Recontamination Sources At Three Sediment Caps In Seattle

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Abstract: Ten years of monitoring at three sediment caps along the Seattle waterfront showed these caps were successful at becoming biologically productive and containing underlying contaminated sediments; however, the results also showed that re-suspension of contaminated historic sediment was an important source of recontamination to the cap surface. The fastest recontamination occurred at the 4.5-acre Pier 53-55 cap, installed in 1992, north of Coleman Ferry Dock and away from any discharges pipes. Within one year, a large piling removal project at an adjacent pier re-suspended creosote laden sediments onto all 7 surface monitoring stations and 3 stations exceeded state Sediment Management Standards (SMS) for polynuclear aromatic hydrocarbons (PAHs), but after three years all PAHs decreased to below SMS. The appearance of both PCBs and bis(2-ethylhexyl)phthalate (BEHP) on the cap after 4 and 10 years suggests these chemicals came from re-suspension of contaminated historic sediment beyond the cap boundary due to human or natural causes. The 4-acre Pier 64-64 cap, installed in 1994, experienced PAH recontamination due to re-suspension of contaminated historic sediment during piling repair work at the adjacent Pier 62/63. Piling repair work caused minor recontamination in 1996 (2 years post cap) and major recontamination in 2002 (8 years post cap) when the three cap stations exceeded SMS for HPAHs, but PAH levels dropped below the SMS in 2 years. The 3-acre Denny Way cap was installed in 1990, with the inshore boundary at a water depth of –20 feet MLLW to avoid erosion of the sand cap. Contaminated historic sediment from a 1-acre area inshore of the cap were re-suspended by wave action and CSO discharges at low tide and both these sources greatly influenced the rate of recontamination and distribution of chemicals on the cap. In 4 years, BEHP exceeded the SMS at the one inshore cap station closest to the highest inshore concentrations, but the rapid PAH increase at the most inshore station reached a steady state in 4 years and values were much less then SMS. Both PCBs and benzyl butyl phthalate (BBP) showed up rapidly at the most inshore station, but it took 6-10 years for these chemicals to appear at the two stations located farthest away; however, after 10 years one or both stations farther away exceeded the SMS for these chemicals.

Introduction:

From 1990-1994 three sediment caps were constructed along the Seattle waterfront using clean sand dredged from the Duwamish turning basin by the US Army Corps of Engineers (USACE) to restore channel depth and restore storage capacity for more sand deposition. To obtain the cleanest sand for capping projects, the USACE used only the sand from the most upstream part of the turning basin, which contained the least amount of fine-grained silt or clay. The USACE placed the caps using controlled release of sand from specially equipped bottom dump barges to achieve the desired cap thickness (Sumeri 1991). The 10-year monitoring program for each cap was designed to determine whether the caps functioned properly to isolate the underlying sediment contamination, resist erosion, become biologically productive, and also to document any recontamination of the cap surface. As monitoring results were generated over the years this information was presented in monitoring reports and papers to aid regulatory agencies in making decisions about other proposed capping projects. Complete details of the monitoring results were included in the monitoring reports, which were listed in the references.

Pier 53-55 Cap:

The fastest rate of recontamination occurred at the Pier 53-55 cap, which was a surprising because the cap was located away from any significant discharge sources of combined sewer overflow (CSO) or storm drain (SD) input. The 4.5-acre Pier 53-55 cap was installed in 1992, north of the Coleman Ferry Dock to isolate contaminated sediment near a historic City of Seattle CSO located offshore from Pier 53 (Fire Department Pier), Pier 54 (Ivar's Restaurant), and Pier 55 (Harbor Tour's dock). The City was the lead agency that obtained permits for the project and the Elliott Bay/Duwamish Restoration Program provided funding (EBDRP 1992). Long-term monitoring was performed by Metro, which became part of King County in 1994. Most of the sand cap was three feet thick except for the northern near shore edge, which was one foot thick to minimize loss of navigation depth. Surface recontamination for this cap was anticipated to be slow because the inshore edge of the cap was about 300 feet from the edge of the sea wall and there were no significant discharge sources near the cap.

