliably mapped, due to the presence of significant gravel in the creek deltas – significant amounts of coarse-grain material and dynamic sedimentation characteristics obscure the definition of the interface with the pre-development layer. In those areas with finer grain sediment within the harbor, high wood content also caused acoustic signal attenuation. In these cases, layer surfaces could not be mapped. Additionally, it was not possible to map beneath the present-day log rafting area in the southeast part of the harbor because of limited access. Sample SH-24 was obtained close to the existing log rafts and contained 50 percent bark at the surface. A core sample was not collected in this location due to refusal of the sampling equipment. As a result of these factors, the significant accumulation of wood in the south harbor area shown on Figure 4-3 could neither be accurately mapped or quantified.

Figures 5-3 and 5-4 provide comparisons of geophysical results to core log information (cores with wood at the bottom did not reach the bottom of the wood layer, due to refusal). Wood was identified in recent deposits where wood was intensively handled (i.e., in deeper portions of Shelton Harbor, at rafting locations around the perimeter of Oakland Bay) and adjacent to the trough along the north shoreline of lower Oakland Bay where finer grain sediment has tended to accumulate – compare area-wide color shades (recent depositional layer thickness) to circle sizes (average visible wood thickness at core locations). Note that the relatively thick deposit extending along the north shoreline of lower Oakland Bay is well represented by OB-02 and OB-17 and that the deposit boundaries are defined by HI-7, OB-03, -05, and -15.

No wood was found in cores collected from the center of Oakland Bay (OB-03, -05, -09, and -15) where wood rafts were not regularly stored (a review of available historical information identified a log raft lease area at the mouth of Chapman Cove [Herrera 2008a] and various aerial photographs indicated rafting along the shoreline of lower Oakland Bay and across Shelton Harbor [Appendix E]).

Wood waste was found in two distinct modes across the study area: broadly distributed, low concentrations of wood (less than 20 percent) mixed with sediment, and thick, highly concentrated wood layers. Figures 5-1 and 5-2 indicate the vertical distribution of wood content at each sampling station based on visual estimates (provided in Appendix F). Table 5-1 provides a summary of the general presence of wood waste across the study area by depth.

Table 5-1. Summary of Oakland Bay study core samples containing visible wood.

Core Section (feet)	Shelton Harbor		Oakland Bay		Hammersley Inlet	
	Wood Present	No. of Samples	Wood Present	No. of Samples	Wood Present	No. of Samples
0-1	76%	22 of 29	35%	6 of 17	43%	3 of 7
1-2	65%	17 of 26	53%	9 of 17	50%	3 of 6
2-3	60%	15 of 25	41%	7 of 17	0%	0 of 6
3-4	45%	10 of 22	19%	3 of 16	17%	1 of 6
4-5	25%	5 of 20	21%	3 of 14	0%	0 of 6
5-6	29%	5 of 17	50%	2 of 4	0%	0 of 4
6-7	27%	3 of 11	20%	1 of 5	0%	0 of 1

Observed wood was categorized in four forms: bark, chips, fibers, and sawdust (see Appendix F). Large chunks of bark and chips were removed during sample processing, but wood fibers and sawdust were not and remained in samples delivered to the laboratories. Wood fibers appeared as thin strands, almost like thick hair. Approximately half of the time, only one form of wood was found in a core.

Wood waste distribution was most prevalent as bark, found at 70 percent of all sampling stations. Fourteen locations exhibited bark at greater than 5 percent wood content and 23 locations exhibited less than 5 percent wood. Bark was found in 65 percent of Shelton Harbor stations, 88 percent of Oakland Bay stations, and 43 percent of Hammersley Inlet stations. The primary source of bark is likely from log rafts that have historically been stored across much of Shelton Harbor and the perimeter of Oakland Bay, including multi-acre tracts west of Chapman Cove and west of Munson Point (Herrera 2008a). The majority of this material was found in Shelton Harbor, where logs were delivered to the water by train (railway log dump), and by tug boats. Concentrated log handling activities along the shoreline where logs have been transferred in and out of storage have resulted in the largest accumulations of bark.

Wood waste was found as chips at 26 percent of the sampling stations. Two locations exhibited chips at greater than 5 percent wood content and 12 locations exhibited chips at less than 5 percent wood content. Chips were found in 45 percent of Shelton Harbor stations, no Oakland Bay stations, and one Hammersley Inlet station. The primary source of chips is likely from wood processing operations.

Wood waste was found as fibers at 23 percent of the sampling stations. Three locations exhibited fibers at greater than 5 percent wood content and nine locations exhibited fibers at less than 5 percent wood content. Fibers were found in 45 percent of Shelton Harbor stations, two



Figure 5-1.
 Visible percent wood content in
 Oakland Bay and Hammersley Inlet
 sediment samples at 1-foot intervals.

Legend

Total percent wood content

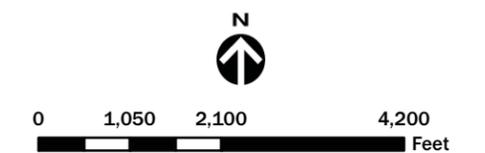
- Sample location - no wood found at any depth
- No wood at given depth
- 0.5 to 5%
- 5.1 to 10%
- 10.1 to 20%
- 20.1 to 50%
- > 50%

**Collected sample depth
 (1-foot intervals)**

- 0-1 foot
- 1-2 feet
- 2-3 feet
- 3-4 feet
- 4-5 feet
- 5-6 feet
- 6-7 feet
- 7-8 feet
- 8-9 feet
- 9-10 feet

Notes: Each station shown to the depth sampled; top box represents sample station location.

No core collected at HI-05. Wood content reflects that found in surface grab sample.



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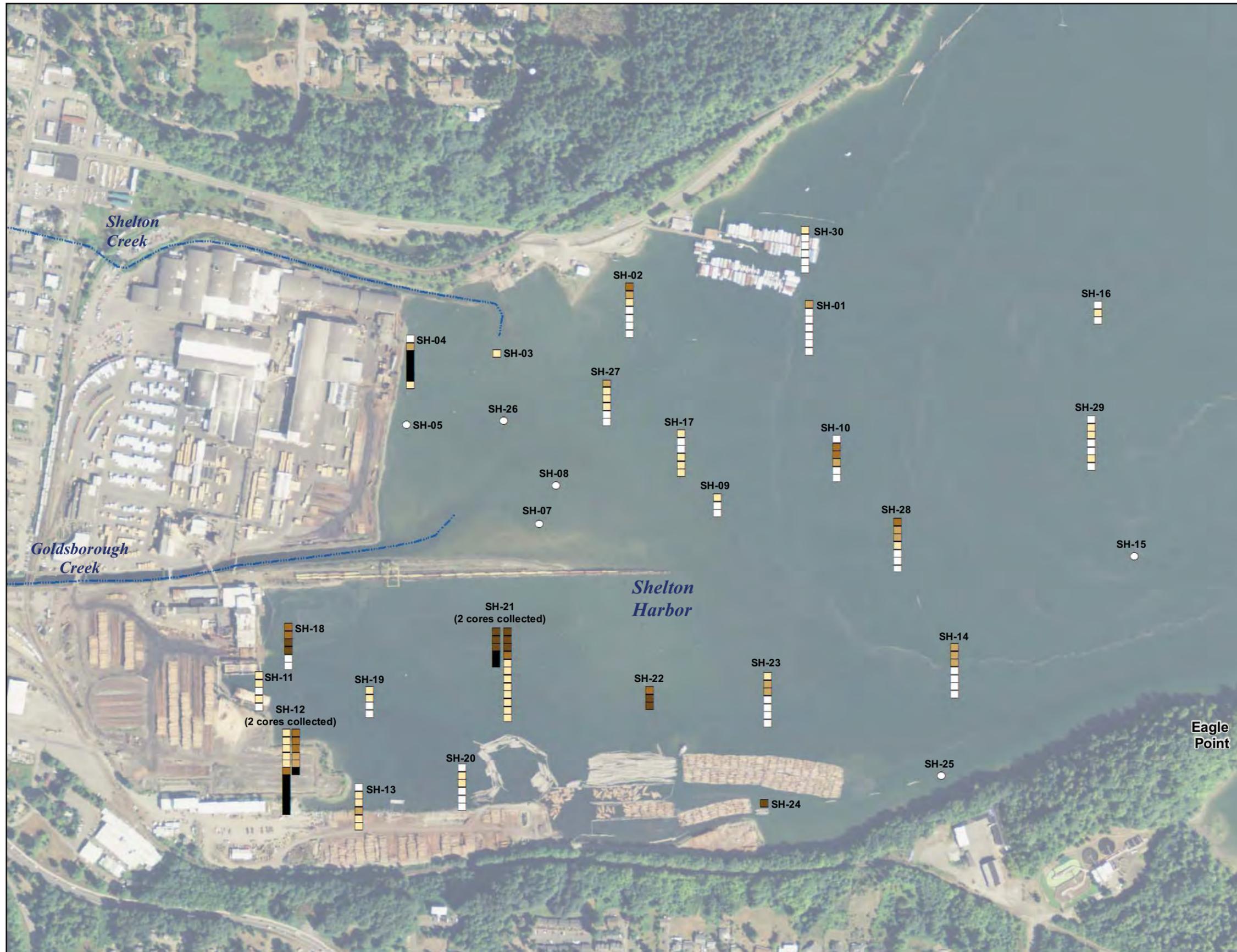


Figure 5-2.
Visible percent wood content in Shelton Harbor sediment samples at 1-foot intervals.

Legend

Total percent wood content

- Sample location - no wood found at any depth
- No wood at given depth
- 0.5 to 5%
- 5.1 to 10%
- 10.1 to 20%
- 20.1 to 50%
- > 50%

Collected sample depth (1-foot intervals)

- 0-1 foot
- 1-2 feet
- 2-3 feet
- 3-4 feet
- 4-5 feet
- 5-6 feet
- 6-7 feet
- 7-8 feet
- 8-9 feet
- 9-10 feet

Notes: Each station shown to the depth sampled; top box represents sample station location.

No surface grab or core collected at SH-06, due to high cobble content (not shown on map).

No cores collected at SH-03, SH-24, and SH-25; wood content reflects that found in surface grab sample.

Wood content based on visual inspection, provided in Appendix F.