Less then one year after the Pier 53-55 cap was installed, a large amount of contaminated sediment was released onto the cap when the Ferry Terminal removed a long row of creosote treated pilings that formed a wing wall in an area that boarded the inshore corner of the cap (southeast corner). The contractor used a clamshell bucket to remove the piling; however, a large amount of excess contaminated sediment was re-suspended and spread around the area because the contractor repeatedly dug down into the mud to remove pilings that broke off during removal. Based on the Pier 53-55 monitoring results, regulatory agencies quickly recognized the recontamination problems with piling removal from contaminated sediment and developed regulations and procedures to minimized spread of contaminated sediment during piling removal work. Regulations banned using a clamshell bucket to remove pilings from contaminated sediments.

There were 7 surface grab stations on the Pier 53-55 cap that were sampled 4 times, including 1992, 1993, 1996 and 2002, which represented a zero-year baseline, 1-year post cap, 4-years post cap, and 10-years post cap (EBDRP 1995 and 1997). The baseline chemical values were low, but after one year the samples showed all 7 stations were recontaminated primarily with PAHs from the creosote-laden sediment. The most impacted station exceeded the SMS for most of the 15 regulated PAH compounds (Ecology 1991) and two other stations exceeded SMS. PAH values in surface stations showed a decreasing concentration gradient with distance from the source so the highest values were at Station VG5 on the south east side of the cap and the lowest values were at Station VG7 located the farthest distance off shore (see Table 1 for dry weight total PAH values).

Two sediment samples taken at the site of the previous wing wall showed very high LPAH values with a range of 152,760 to 250,840 ppb DW and the corresponding HPAH values had a range of 102,400 to 146,000 ppb DW. The two most impacted stations (VG5 and VG6) had LPAH values of 70,100 and 8,870 ppb DW, respectively, while the least impacted station (VG7) was 570 ppb DW. The HPAH values at the two most impacted stations were 75,700 and 15,550 ppb DW, while the least impacted station was 1,600 ppb DW. The 1996 data showed that in 3 years a major reduction in PAH values occurred, especially, for the most impacted stations, which all decreased to below the SMS. When PAH values decreased they did not return to the original low values measured in the capping material, but PAH values remained at a new elevated background or equilibrium concentrations. PAH values at five stations grouped together (VG1, VG2, VG3, VG4, and VG6) with an apparent equilibrium range for LPAH values of 340 to 910 ppb DW and a corresponding equilibrium range for HPAH values of 2,480 to 5,025 ppb DW. After 10 years, the most impacted station (VG5) still exceeded the equilibrium range with LPAH/HPAH values of 1,715/5,995 ppb DW. The LPAH/HPAH values for the second most impacted station (VG6) were elevated above the equilibrium range after 3 years (1,315/ 7,030 ppb DW), but after another 6 years the values at this station decreased to 570/2,500 ppb DW, which was within the new range. The least impacted station (VG7) remained below the new range for the other 5 stations. For metals, both lead and mercury values increased at the most impacted station (VG5) during the 1993 sampling event when PAH values increased, but after 3 years both metals decreased to background levels and no other increases were observed at the end of 10 years.

The only two chemicals to show an increase over time on the Pier 53-55 cap were PCBs and bis(2-ethylhexyl)phthalate (BEHP) as shown in Table 1. Four years after the cap was placed, PCBs were first detected at four stations on the cap (VG2, VG3, VG5 and VG6), but after an additional 6 years PCBs were detected at one more station (VG4) and two stations showed increased PCB values (VG2 and VG3). The source for the PCBs that accumulated on the cap was most likely due to re-suspension of surrounding contaminated historic sediments, because PCB concentration in CSO or SD discharges would be very low compared to PCB values in contaminated historic sediment. The appearance of BEHP on the cap was similar to PCBs because after 4 years BEHP was above the detection limit at all stations. After an additional 6 years the 10-year samples showed BEHP values were highest at the two stations located on each end of the cap (VG4 and VG5), which indicated input from re-suspension of contaminated historic sediment that contained BEHP. The highest BEHP value was on the north edge of the cap (VG4) and this station exceeded the SQS values after 10 years. Previous reports identified propeller prop wash as the primary re-suspension source along the waterfront (Ecology 1995b and 1995c).