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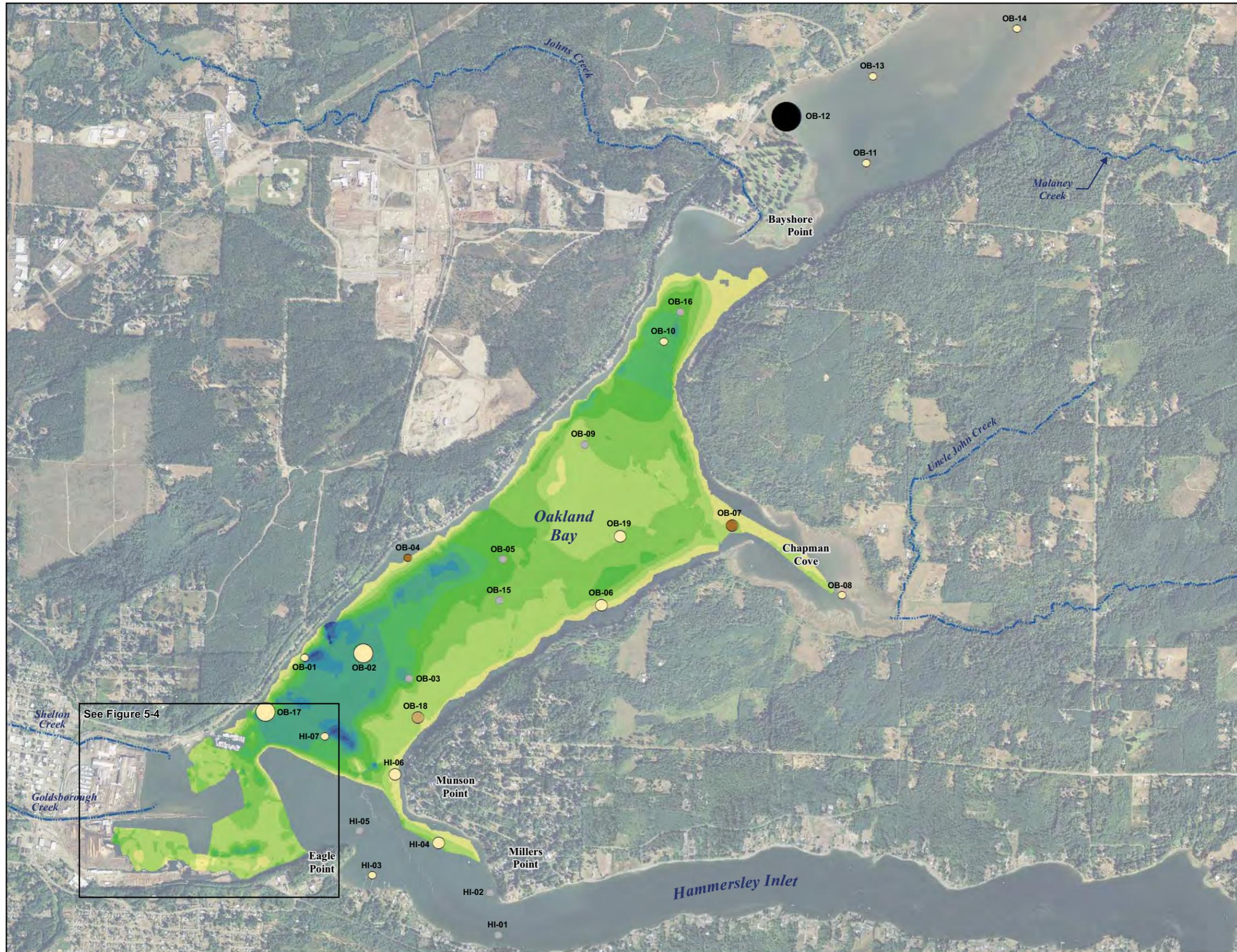


Figure 5-3.
 Total percent visible wood content compared to recent depositional layer thickness in Oakland Bay and Hammersley Inlet.

Legend

Total percent visible wood content at sample location

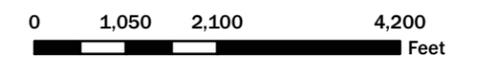
- No wood found at any depth
- 0.5 to 5%
- 5.1 to 10%
- 10.1 to 20%
- 20.1 to 50%
- > 50%

Visible wood thickness at sample location (feet)

- 1 foot
- 2 to 4 feet
- 5 to 7 feet
- > 7 feet

Recent depositional layer thickness (feet)

- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 5
- 5 to 6
- 6 to 7
- 7 to 8
- 8 to 9
- > 9



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Aerial: USDA, 2009

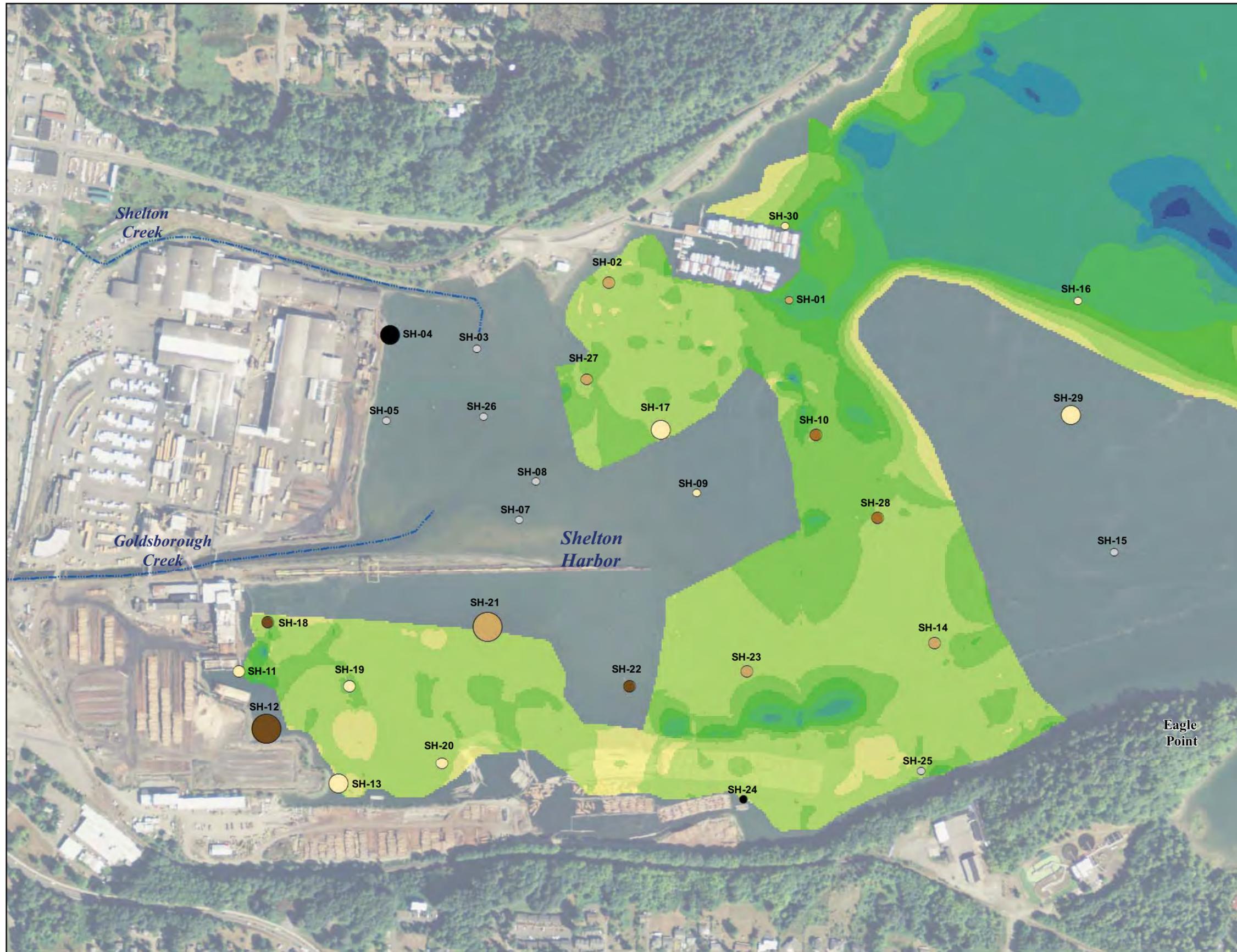


Figure 5-4.
 Total percent visible wood content compared to recent depositional layer thickness in Shelton Harbor.

Legend

Total percent visible wood content sample location

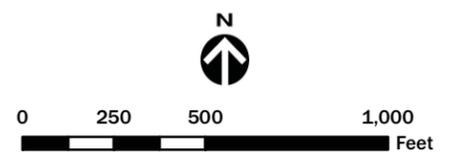
- No wood found at any depth
- 0.5 to 5%
- 5.1 to 10%
- 10.1 to 20%
- 20.1 to 50%
- > 50%

Visible wood thickness at sample location (feet)

- 1 foot
- 2 to 4 feet
- 5 to 7 feet
- > 7 feet

Recent depositional layer thickness (feet)

- 0 to 1
- 1 to 2
- 2 to 3
- 3 to 4
- 4 to 5
- 5 to 6
- 6 to 7
- 7 to 8
- 8 to 9
- > 9



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Oakland Bay stations, and one Hammersley Inlet station. The primary source of fibers is likely from wood processing operations. Fibers were likely discharged as part of the sulfite liquor waste associated with historical paper production and as waste from fiberboard processing; their presence appears to be restricted mostly to the south side of Shelton Harbor and, to a limited extent, to the north side of the harbor and along the southern shore of lower Oakland Bay.

Wood waste was found as sawdust at 6 percent of the sampling stations. All three locations with sawdust exhibited significant accumulations (greater than 50 percent). The primary source of sawdust is likely from wood sawing operations located at the west end of Shelton Harbor and at the head of Oakland Bay, likely associated with an historical sawmill, either located on the adjacent shore (not found in the historical review) or across the bay (discussed in Section 5.2.3.2).

Wood was not found in four portions of the study area:

- Shelton Harbor within the alluvial fans of Goldsborough and Shelton Creeks, due to high sand and gravel content (SH-03, -05, -07, -08, -26)
- Shelton Harbor and Hammersley Inlet along the Eagle Point shoreline, extending out in to the channel, due to the presence of bedrock and gravel content (SH-15, -25; HI-01, -02, -05)
- Central Oakland Bay, likely due to a general lack of sources (OB-03, -05, -09, -15, -16)
- Bathymetric low spot at the Head of the Bay where shell fragments dominate (OB-11)

5.2.3.1 Area-wide Distribution

Wood waste was found at 80 percent of all sample locations across the study area. Except for localized areas of high accumulation, wood was found at less than 20 percent by volume across the uppermost layer of sediment, associated with the onset of European settlement and development. This post-development layer was defined by sediment lithology (i.e., core logs) and the geophysical survey (acoustic tomography) that identified a distinct layer of recent sediment accumulation ranging from 1 to 8 feet (0.3 to 2.5 meter) in depth across the study area (Figures 5-1 and 5-2).

When averaged throughout the bay, the thickness of visible wood waste deposits (Table 5-2) was nearly identical to the average 3 foot (1 meter) post-development layer thickness estimated from the geophysical surveys (this does not account for localized areas of higher wood waste accumulation, discussed below). The recent depositional layer contained approximately 5 percent wood waste by volume when averaged across the study area; the variation of visible wood content was relatively small, with higher concentrations noted in Shelton Harbor compared to Oakland Bay (and an absence of wood along the center of the bay). Assuming an average wood content over the area of deposition (based on the core observations) and using the thickness of

the recent deposition layer associated with wide-spread wood presence (based on the geophysical surveys), an estimated 240,000 cubic yards (183,500 cubic meters) of wood is present across the bay. This does not include areas of significant wood accumulation, discussed below. The single, well-defined, recent depositional layer was absent in Hammersley Inlet (due to input of coarse-grain material from outside of the Oakland Bay system), on the creek deltas (due to large amounts of recent sediment accumulation), and along the center of Oakland Bay where no sources were identified.

Table 5-2. Distribution of visible wood waste.

Core ID ^a	Wood Waste Thickness ^b (ft)	Average Wood Waste Content ^c (%)	Predevelopment Sediment Depth ^d (ft)
SH-01	1.0	10.0	5.0
SH-02	3.0	8.7	2.0
SH-10	4.0	12.5	3.0
SH-11	4.0	2.8	4.0
SH-14	3.0	10.0	2.0
SH-16	2.0	0.5	5.0
SH-19	2.0	1.0	3.0
SH-20	3.0	2.0	2.0
SH-23	3.0	8.3	2.0
SH-27	4.0	9.0	2.0
SH-28	4.0	11.3	3.0
OB-02	5.0	0.8	6.0
OB-03	NA	NA	5.0
OB-05	NA	NA	4.0
OB-07	4.0	5.3	2.0
OB-09	NA	NA	2.0
OB-10	3.0	0.3	5.0
OB-17	6.0	2.7	4.0
OB-18	3.0	8.7	2.0
OB-19	3.0	2.0	2.0
HI-04	4.0	2.0	3.0
Average	3.3	5.4	3.2

^a Cores outside the geophysical survey area, those in deltas, and cores without recovery are not part of this analysis.

^b Depth measured from the surface to the deepest point in the core at which wood waste was found; "NA", indicates no wood waste found and it was not compared in subsequent analyses.

^c Average wood waste content based on percentages reported in 1-foot (0.3 meter) core samples.

^d Predevelopment sediment depth areas based on interpolation between geophysical survey lines.

The post-development layer generally thins and decreases in wood waste content moving away from Shelton Harbor into southern Oakland Bay to the north, increasing again near Chapman Cove and the adjacent log storage lease area there (Figure 5-3; Appendix E, Figure C4 shows log rafts in the lease area). The recent depositional layer contains significant clayey silt and usually overlies a more consolidated, wood-free silty clay layer associated with predevelopment

conditions (see core logs in Appendix B). In a few instances near the shoreline, the silt layer overlies sand, where the recent supply of sand has been lost due to disconnection of the bluffs along the shoreline by roadway construction and other development. The core log shown in Figure 5-5 indicates a cap of wood waste-free silt on top of older wood-containing sediments, another common feature in deeper portions of Oakland Bay, distant from modern wood waste sources. This cleaner cap, in places, indicates that most of the wood waste accumulation in these areas is from historical activities.

Wood waste generally was not found in Hammersley Inlet, where erosion processes leave only consolidated glacial sediments on the seabed. Where sediment does exist, it is usually much coarser than that found in most of Oakland Bay, suggesting that it is derived from erosion of nearby consolidated glacial sediments (e.g., where Oakland Bay and Hammersley Inlet meet). Wood waste also generally was not found in cores collected from creek deltas. At most creek deltas, it is likely that old wood waste deposits (where they occur) are buried by recently accumulated clean sediment.

5.2.3.2 *Concentrated Wood Waste Accumulations*

Significant wood waste accumulation was identified at four locations across the study area. A significant accumulation was determined to be total visible wood in excess of 20 percent by volume. Outside of these four locations, individual cores with 20 percent wood by volume occurred over short depth intervals, including SH-10 with 2 feet (0.6 meters) of 20 percent wood, the surface grab sample at SH-24 with 50 percent wood (no core could be collected due to refusal), SH-28 with 1 foot (0.3 meter) of 20 percent wood, and OB-7 with 1 foot (0.3 meter) of 20 percent wood. These cores were not considered to represent significant accumulations. The four locations with heavy wood accumulations were typically associated with known, historical sources of wood debris, and are described as follows:

- *Former pond saw*— This small wood accumulation area is located adjacent to the Simpson Planing Mill in shallow water, defined by core SH-04 (Figure 4-3). The nature of the wood waste was consistent with a mill byproduct (sawdust). High wood waste content (80 percent) was found between 2 and 6 feet (0.6 and 1.8 meters) deep, indicating an older deposition that has been covered by recent sediment build up (less than 5 percent wood content).
- *Railway log dump* – This wood accumulation area extends from the Simpson shoreline to the east, south of the rail line berm that keeps the creek flowing to the north, and is defined by cores SH-18, SH-21, and SH-22 (Figure 4-3). At sample station SH-18, high wood content (15 to 30 percent) was identified from the surface to 4 feet (1.2 meters) deep; no wood was seen in the bottom 2 feet (0.6 meters) of the core. At sample station SH-21, high wood content (25 to 70 percent) was initially identified extending from the surface to 5 feet (1.5 meters) deep. Sediment included increasing fiber content with depth, decreasing chips with depth, and the appearance of bark near the bottom.

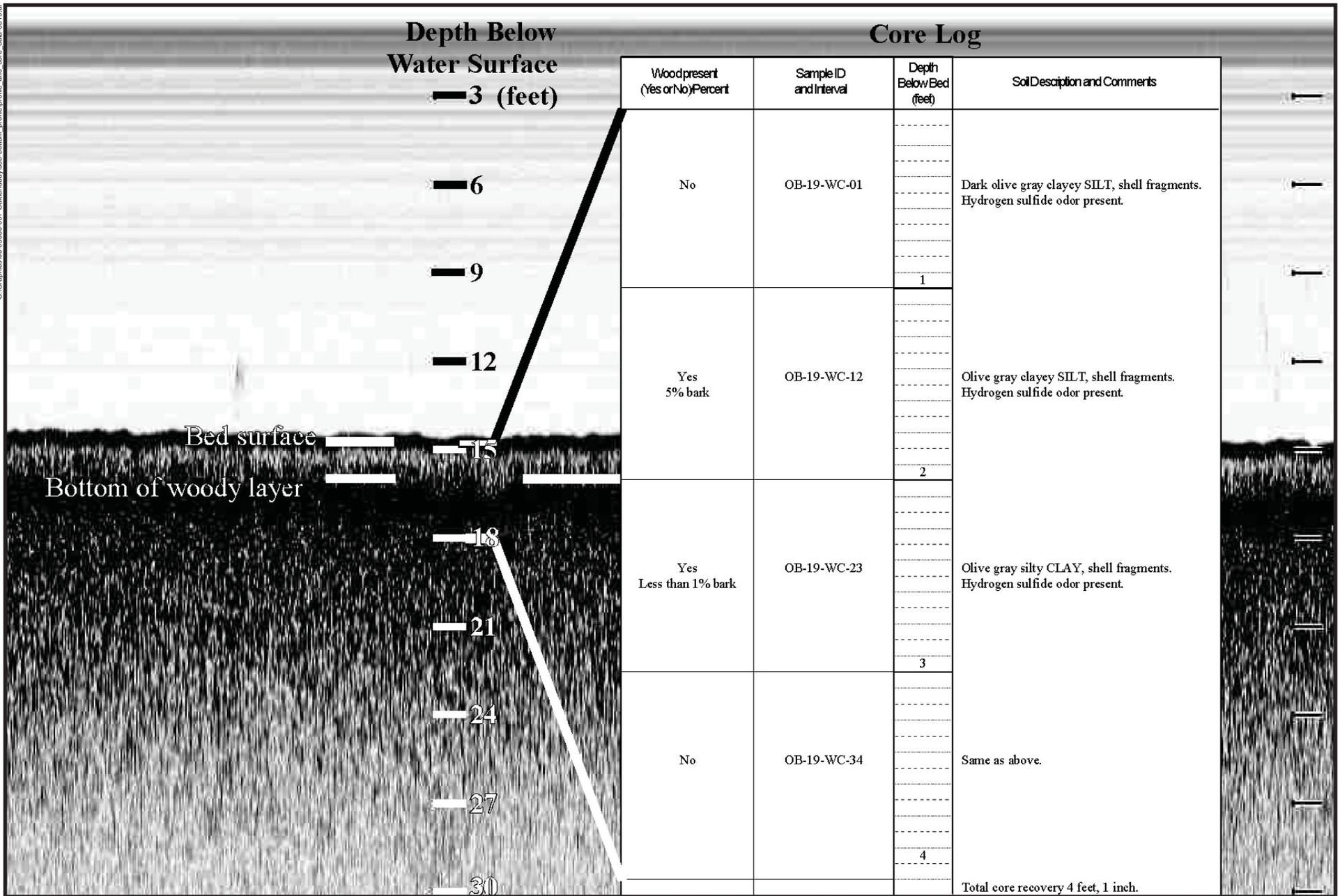


Figure 5-5. Example of a sub-bottom profile and accompanying core data (OB-19).

The second, deeper core advanced at that station indicated only moderate wood content (20 to 25 percent) in the top 4 feet (1.2 meters) and 5 percent or less wood extending to the bottom at 12 feet (3.7 meters). Nearby station SH-22 identified high wood content (40 percent, all bark) in the 2-3 core section before the core tube encountered refusal; additional attempts could not advance the core tube past 2 feet (0.6 meters) due to high wood content. It appears that significant wood waste exists in this area, but that it is distributed unevenly.

- *Former sawmill #4* – This small wood accumulation area was located adjacent to former sawmill #4, defined by core SH-12 (Figure 4-3). High wood content (65 percent) was initially identified at 5 feet (1.5 meters) deep as fiber (50 percent), bark (10 percent), and chips (5 percent). Wood content above the 5 foot (1.52 meter) mark was primarily fiber at 10 percent. The second, deeper core advanced at that station indicated fiber from less than 5 percent to 10 percent in the first 5 feet (1.5 meters) and then 75 to 100 percent sawdust to 10.5 feet (3.2 meters). The nature of the deeper wood waste is consistent with mill operations. Current nearby loading of wood chips to barges, observed during sampling, led to expectations of high wood content at nearby station SH-11, but less than 5 percent wood was noted in the top 4.5 feet (1.4 meters); no deep core was advanced.
- *Head of Bay* – The wood accumulation area immediately north of Bayshore Point was identified by core OB-12; the three other sample stations in the head of the bay were spread wide apart and contained very little wood. High wood content (75 to 100 percent) was initially identified between 3 and 5 feet (0.9 and 1.5 meters) deep as sawdust. A small amount of bark (less than 5 percent) was noted only in the 1-2 foot core section above. The second, deeper core advanced at that station indicated 50 to 100 percent sawdust from 4 to 9.5 feet (1.2 to 2.9 meters) and 5 percent bark in the 1-2 foot core section. The nature of the deeper wood waste is consistent with mill operations. An 1889 map of Oakland Bay identified Willey's Mill located directly across the bay on the eastern shoreline (Fredson 1976). The history of this mill is not known. No evidence of an historical mill adjacent to the sample station was found.

Cores did not reach the bottom of most of these wood deposits and the limited number of sampling stations did not allow for accurate mapping of their aerial extents. Table 5-3 provides estimates of wood volume at each location based on the minimum depth of wood found in the representative core(s) multiplied by an assumed areal extent of each area of accumulation, estimated from a combination of geophysical survey results and proximity to cores not exhibiting large quantities of wood. The extents of the three Shelton Harbor areas of accumulation (former pond saw, railway log dump, and former sawmill#4) are well constrained by a dense network of adjacent (clean) cores; however, the size of the Head of Bay accumulation is not well known, due to the lack of nearby cores and no geophysical data.

Table 5-3. Wood waste volume estimates in high accumulation areas.

Name	Cores In Accumulation Area	Bottom Reached	Approximate Area of Wood Waste Accumulation (ft ²) [acres]	Minimum Average Thickness ^b (ft)	Minimum Total Volume of Deposit (cubic yards)	Average Wood Waste Content (%)	Minimum Wood Waste Volume (cubic yards)
Former Pond Saw	SH-04	No	45,000 [1.0]	6.7	11,167	50.3	5,617
Railway Log Dump	SH-18, SH-21, SH-22	No ^a	800,000 [18.4]	6.2	183,704	45.7	83,953
Former Sawmill #4	SH-12	No	45,000 [1.0]	10.4	17,333	33.4	5,789
Head of Bay	OB-12	No	N/A	9.3	N/A	46.7	N/A
Total			890,000 [20.4]		212,204		95,359

^a Bottom of wood reached in core SH18, but not in SH-21 and SH-22.

^b Depth of core penetration in those samples where bottom of wood was not found; where multiple cores found considerable wood, average depth of wood encountered was used.

N/A Not available

Total volume estimates assume that the average concentration of wood waste visually identified in the core(s) is typical of the entire wood accumulation area. The total estimate of approximately 95,359 cubic yards (72,900 cubic meters) should be considered a rough minimum estimate, since the total depth of the wood waste in portions of these areas could be much greater than that observed in the cores (plus, the Head of Bay area could not be reliably estimated).