Table 1. Pier 53-55 Sediment Cap, Surface Chemistry Data For Four Sampling Events During 10 Years.

		STATIONS AND CONCENTRATIONS IN PPB DRY WEIGHT						
YEAR	CHEMICAL	VG5	VG6	VG2	VG1	VG3	VG4	VG7
1992	LPAH	275	185	190	110	105	160	130
1993	LPAH	70,100	8,870	5,355	3,490	1,610	965	570
1996	LPAH	3,590	1,315	860	750	905	720	280
2002	LPAH	1,715	570	645	340	685	910	225
1992	HPAH	750	480	500	265	380	405	255
1993	HPAH	75,700	15,550	10,520	6,500	4,695	3,090	1,600
1996	HPAH	21,390	7,030	5,025	3,505	5,000	3,140	860
2002	HPAH	5,995	2,500	4,865	2,480	3,290	3,690	1,000
1992	PCB	<20	<20	<20	<20	<20	<20	<20
1993	PCB	<10	<10	<10	<10	<10	<10	<10
1996	PCB	150	35	35	<20	25	<18	<15
2002	PCB	26	20	90	51	65	25	5
1992	BEHP	<10	<10	<10	<10	<10	<10	<10
1993	BEHP	<200	<20	<20	<20	<20	<10	<10
1996	BEHP	350	280	265	145	290	370	60
2002	BEHP	350	185	230	120	210	420	35

< denotes that the values were below the detection limit of the instrument
All values rounded to nearest unit of 5 or 10.

Pier 64-65 Cap:
The second sediment cap impacted by PAHs re-suspended during pier renovation work was the 4-acre Pier 64 –65 cap installed in 1994, north of Pier 62/63 (public concert pier) and south of Pier 66 (new Bell Street Convention Center). The Port of Seattle was the lead agency that obtained permits for the Pier 64-65 cap and the cap thickness of one to two feet of sand was designed to isolate contaminated historic sediment and provide benthic habitat in the new Bell Street Marina area. The three surface monitoring stations (CS1, CS2 and CS3) were sampled in 1994, 1997, 2002 and 2004, which provided a zero-year baseline, a 3-year post cap, an 8-year post cap, and a 10-year post cap (Polaris 2002 and 2003). In 2004, many more sampling stations were added to provide complete coverage over the entire surface of the cap, which resulted in a total of 14 surface samples collected from the cap during the 10-year sampling event (Polaris 2004).

Concern about PAH recontamination on the Pier 64-65 cap arose in 2 years when the Seattle Parks Department wanted to proceed with piling repair work at the large combined Pier 62/63 located immediately south of the Pier 64-65 cap. The contractor planned to use water jetting to wash away the contaminated sediment at the base of the piling so the pilings could be cut off below the mud line and a new section of piling attached with a sleeve at the joint. During the permitting process concern was raised that the re-suspended contaminated sediment would move onto the adjacent Pier 64-65 cap. As a result of these concerns, both the USACE permit and the Washington State Fish and Wildlife permit (Hydraulic permit) required that a special sediment trap study be conducted to evaluate the redistribution of the contaminated sediment that was re-suspended due to water jetting around the base of the piling (Ecology, 1996).