5.3 Sediment and Wood Transport Patterns

Wood waste is transported within the bay in much the same way as sediment. However, while sediment enters the bay energetically through creek discharge, wood enters vertically through the water column at log raft and spillage or dumping locations. As such, wood material is not transported vigorously from where it is initially delivered to the water, remaining near its original sources. When it is transported, wood material moves toward deeper portions of Oakland Bay, where it is mixed with sediment and accumulates at low concentrations. In Shelton Harbor, transport is more complicated, due to the numerous and spatially concentrated sources of wood waste in that area. It does appear that some of the wood introduced to the harbor escapes to the central portion of Oakland Bay, based on the interpretation that sediment moves from the harbor to the bay and that low concentrations of wood are present in areas where historical activities were absent. The primary difference between the distribution and transport of sediment and wood waste is that the sources of wood waste are more numerous than sources of sediment.

5.4 Distribution of Chemical Compounds in Surface Sediments

Fifty surface grab samples were collected across the study area; samples could not be collected at three of the originally planned 53 locations. Additionally, three reference sediment surface grab samples were collected from Carr Inlet. Samples were analyzed for the following to evaluate the potential presence of chemicals associated with industrial activities and decaying wood:

- Conventional analytes grain size, ammonia, total sulfides, TOC, and TVS (TVS was measured only at 16 wood waste sample stations)
- Dioxins/furans
- PCBs
- Chlorinated pesticides
- SVOCs
- Metals
- Resin acids and guaiacols (tested only at 16 wood waste sample stations and resin acids at eight selected archived non-wood waste locations in Oakland Bay and Hammersley Inlet)
- TBT (at three selected locations near marine railway and marina)
- Petroleum hydrocarbons (at eight selected locations near areas of historic petroleum usage or stormwater runoff)

5.4.1 Conventional Analytes

Conventional parameters (grain size, ammonia, total sulfides, TOC) were measured at all surface locations across the bay; TVS was measured at the 13 designated wood waste locations in Shelton Harbor and 3 designated wood waste locations Oakland Bay.

Grain size results, represented as gravel, sand, silt, and clay fractions, are shown on Figure 5-6. Sand was the major fraction in 54 percent of the surface locations across the entire site (27 of 50 total locations). The sandy locations were primarily located in Hammersley Inlet (sand fraction ranging from 79.7 to 95.6 percent), along the southwest shoreline and southern portion of Oakland Bay (sand fraction ranging from 40.1 to 77.5 percent), and in outer and northern Shelton Harbor (sand fraction ranging from 44.1 to 96.2 percent). Locations closer to the mouth of Goldsborough Creek and near shellfish areas in upper Oakland Bay and Chapman Cove contained more gravel, ranging from 20.9 to 36.3 percent. Greater than 45 percent total fines (i.e., silt and clay fractions combined) were found near the mouth of Shelton Creek, across the southern portion of Shelton Harbor, Chapman Cove, and in the middle and along the southeast shoreline of Oakland Bay.

Ammonia is a common byproduct of bacterial degradation of wood waste or organic-rich plant and animal materials. Ammonia concentrations are shown on Figure 5-7. As shown in Table 4-1, mean ammonia concentrations measured in surface sediment from Shelton Harbor (12.9 mg/kg), Oakland Bay (9.81 mg/kg), and Hammersley Inlet (7.12 mg/kg), were similar to results from the reference sediment area (12.1 mg/kg). Maximum detected values were slightly higher in Shelton Harbor (32.4 mg/kg) and Oakland Bay (22.4 mg/kg) than the reference sediment area (14.4 mg/kg).

Two of the four sampling stations exhibiting relatively high ammonia content (>20 mg/kg) had visible wood present, 10 of 19 sampling stations with medium level ammonia content (10 to 20 mg/kg) had visible wood present, and 11 of 27 sampling stations with relatively low ammonia content (<10 mg/kg) had visible wood present.

Sulfides are also a common byproduct of bacterial degradation of wood waste. Accumulation of sulfides in sediment may also occur in areas with restricted water circulation (e.g. terminal inlets), particulate organic input, and water column density stratification associated with discharge plumes from creeks. Sulfide concentrations are shown on Figure 5-8. The highest concentrations of total sulfides were found in surface sediments throughout the southwest portion of Shelton Harbor and along the shoreline and middle of Oakland Bay. The station with the highest sulfide concentrations (SH-21) corresponds with a wood waste accumulation area identified on Figure 5-2. Mean concentrations of total sulfides in surface sediment in Shelton Harbor (661 mg/kg) and Oakland Bay (666 mg/kg) were greater than the mean reference sediment result (168 mg/kg); the mean concentration of total sulfides in surface sediment in Hammersley Inlet (82.3 mg/kg) was less than the mean concentration in the reference sediment area (see Table 4-1).

Fifteen of the 34 sampling stations exhibiting relatively high sulfides content (>200 mg/kg) had visible wood present, all six sampling stations with medium level sulfides content (20 to 200 mg/kg) had visible wood present, and seven of 10 sampling stations with relatively low sulfides content (<20 mg/kg) had visible wood present.

TOC may be elevated in areas with organic debris, such as wood waste. TOC concentrations are shown on Figure 5-9. TOC content in sediments collected from Shelton Harbor was generally high, with a mean value in surface sediment of 3.20 percent (see Table 4-1). The maximum TOC concentration found in Shelton Harbor was 11.0 percent at station SH-13. In general, TOC values above 4 percent were found along the shoreline in the former pond saw area (stations SH-03, SH-04, and SH-05) and throughout the southwest portion of Shelton Harbor (stations SH-11 through SH-14, and SH-18 through SH-24). This also corresponds to locations with total fines greater than 45 percent. In general, TOC content was less than 2 percent in Hammersley Inlet and was less than 4 percent in Oakland Bay. One surface sediment sample (OB-06) collected from along the eastern shoreline of Oakland Bay, where logs were once rafted, had TOC content above 4 percent.

Nine of 10 sampling stations exhibiting relatively high TOC content (>4 percent) had visible wood present and 14 of 40 sampling stations with medium level TOC content (0.05 to 4 percent) had visible wood present; no sampling stations exhibited low TOC content (<0.05 percent).

TVS was analyzed in surface sediment samples at 13 locations in Shelton Harbor and at 3 locations in Oakland Bay. These were designated as wood waste samples before sampling, based on expectations of finding wood accumulations in these areas (wood was not evident at five of the 16 locations). TVS is used as a method to determine relative amounts of wood waste present; it measures the total combustible content of a sample, expected to be primarily composed of wood. Mean TVS values for surface sediment in Shelton Harbor and Oakland Bay

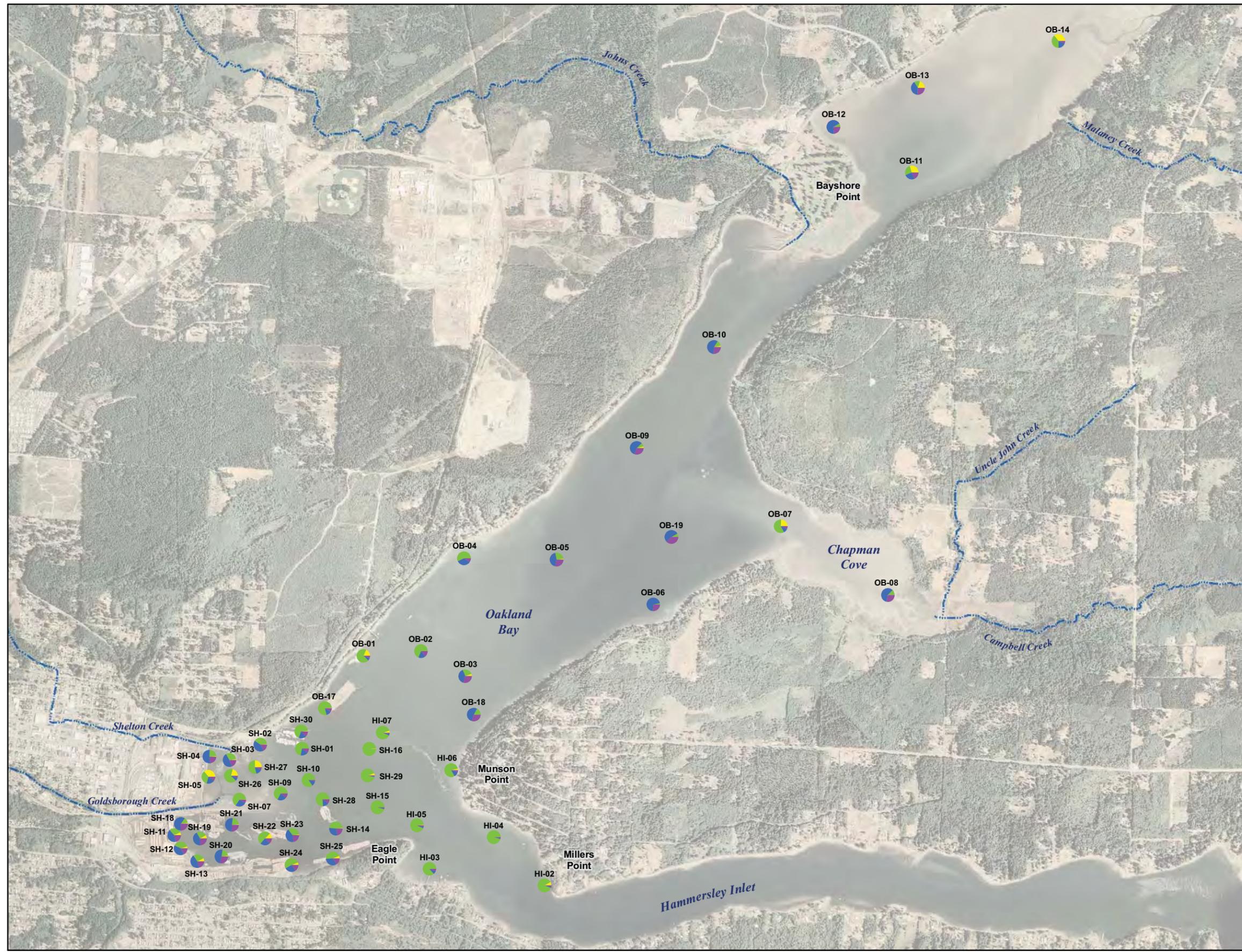
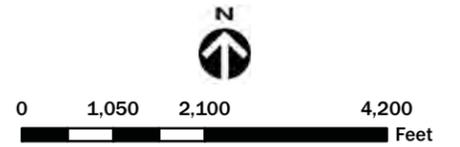


Figure 5-6.
Surface sample grain size
distribution, across the Oakland Bay
study area.

Legend

-   Gravel
-  Sand
-  Silt
-  Clay



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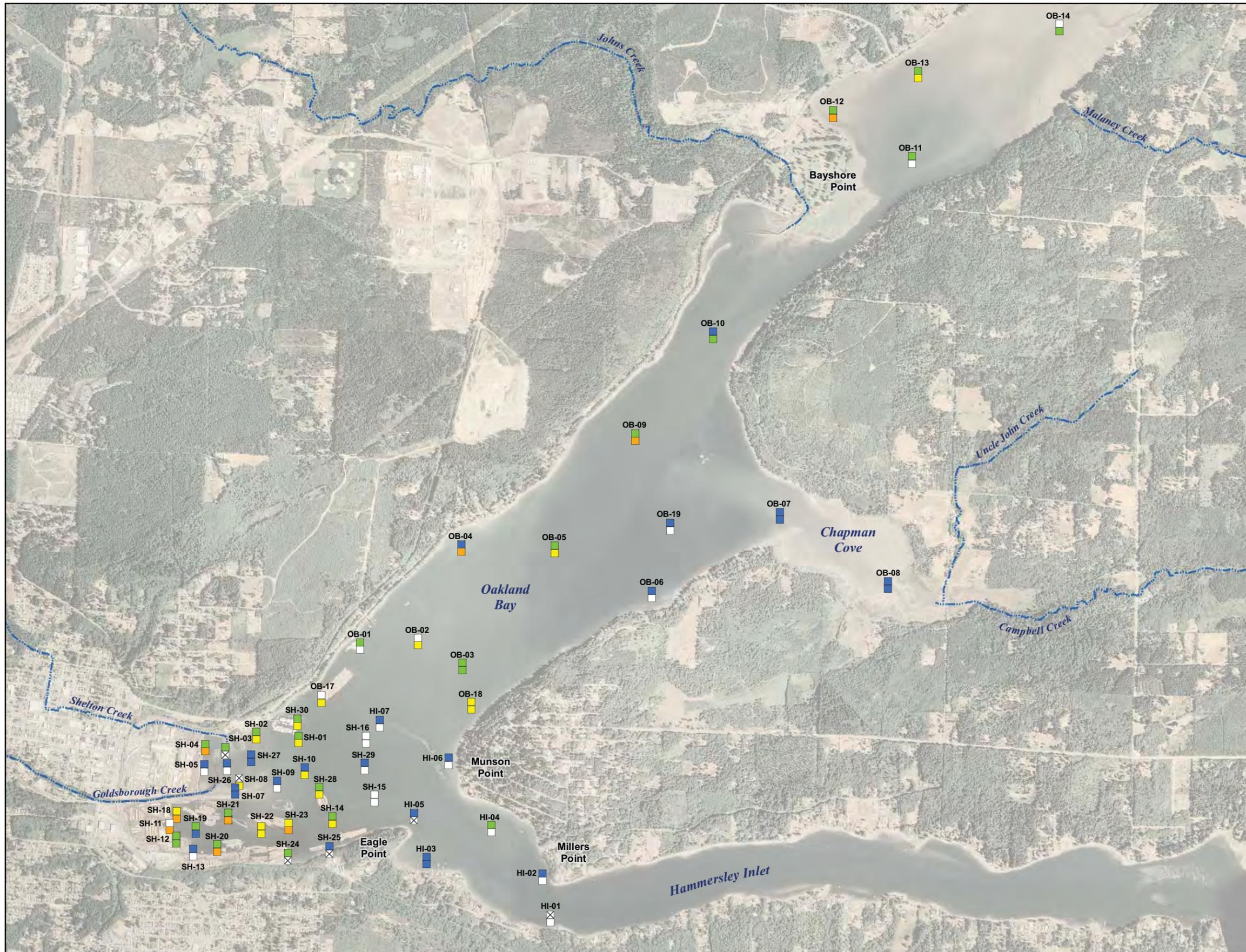


Figure 5-7.
 Surface and subsurface sample ammonia distribution across the Oakland Bay study area.

Legend

Total ammonia (mg/kg)

- 0.1 to 5
- 5 to 10
- 10 to 20
- 20 to 50
- >50
- ⊗ No data

Collected Sample Depth

- Surface sample (top 0.3 feet)
- 1-2 feet



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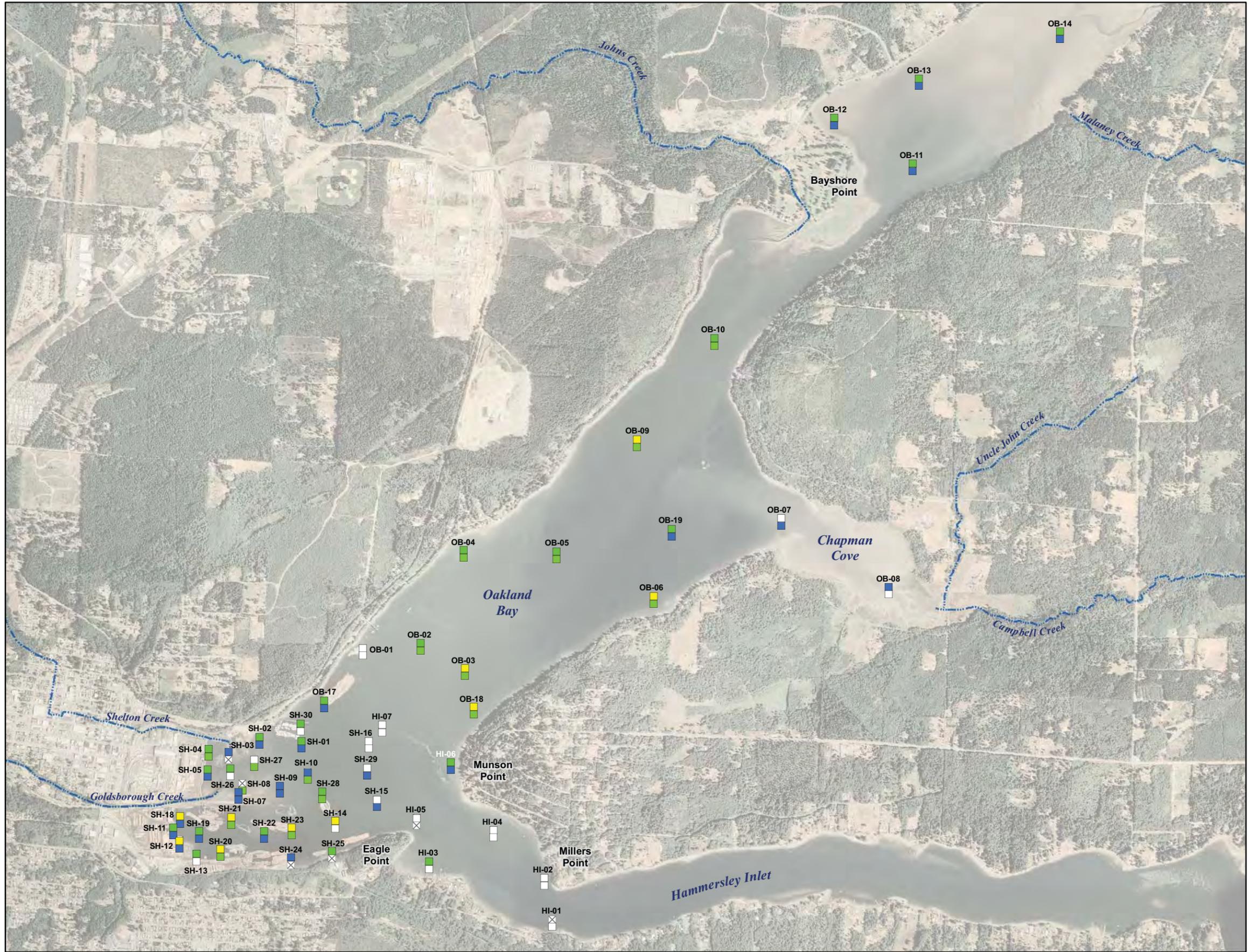


Figure 5-8.
 Surface and subsurface sample sulfide distribution across the Oakland Bay study area.

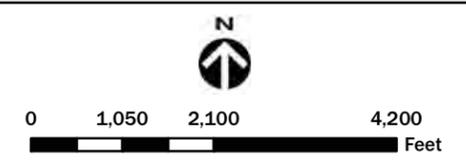
Legend

Sulfide (mg/kg)

- < 20, no effect
- 20 to 200, minor effects
- 200 to 1000, max proposed level for open disposal
- > 1000

Collected Sample Depth

- Surface sample (top 0.3 feet)
- 1-2 feet



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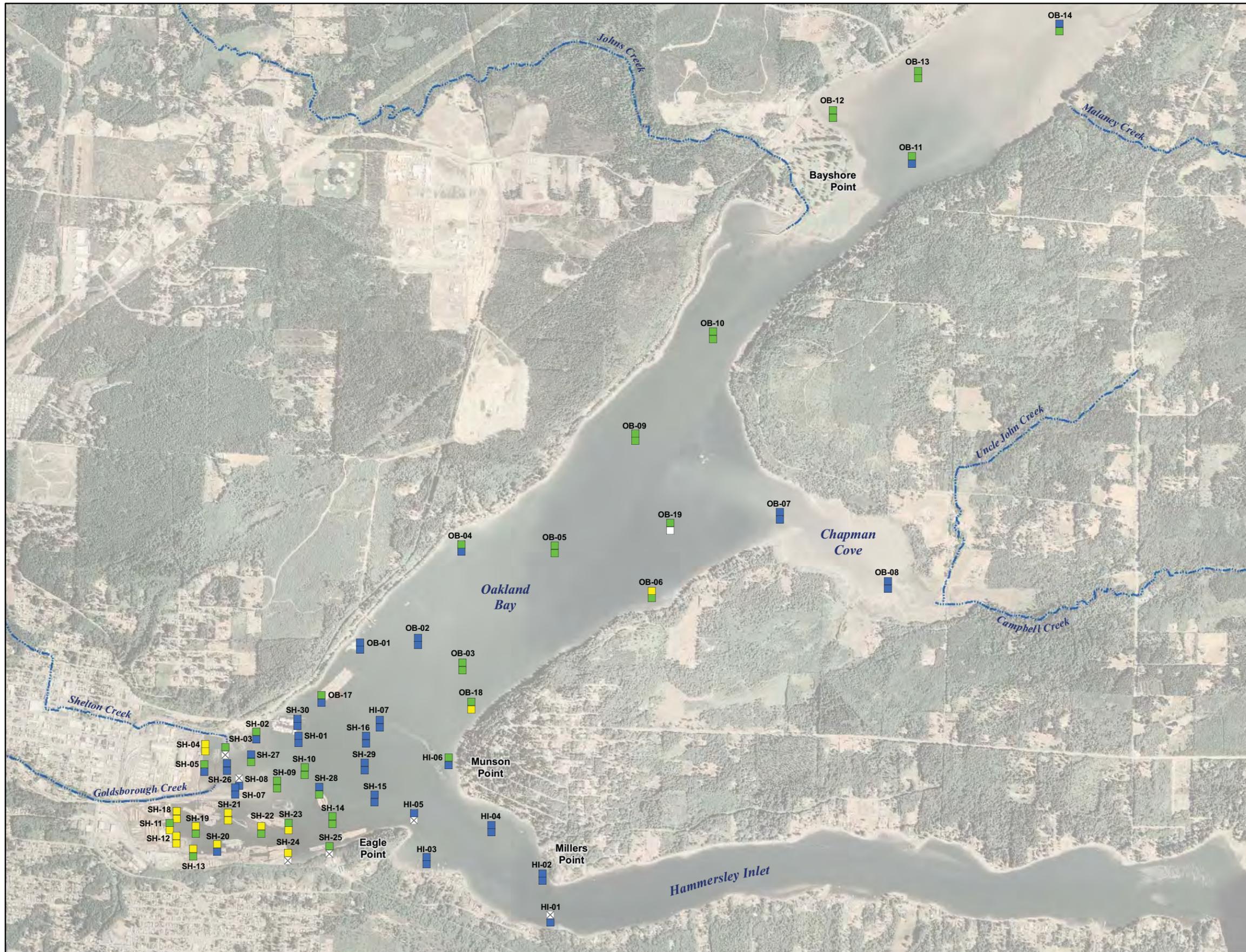


Figure 5-9.
Surface and subsurface sample total organic carbon distribution across the Oakland Bay study area.

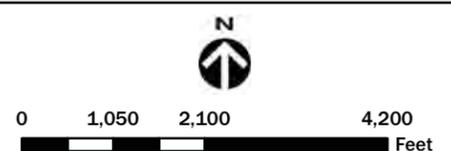
Legend

Total organic carbon (%)

- < 0.05
- 0.05 to 2
- 2 to 4
- > 4
- ⊗ No data

Collected Sample Depth

- Surface sample (top 0.3 feet)
- 1-2 feet



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were 10.6 and 7.67 percent, respectively, with maximum concentrations of 19.7 and 9.35 percent, respectively (Table 4-1). In general, TVS values were highest throughout the southwest portion of Shelton Harbor (stations SH-18 through SH-25) and along the eastern shoreline of Oakland Bay (stations OB-18 and OB-19 – although only three stations in Oakland Bay were tested for TVS). The mean TVS at the reference stations was 2.0 percent, with a maximum reference location of 2.6 percent. The highest concentration in Shelton Harbor, at SH-22, corresponds to a wood waste accumulation area identified on Figure 5-2.