Ecology performed the sediment trap study for the Parks Department and deployed three sediment traps during the two month piling work period from mid February to mid April 1996 (traps in 2/14/96-4/17/96). One trap was moored close to the north side of Pier 62/63 where the piling repair work was conducted. A second trap was moored near the south side of the Pier 64-65 cap closest to the piling repair work and the third trap was moored south of Pier 59 to provide a reference station. Results of the sediment trap study

were reported by Norton (Ecology 1996) and showed that the one sediment trap adjacent to Pier 62/63 contained high concentrations of LPAH and HPAH, which indicated that contaminated bottom sediments were being re-suspended in a local area immediately adjacent to the Pier 62/63 construction site. However, the trap located on the closest end of the Pier 64-65 cap showed only a small increase in PAHs, except for a few LPAH values. Ecology concluded there would not likely be any long-term recontamination of the Pier 64-65 cap because the piling repair work was short duration and the few LPAH values that exceeded SQS were relatively low. Also, LPAH values were expected to drop rapidly due to chemical weathering processes. These expectations appeared to be met when the 1997 surface sediment samples from the Pier 64-65 cap showed no high values for LPAHs or HPAHs, but conditions changed in 2002 when additional piling repair work was conducted.

When the Parks Department conducted more piling repair work in the winter of 2002 there was no requirement for additional sediment trap studies based on the small effect observed during 1996. The 2002 piling repair work occurred shortly before surface sediment samples were collected from the Pier 64-65 cap and these 2002 surface samples showed high concentrations of PAHs that exceeded the sediment quality standard (SQS) value for HPAH at all three of the monitoring stations. The high PAH values on the Pier 64-65 cap were believed to be caused by a greater amount of contaminated sediment being re-suspended during the 2002 piling repair work and deposition of the re-suspended sediment over a large area of the Pier 64-65 cap (Polaris 1997). The rapid reduction of PAH values on the surface of the cap was evident in the results when surface samples were collected from the cap two years later in 2004. Of the 14 surface sediment samples taken from the cap during the 10-year monitoring event (two years elapsed time), there was only one station with surface values that exceeded SMS for PAHs and the cause was unrelated to deposition of PAHs from the re-suspended sediment during 2002 piling repair work (Gerald Erickson, personal communication 2004). While the 10-year monitoring results showed that all PAH values from re-suspended sediment had decreased to below the SQS on the Pier 64-65 cap, the degree of short-term PAH recontamination appeared to be much greater in 2002 then in 1996. Also, the final PAH values on the surface of the Pier 64-65 cap do not decrease to same low levels observed in the original capping material.

Denny Way CSO Cap:
The 3-acre Denny Way cap was a voluntary cleanup action implemented by the Municipality of Metropolitan Seattle (Metro) before Washington State adopted SMS in 1991. Various studies in the 1980's identified Denny Way CSO as a problem area due to contaminated sediment that accumulated from a historic sewer outfall that discharged offshore for over 70 years (1895-1967) plus 20 years of discharge from the Denny Way CSO outfall (1967-1987)(Comiskey 1984, Romberg 1984). Despite this knowledge, Metro was unable to move forward with a CSO control project at Denny Way because all available capital improvement funds were being used to upgrade the West Point sewage treatment plant from primary treatment to secondary treatment to comply with federal regulations for the discharge into Puget Sound.

Ideally, CSO source control could occur prior to sediment remediation, but Metro viewed the Denny Way cap as an economical way to create an immediate improvement in sediment quality within a large three-acre area of Elliott Bay without waiting 10-15 years for a CSO reduction project to be completed at the Denny Way CSO. The three foot thick cap was designed to use all the clean sand that the USACE had approved for capping during 1990 (20,000 cubic yards) to cover the largest surface area of the most contaminated sediments near the Denny Way CSO outfall. The inshore edge of the sand cap was set at a water depth of minus 20 feet MLLW to avoid erosion of the sand by wave generated currents at shallower water depths. The surface area of the contaminated sediment located inshore of the cap was about one acre, but the surface area of the clean cap was about 3 times larger then the area that was not capped. Re-suspension of this contaminated inshore sediment was recognized as a potential recontamination source. Another source of recontamination was the erosion and re-suspension of contaminated historic sediment that occurred when the CSO discharged at low tide because the CSO flow traveled across a small beach that was exposed at low tide.