Seven of eight sampling stations exhibiting relatively high TVS content (>10 percent) had visible wood present, none of four sampling stations with medium level TVS content (5 to 10 percent) had visible wood present, and two of four sampling stations exhibiting relatively low TVS content (<5 percent) had visible wood present.

5.4.2 Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans

Dioxins/furans were detected in all surface sediment samples. The mean total dioxin TEQ result was highest in Shelton Harbor (42.8 ng/kg TEQ);, mean total dioxin TEQ results for Oakland Bay (32.1 ng/kg TEQ) and Hammersley Inlet (5.42 ng/kg TEQ) were also both elevated compared to the reference sediment samples (0.482 ng/kg TEQ) (see Table 4-1).

Dioxins/furans do not have numerical criteria under SMS, but two benchmark values (4.0 and 10 ng/kg TEQ) were used for this investigation to graphically display total dioxin TEQ result distributions (Figure 5-10). The first benchmark value of 4.0 ng/kg TEQ is the proposed (interim) Puget Sound-wide background level based on an upper bound estimate of the distribution of dioxin in non-urban areas (DMMP 2010; USACE 2009), and the second benchmark value of 10 ng/kg TEQ is the draft maximum concentration allowable for open-water disposal under DMMP. The OSV Bold Study (USACE 2009) monitored ambient dioxin concentrations in sediments at background reference areas throughout Puget Sound.

Additional benchmarks of 10 to 20, 20 to 60, 60 to 100, and 100 to 200 ng/kg were also indicated on the figure. Dioxin TEQ concentrations are depicted as low (white and blue), medium (yellow and green), and high (orange and pink) relative to the range of values found during this investigation; however, all medium and high values should be considered as high within the context of evaluating potential action levels.

Dioxins/furans were identified in surface sediment at all 50 locations sampled, ranging from 1 to 175 ng/kg TEQ. The following surface sediment observations from Figure 5-10 can be made:

- The highest concentrations were found at five locations along the western edge of Shelton Harbor where the majority of wood processing has historically taken place, including wood waste burning, sulfite liquor discharge and burning, and PCP use.
- Medium level concentrations were found to be distributed across the entire study area, except for Hammersley Inlet.

- Low level concentrations were found to be distributed in areas of high sedimentation (creek deltas), where mixing likely has occurred (the southwest shore of Shelton Harbor), and along the perimeter of Hammersley Inlet and Oakland Bay where sediment does not accumulate.

High dioxin TEQ concentrations throughout Shelton Harbor and Oakland Bay relative to the greater Puget Sound indicate a local source area. Sediment transport analysis results and generally consistent chemical concentrations observed across Oakland Bay indicate that once dioxins/furans enter the system, they do not leave the system.

5.4.3 Polychlorinated Biphenyls

PCBs were measured in all surface samples, and were detected in surface sediment at two locations, Aroclor 1260 was detected at the Shelton Marina (SH-01) and a mixture of Aroclors 1260 and 1016 was detected near Munson Point (HI-06). Concentrations at both locations were well below SMS criteria (see Appendix G).

5.4.4 Chlorinated Pesticides

Chlorinated pesticides were measured in all surface samples. In general, low levels of chlorinated pesticides were found in surface sediment across Shelton Harbor, Oakland Bay, and Hammersley Inlet (see Table 4-1). The most common compound found was 4,4'-DDT and associated breakdown products (4,4'-DDD and 4,4'-DDE). Aldrin and alpha-chlordane were found in Shelton Harbor surface sediments, but not in Oakland Bay or Hammersley Inlet. No LAET criteria (established only for DDT, DDD, and DDE) were exceeded (see Appendix G).

5.4.5 Semivolatile Organic Compounds: PAHs, Phthalates, and Phenols

SVOCs were measured in all surface samples. The most common SVOCs detected in surface sediments were PAHs. Total LPAHs were detected in 67 percent of Shelton Harbor surface sediment samples, 12 percent of Oakland Bay surface sediments samples, and were not detected in Hammersley Inlet surface sediment samples. Total HPAHs were detected in 89 percent of Shelton Harbor surface sediment samples, 41 percent of Oakland Bay surface sediments samples, and 17 percent of Hammersley Inlet surface sediment samples (see Table 4-1). No detected SVOCs exceeded SQS criteria; one sample exceeded the LAET criterion for fluoranthene in Shelton Harbor. Detection limits for 2,4-dimethylphenol and hexachlorobenzene exceeded SMS criteria; however, these compounds were not detected at any sample location (see discussion in Section 4.2).

In Shelton Harbor, total low molecular weight polycyclic aromatic hydrocarbon (LPAH) and high molecular weight polycyclic aromatic hydrocarbon (HPAH) concentrations were highest near the former marine railway and in the southwest portion of harbor. In general, PAH concentrations decrease to the east, leaving Shelton Harbor.

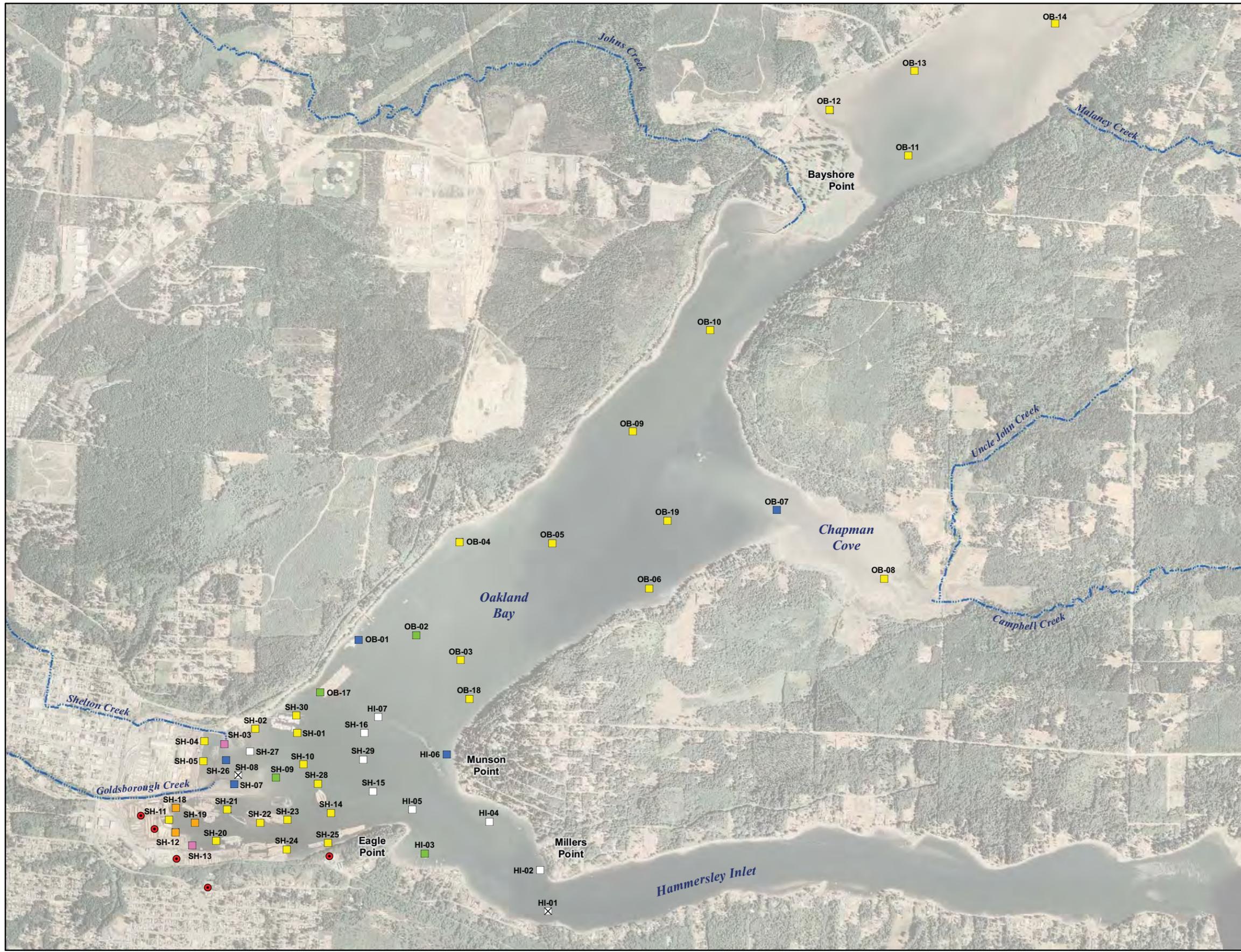


Figure 5-10.
Surface sample dioxin distribution
across the Oakland Bay study area.

Legend

- Historic emission stack

Dioxin (TEQ) (ng/kg)

- < 4
- 4 to 10
- 10 to 20
- 20 to 60
- 60 to 100
- 100 to 200
- ⊗ No data

Note: Surface samples collected from top 0.3 feet.

N

0 1,050 2,100 4,200
 Feet

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Low-level total LPAHs and HPAHs were detected in Oakland Bay surface sediments north of the Shelton Marina (OB-17 and OB-04), near Chapman Cove (OB-07), and in upper Oakland Bay (OB-12 and OB-13; only total HPAHs were detected); LPAHs and HPAHs were not detected in any other surface sediment samples in Oakland Bay. Total HPAHs were detected in one surface sediment sample from Hammersley Inlet (HI-03), located in a depositional area.

Two phthalate compounds, BEHP and butylbenzylphthalate, and two phenols (4-methylphenol and phenol) were detected at low levels in surface sediment samples. BEHP was found throughout Shelton Harbor and lower Oakland Bay, while butylbenzylphthalate was detected at only one location near the mouth of Shelton Creek (SH-03).

Phenol was found near Shelton Marina, throughout the southern portion of Shelton Harbor, and in portions of Oakland Bay and Hammersley Inlet. Pentachlorophenol was not detected in any surface or subsurface sample in this study. However, in the 2000 Reconnaissance Survey of Inner Shelton Harbor Sediments, pentachlorophenol was detected in 9 of 10 surface chemical screening locations in Shelton Harbor, with concentrations ranging from 100 to 400 ppb (Ecology 2000).

No other SMS SVOC compounds were detected above laboratory reporting limits in any surface sediment samples across the study area.

5.4.6 Resin Acids and Guaiacols

Resin acids and guaiacols are byproducts of wood waste decomposition and the pulp industry, and were analyzed at 13 wood waste sample stations within Shelton Harbor and 3 wood waste stations within Oakland Bay. Eight additional surface sediment samples in Oakland Bay and Hammersley Inlet were selected for analysis of resin acids after initial sample results were received. One or more resin acid compounds were detected in all surface wood waste sediment samples analyzed; no guaiacol compounds were detected in any samples. The most common resin acid compounds detected in surface sediment samples collected in Shelton Harbor and Oakland Bay were abietic acid, dehydroabietic acid, oleic acid, and retene. In addition, linolenic acid was detected in approximately 50 percent of the Shelton Harbor surface sediment samples, 11 percent of Oakland Bay surface sediment samples, and in all of the Hammersley Inlet surface sediment samples. The only resin acid compounds detected in Hammersley Inlet surface sediment samples were linolenic acid and oleic acid.

There are no numerical SMS criteria for resin acids. To compare concentrations across the site, resin acid compounds were summed to provide a total resin acid concentration. As shown in Table 4-1, total resin acids are present in Shelton Harbor at a level twice the value in Oakland Bay, based on mean concentration (3,300 µg/kg in Shelton Harbor and 1,500 µg/kg in Oakland Bay). The highest total resin acid concentrations are present in the south and southwest portion of the harbor. The highest total resin acid concentration (9,000 mg/kg) was found at location SH-24, on the southern shoreline of Shelton Harbor where logs have been stored and handled for many years. Wood waste was found at this location; however, other surface sediment stations with high total resin acid values do not directly correspond to areas of wood waste accumulation

identified in Figure 5-2. The presence of resin acids may also be associated with the historical discharges of sulfite liquor from the Rayonier pulp mill, as resin acids are known to be present in high concentrations in pulp mill waste liquor.

All four sampling stations exhibiting relatively high resin acid content ($>3,500 \mu\text{g}/\text{kg}$) had visible wood present, six of 11 sampling stations with medium level resin acid content (1,500 to $3,500 \mu\text{g}/\text{kg}$) had visible wood present, and one of eight sampling stations exhibiting relatively low resin acid content ($<1,000 \mu\text{g}/\text{kg}$) had visible wood present.

5.4.7 Tributyltins

TBTs were analyzed at three locations near the marina and former marine railway, based on results of the 1999 Reconnaissance Survey. TBTs were found in surface sediment at SH-02, south of the vessel haul out at the end of the Pine Street right of way (public boat ramp). The concentrations measured at SH-02 ($8.0 \mu\text{g}/\text{kg}$ butyltin ion, $30 \mu\text{g}/\text{kg}$ dibutyltin ion, and $13 \mu\text{g}/\text{kg}$ tributyltin ion) were all well below concentrations found during the Reconnaissance Survey (concentrations near the base of the launching rails were $1,300 \mu\text{g}/\text{kg}$ butyltin ion, $4,100 \mu\text{g}/\text{kg}$ dibutyltin ion, and $1,500 \mu\text{g}/\text{kg}$ tributyltin ion) (Ecology 2000).

TBTs were not detected at locations near the Shelton Marina (SH-01 and SH-30).

5.4.8 Metals

Metals were detected at low levels in all samples across the project site; however, no values exceeded SMS criteria. In general, mean concentrations of metals in surface sediment samples were similar in Shelton Harbor and Oakland Bay, and slightly lower in Hammersley Inlet, which were similar to reference sediment samples (see Table 4-1).

The highest concentrations of metals were found in Shelton Harbor near the sawdust loading area (SH-11, SH-18, and SH-19).

5.4.9 Petroleum Hydrocarbons

Petroleum hydrocarbons were analyzed in sediment from eight locations along the Shelton Harbor and Oakland Bay shorelines where historical use had been noted. Lube oil- range hydrocarbons were found at a concentration of $220 \text{ mg}/\text{kg}$ in the surface sediment sample collected at station SH-05, located on the western shoreline of Shelton Harbor; petroleum hydrocarbons were not detected in any other surface sediment samples.

5.5 Distribution of Chemical Compounds in Subsurface Sediments

A total of 48 subsurface cores were collected across the study area for chemical analyses; core samples could not be collected at 5 of the planned 53 subsurface locations. Additionally, three

cores were collected for radioisotope analyses (discussed in Section 5.2.2). Sediment cores were separated into 1 foot (0.3 meter) lengths; and subjected to analysis as described below: Initially all 1 foot (0.3 meter) core sections below 1-2 feet were frozen and archived for possible future analysis. Based on surface sediment results, selected 1-2 foot and 2-3 foot core sections were later analyzed for dioxins/furans.

- All 1-2 foot cores were analyzed for conventional analytes grain size, ammonia, total sulfides, and TOC. TVS was analyzed only at 14 wood waste sample stations.
- All 1-2 foot cores from Shelton Harbor, and from three wood waste locations within Oakland Bay were analyzed for:
 - PCBs
 - Chlorinated pesticides
 - SVOCs
 - Metals
- All 1-2 foot cores from 11 designated wood waste stations in Shelton Harbor and 3 wood waste locations in Oakland Bay were tested for resin acids and guaiacols.
- Selected archived samples from 1-2 and/or 2-3 feet were later tested for dioxins/furans.
- TBT (at three selected locations near marine railway and marina)
- Petroleum hydrocarbons (at two selected locations near areas of former petroleum usage)

5.5.1 Conventional Analytes

Conventional parameters (ammonia, total sulfides, TOC) were measured at all subsurface locations across the bay. TVS was measured at wood waste sample locations in Shelton Harbor (11 locations) and Oakland Bay (three locations) where accumulation of wood was anticipated.

Ammonia concentrations are shown on Figure 5-7. As shown in Table 4-1, mean ammonia concentrations measured in subsurface sediment from Shelton Harbor (31.1 mg/kg) and Oakland Bay (26.7 mg/kg) were higher than Hammersley Inlet (2.53 mg/kg). Maximum detected values were slightly higher in Shelton Harbor (113 mg/kg) than Oakland Bay (75.5 mg/kg). Mean concentrations in subsurface samples were almost three times higher than surface samples in Shelton Harbor and Oakland Bay and three times lower than surface samples in Hammersley Inlet.

Fifteen of the 22 sampling stations exhibiting relatively high ammonia content (>20 mg/kg) had visible wood present, two of four sampling stations with medium level ammonia content (10 to

20 mg/kg) had visible wood present, and 10 of 22 sampling stations with relatively low ammonia content (<10 mg/kg) had visible wood present.

Total sulfides concentrations are shown on Figure 5-8. As shown in Table 4-1, mean concentration of total sulfides in subsurface sediment was significantly higher in Shelton Harbor (194 mg/kg) and Oakland Bay (181 mg/kg) compared to Hammersley Inlet (32.0 mg/kg). Mean concentrations in subsurface samples were approximately one-third the surface sample concentrations across the study area.

Eight of the 16 sampling stations exhibiting relatively high sulfide content (>200 mg/kg) had visible wood present, 14 of 20 sampling stations with medium level sulfide content (20 to 200 mg/kg) had visible wood present, and 5 of 12 sampling stations with relatively low sulfide content (<20 mg/kg) had visible wood present.

TOC concentrations are shown on Figure 5-9. TOC content in subsurface sediments collected from Shelton Harbor were elevated, with mean values in subsurface sediment of 3.03 percent (see Table 4-1). Maximum TOC concentrations found in Shelton Harbor were 11.1 percent at station SH-21, which corresponds to areas of wood waste accumulation identified on Figure 5-2. In general, TOC values above 4 percent were found along the western shoreline (stations SH-04, SH-18, SH-11, and SH-12) and in log rafting areas south of the railway log dump (SH-21 and SH-23). One subsurface sediment sample (OB-08) collected from along the eastern shoreline of Oakland Bay where logs are rafted also had TOC content above 4 percent. Mean concentrations of subsurface samples were generally comparable to surface concentrations in Shelton Harbor and Oakland Bay, and approximately one-half the mean surface concentration of Hammersley Inlet.

Six of the seven sampling stations exhibiting relatively high TOC content (>4 percent) had visible wood present, 16 of 30 sampling stations with medium level TOC content (0.05 to 4 percent) had visible wood present, and five of 11 sampling stations with relatively low TOC content (<0.05 mg/kg) had visible wood present.

Mean TVS values for subsurface sediment in Shelton Harbor and Oakland Bay were 12.6 and 10.7 percent, respectively, with maximum concentrations of 39.5 and 13.6 percent (see Table 4-1). In general, TVS values were highest throughout the southwest portion of Shelton Harbor (stations SH-18 through SH-23) and along the eastern shoreline of Oakland Bay (stations OB-18 and OB-19 – although only three stations were tested). The highest value for TVS occurred at station SH-21, located in an area of wood waste accumulation (Figure 5-2). Subsurface TVS mean concentrations were slightly higher than surface mean concentrations in both areas.

All five sampling stations exhibiting relatively high TVS content (>10 percent) had visible wood present, all five sampling stations with medium level TVS content (5 to 10 percent) had visible wood present, and one of three sampling stations exhibiting relatively low TVS content (<5 percent) had visible wood present.

5.5.2 Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans

Subsurface sediment samples were analyzed for dioxins/furans at seven stations located in Shelton Harbor and five stations located in Oakland Bay, based on relatively high concentrations first found in surface samples (Figure 5-11). Samples were analyzed representing either the 1-2 foot or 2-3 foot core sections (both core sections were analyzed at two locations in Shelton Harbor along the western shore, resulting in a total of 14 samples); dioxins/furans were detected in every sample. The mean total dioxin TEQ result was higher in Shelton Harbor, based on seven samples from 2-3 foot depth and two samples from 1-2 foot depth (198 ng/kg TEQ), than Oakland Bay, based on 5 samples from the 1-2 foot depth (97.8 ng/kg TEQ); These were well above mean surface sediment values of 42.8 and 32.1 ng/kg TEQ, respectively (see Table 4-1).

Higher dioxin/furan concentrations found at depth at 10 of the 12 stations sampled across the study area (including the head of the bay) indicates higher historical input levels. With only two sample depths analyzed at each location, it is not possible to correlate concentration trends with time, other than to suggest that dioxin input to the bay has decreased in the recent past. It is not known why surface sediments continue to contain dioxin. This could be related to disturbance/mixing of the sediments by natural or man-influenced actions; redistribution of sediments from higher-concentration areas by currents, or an ongoing source of dioxin.

Due to a lack of concentration gradients moving away from potential shoreline inputs, dioxins/furans appear to have been disbursed by both aerial and fluvial processes. Once incorporated into sediments, there has been little movement out of the Oakland Bay system. The two locations with higher concentrations at the surface versus the subsurface include one in the Goldsborough Creek alluvial fan with coarser-grain material at depth and along the southwest shoreline with a high potential for mixing to occur associated with historical dredging activities.

5.5.3 Polychlorinated Biphenyls

All samples from 1-2 foot depth within Shelton Harbor and three samples from 1-2 foot depth in Oakland Bay were measured for PCBs. Total PCBs were not detected in any subsurface sediment sample (see Appendix G). All detection limits were below the SMS criterion.

5.5.4 Chlorinated Pesticides

All samples from 1-2 foot depth within Shelton Harbor and three samples from 1-2 foot depth in Oakland Bay were measured for chlorinated pesticides. In general, low levels of chlorinated pesticides were found in subsurface sediments across Shelton Harbor and Oakland Bay. The most common compounds found were 4,4'-DDT or associated breakdown products (4,4'-DDD and 4,4'-DDE) and alpha-chlordane. Aldrin, dieldrin, and heptachlor were found in Shelton Harbor subsurface sediments, but not in Oakland Bay. The concentration of aldrin (19 µg/kg) and heptachlor (16 µg/kg) in subsurface sediment were more than twice the value in surface sediment at location SH-08. No LAET criteria (established only for DDT, DDD, and DDE) were exceeded.

5.5.5 Semivolatile Organic Compounds: PAHs, Phthalates, and Phenols

All samples from 1-2 foot depth within Shelton Harbor and three samples from 1-2 foot depth in Oakland Bay were measured for SVOCs. No detected values of SVOCs exceeded SMS criteria. The most common SVOCs detected in subsurface sediments were PAHs. Total LPAHs were detected in 72 percent of Shelton Harbor subsurface sediment samples and were not detected in Oakland Bay subsurface sediment samples. Total HPAHs were detected in 80 percent of Shelton Harbor subsurface sediment samples and two of the three Oakland Bay subsurface sediment samples (see Table 4-1).

In Shelton Harbor, total LPAH and HPAH concentrations were highest along the shoreline in the former pond saw area, along the southwest shoreline, and in the log rafting area south of the railway log dump, which corresponds to wood waste accumulation areas identified on Figure 5-2. In general, PAH concentrations decrease to the east, leaving the harbor.