The 10-year monitoring program at Denny Way included two more sampling events then were performed at the other two sediment caps because Denny Way was the first cap and there was interest in gaining additional information on the rate of recontamination due to the continuing CSO discharge. There were 4 surface grab stations on the cap (Station J, K, L and M) that were sampled 6 times including 1990, 1991,

1992, 1994, 1996 and 2000, which provided a zero-year baseline, a 1-year post cap, 2-year post cap, 4-year post cap, 6-year post cap and 10-year post cap (King County 1995, 1999 and 2005). Three additional surface stations (station R, S and Y) were sampled inshore of the cap at various times to identify chemical concentrations in sediment that could be re-suspended and washed onto the cap. The highest chemical concentrations occurred at the three stations inshore of the cap and many of the chemicals exceeded SMS values.

Of the 4 stations on the cap, the fastest rate of recontamination occurred at Station K, which was located closest to the outfall and the most contaminated inshore sediment. At Station K the PAH values showed a rapid increase for 4 years and then concentrations leveled off for 6 years; however, even the highest PAH values at Station K were less then 30% of the SQS values, which was different then the SQS exceedances that occurred at the other two sediment caps. The HPAH values on the Denny Way cap were about 4,500 ppb DW during three sampling events that spanned 6 years and these values were similar to the equilibrium PAH values found on the surface of the Pier 53-55 cap after values decreased from the 1993 recontamination event. On the Denny Way cap the PAH values only increased a small amount at the two stations J and M, which were located farthest away from the inshore chemical sources.

At Station K the chemical that exceeded SMS first was BEHP, which was above the sediment cleanup screening level (CSL) value in 4 years (1,250 ppb DW) and the 6-year value was even higher (2,700 ppb DW), but the 10-year value decreased to 1,600 ppb DW, which was similar to the 4-year value. The CSO discharge contained measurable BEHP levels, but the rapid increase in BEHP at Station K was likely due to a large input from the inshore sediment that contained high concentrations of BEHP. At Station J, located farthest to the north, the BEHP remained low after 10-years and at Station M, located farthest south, there was no BEHP detected even after 10-years.

The second phthalate to show a rapid increase at Station K was benzyl butyl phthalate (BBP), which reached a maximum value in 4 years and then remained stable for 6 years with concentrations in the 75 - 95 ppb DW range. The two stations farthest away had low BBP values after 4 years, but increased in the 6-year and 10-year samples so that during the last sampling event both stations had higher concentration similar to Station K. However, the BBP values at Stations J and M exceeded SQS because there were lower TOC values at these stations compared to Station K (TOC at K= 1.4 % vs. 1.1% and 0.5% at J and M). Increased BBP values at Stations J and M appeared to be influenced by additional sources like elevated BBP concentrations in the inshore sediments.

Changes in PCB concentrations provided a good indicator of input from historic sediment sources because the PCB concentrations in the CSO were very low compared to PCB concentrations in contaminated historic sediment at Denny Way. Within 2 years after the cap was placed, PCB values at Station K increased to a high value of 160 ppb DW, and even though lower values were found after 4-years and 6-years, the 10-year sample was higher again at 135 ppb DW. At Station M, located farthest to the south, the PCB values remained low and were undetected after 10-years. However at Station J, to the north, the PCB started off low with non-detected values at 4-years and 6-years, but in the 10-year sample PCBs increased to a higher value of 120 ppb DW, which was similar to the higher value at Station K after 10 years. The increase at Station J appeared to be influenced by additional sources like the elevated PCB concentrations in the inshore sediments. The total PCB value at Station J was equal to the SQS value because there was lower TOC at Station J compared to Station K (TOC at K= 1.4% vs. 1.1% at J).