Low-concentration total HPAHs were detected in two of the three Oakland Bay subsurface sediment samples, both of which were located along the southeastern shore of Oakland Bay (OB-18 and OB-19).

Several other SVOCs were detected at low levels in subsurface sediment samples, including one phthalate (BEHP), two phenols (4-methylphenol and phenol), and dibenzofuran. No other SMS SVOC compounds were detected above laboratory reporting limits in any subsurface sediment samples across the site.

BEHP was found in subsurface sediment samples only in the northern portion of Shelton Harbor (from station SH-04 extending east to SH-29 and north to SH-30).

4-Methylphenol was found only in subsurface samples from the southern portion of Shelton Harbor (Simpson property shoreline extending east to SH-14). Phenol was found in the middle of Shelton Harbor and at one location in Oakland Bay near Chapman Cove, in the log rafting lease area.

Dibenzofuran was detected in subsurface sediment at two locations, both of which are located along the southwest shoreline near upland discharge outfalls (SH-12 and SH-18).

5.5.6 Resin Acids and Guaiacols

Resin acids and guaiacols were measured in the 1-2 foot depth at 11 stations in Shelton Harbor and 3 stations in Oakland Bay. One or more resin acid compounds were detected in all subsurface wood waste sediment samples analyzed, with the exception of SH-26; no guaiacol compounds were detected in any samples. The most common resin acid compounds detected in subsurface sediment samples were abietic acid, dehydroabietic acid, isopimaric acid, and retene. Additionally, linolenic acid, neoabietic acid, oleic acid, palustric acid, pimaric acid, and sandaracopimaric acid were detected in Shelton Harbor subsurface sediment samples, but not in Oakland Bay subsurface sediment samples.



Figure 5-11.
 Surface and subsurface collocated
 sample dioxin distribution, across
 the Oakland Bay study area.

Legend

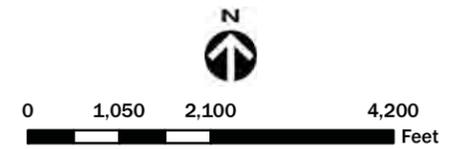
● Historic emission stack

Dioxin (TEQ) (ng/kg)

- < 4
- 4 to 10
- 10 to 20
- 20 to 60
- 60 to 100
- 100 to 200
- 200 to 400
- > 400
- ⊗ No data

Collected Sample Depth

- Surface sample (top 0.3 feet)
- 1-2 feet
- 2-3 feet



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As with surface sediment samples, total resin acids are highest in the south and southwest portions of Shelton Harbor; the highest concentration found was 68,000 µg/kg at SH-21, located within a wood waste accumulation area on Figure 5-2. An elevated total resin acid value (21,000 µg/kg) is also present in the northern portion of Shelton Harbor (SH-27). In general, subsurface sediment results for total resin acids were higher than surface sediment results in both Shelton Harbor and Oakland Bay.

All five sampling stations exhibiting relatively high resin acid content (>3,500 µg/kg) had visible wood present, all five sampling stations with medium level resin acid content (1,500 to 3,500 µg/kg) had visible wood present, and one of three sampling stations exhibiting relatively low resin acid content (<1,000 µg/kg) had visible wood present.

5.5.7 Tributyltins

TBTs were not detected in any of the three subsurface sediment samples where they were measured.

5.5.8 Metals

Metals were analyzed in the 1-2 foot depth sample at all stations in Shelton Harbor and 3 stations in Oakland Bay. Metals were detected at low levels in all samples across the study area; no values exceeded SMS criteria. In general, mean concentrations of metals in subsurface sediment samples were similar in Shelton Harbor and Oakland Bay. The highest concentration of metals was found in Shelton Harbor near the sawdust loading area (SH-11, SH-12, and SH-18).

5.5.9 Petroleum Hydrocarbons

Petroleum hydrocarbons were tested at two subsurface locations. Lube oil-range hydrocarbons were found at a concentration of 270 mg/kg in the subsurface sediment sample collected at station SH-02, located south of the vessel haul out (lube oil-range hydrocarbons were found in surface sediment only at SH-05). Petroleum hydrocarbons were not detected in the other subsurface sediment sample collected at station SH-01.

5.6 Bioassay Toxicity

Bioassay test results across the Oakland Bay study area are provided in Figure 5-12. SQS and CSL failures occurred throughout Shelton Harbor and Oakland Bay, both along the shoreline and across the entire water bodies. The only Hammersley Inlet failure occurred along the shoreline at Millers Point. A comparison of the combined toxicity test results (pass/fail inclusive of all four toxicity tests) with wood presence in surface samples is provided in Table 5-4; a detailed statistical evaluation for each test is provided in Section 7.4.

Table 5-4. Bioassay test results compared to visible wood presence in surface sediment across the Oakland Bay study area.

SMS Toxicity Test Result	Oakland Bay		Hammersley Inlet		Shelton Harbor		Study Area	
	Wood	No Wood	Wood	No Wood	Wood	No Wood	Wood	No Wood
Pass	2	4	1	4	6	8	9	16
Fail	2	9	0	1	11	2	13	12

SMS Sediment Management Standards

Toxicity test pass/fail results for samples collected in areas with high accumulation of wood waste were inconsistent (compare Figure 5-12 with Figures 5-1 and 5-2). Samples collected from the Shelton Creek and Goldsborough Creek alluvial fan area generally failed the larval acute test; however, two samples collected from the former sawmill#4 wood waste accumulation area passed all tests.

5.6.1 10-Day Amphipod

Only one location (OB-03) had a marginal (4 percent) exceedance for the amphipod toxicity test; all other toxicity tests at this location passed SMS criteria. Percent fines measured in the field by wet sieving was 54 percent, indicating that the toxicity analysis should be performed using *A. abdita* as the test organism (i.e., less than 60 percent fines). Later laboratory testing measured total fines for this sample as 70 percent. The failure may have resulted from improper test organism selection associated with the less accurate field measurement.

5.6.2 Larval Development

In Shelton Harbor, larval toxicity failures primarily occurred along the north and northwest shoreline (SH-02 through SH-07) and in the south, associated with areas of wood waste accumulation (Figure 5-2). Of the 11 larval toxicity failures in Shelton Harbor, 82 percent (nine locations) failed CSL criteria and 18 percent (two locations) failed SQS criteria.

In Oakland Bay, larval toxicity failures primarily occurred in the central and upper portions of the bay. Two failures also occurred along the eastern side of the bay, where logs have historically been rafted (OB-18 and OB-19). Of the 10 larval toxicity failures in Oakland Bay, 50 percent (five locations) failed CSL criteria and 50 percent (five locations) failed SQS criteria.

5.6.3 Juvenile Polychaete

Four locations in Shelton Harbor failed SQS criteria for juvenile polychaete toxicity. All failures (SH-13, SH-19, SH-22, and SH-28) were within 10 percent of the 70 percent criterion for mean individual growth rate. Only two locations (SH-19 and SH-22) had an additional toxicity test failure (larval toxicity).

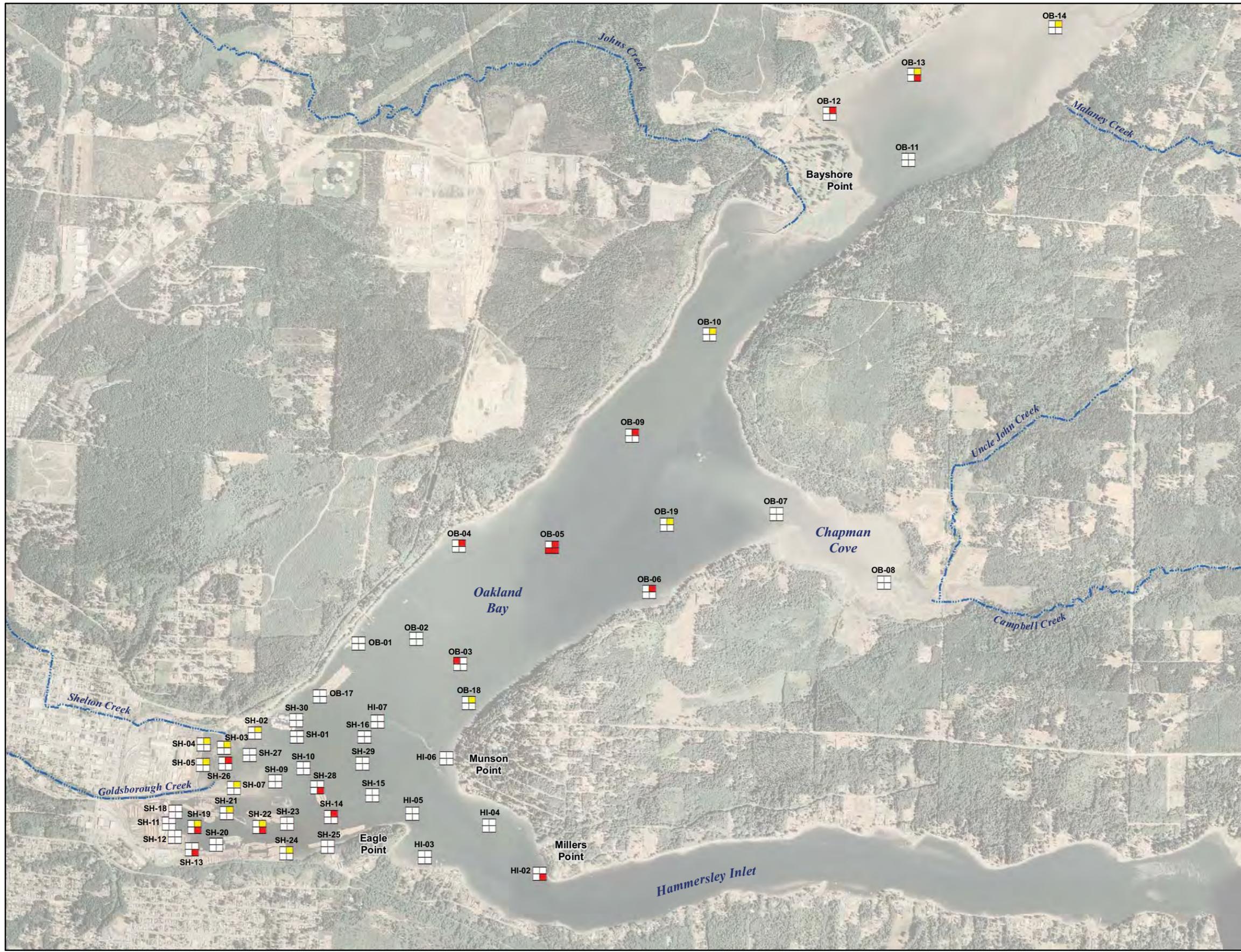


Figure 5-12.
Bioassay test results across the
Oakland Bay study area.

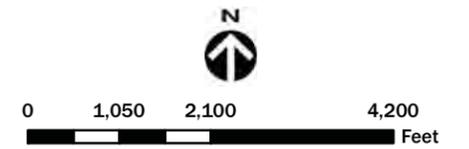
Legend

- Pass SMS criteria
- Fail CSL criteria
- Fail SQS criteria

Bioassay tests

- Amphipod Larval
- Microtox Polychaete

Note: Surface samples collected from top 0.3 feet.



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Two locations (OB-05 and OB-13) in Oakland Bay failed SQS criteria for juvenile polychaete toxicity. Location OB-05 also failed for both larval development toxicity and Microtox testing; location OB-13 had one additional toxicity test failure (larval toxicity).

One location (HI-02) in Hammersley Inlet failed SQS criteria for juvenile polychaete toxicity. This sample is located along the shore, near Millers Point.

5.6.4 Microtox

One location (OB-05) failed SQS criteria for Microtox testing. This sample also failed SQS criteria for both larval and juvenile polychaete toxicity.