On the Denny Way cap most of the 8 SMS metals showed no visual or statistical change from the natural background metal concentrations measured in the original capping material except for chromium and zinc at Station K. The values at Station K tended to stabilize after 4 years for both metals and were far below the SMS.

In 1999, King County developed a preliminary sediment cleanup plan for contaminated sediments surrounding the Denny Way cap and specifically identified the need to eliminate the contaminated sediment located on the inshore side of the cap before addressing other areas around the sediment cap (King County 1999). The current schedule for addressing the inshore sediment was for implementation in 2006. Also, conditions at the Denny Way cap changed due to a large CSO reduction project that

constructed two new CSO outfalls and will provide a 50 percent reduction in the suspended solids discharged to the bay from Denny Way CSO by using a 7.2 million gallon storage tunnel. Treated CSO discharges will occur 4 - 20 times a year at a water depth of minus 60 feet MLLW from the new 600-foot long outfall pipe that extends beyond the offshore edge of the sediment cap (Symonds 2005). The long outfall pipe was supported by concrete pilings driven through the cap and the pipe was covered with an armoring blanket of concrete matting and rock to protect the pipe. The material used to cover the pipe also covered over the original sampling Stations K and L. A maximum of one untreated CSO discharge per year will occur at a water depth of minus 20 feet MLLW from a new short outfall pipe that extends to the inshore edge of the cap.

Summary and Conclusions:

Re-suspension of contaminated historic sediment was identified as an important source of recontamination to the surface sediment at three sediment caps. The identified causes of re-suspension were mostly due to human causes, but there was one natural cause. The human causes included the following: 1) Use of clamshell bucket to remove pilings and digging into bottom to remove broken pilings, 2) Repair of pilings that requires cutting pilings off below the mud line, 3) Propeller wash from large vessels and ferry boats along the waterfront, and 4) Denny Way CSO discharge eroding contaminated beach sediment at low tide. The most significant natural cause of re-suspension was high velocity water currents generated by large waves when the waves enter water depths of less then 20 feet MLLW. At Denny Way a sediment cleanup plan will eliminate the contaminated historic sediment located inshore of the Denny Way cap, which was found to be a significant source of recontamination to the Denny Way cap. At other sites along the central waterfront, the amount of recontamination caused by re-suspension of contaminated historic sediments from propeller wash must be compared to the potential recontamination caused by the remaining discharge sources to determine priorities and whether additional capping could be effectively used in the near term to reduce re-suspension of contaminated historic sediments along the waterfront.

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References:

Comiskey, E., T. Farmer, C. Brandt, and P.Romberg. 1984. *Toxicant Pretreatment Planning Study, Technical Report 2: Puget Sound Benthic Studies and Ecological Implications.* Seattle, Washington: Metro.

Ecology (Washington State Department of Ecology). 1991. *Sediment Management Standards – WAC 173-204*. Olympia, Washington.

Elliott Bay/Duwamish Restoration Program (EB/DRP). 1993. *Pier 53-55 Sediment Cap and Enhanced Natural Recovery Area Remediation Project.* Prepared by Municipality of Metropolitan Seattle (Metro). Seattle, Washington.

Elliott Bay/Duwamish Restoration Program (EB/DRP). 1995a. *Pier 53-55 Sediment Cap and Enhanced Natural Recovery Area Remediation Project, 1993 Data*. Prepared by the King County Department of Metropolitan Services. Seattle, Washington.

Elliott Bay/Duwamish Restoration Program (EB/DRP). 1995b. *Elliott Bay Waterfront Recontamination Study. Volume I: Field Investigation Report.* Panel publication 9. Prepared by Ecology. Bellevue, Washington.

Elliott Bay/Duwamish Restoration Program (EB/DRP). 1995c. *Elliott Bay Waterfront Recontamination Study. Volume II: Data Evaluation and Remedial Design Recommendations Report.* Panel publication 10. Prepared by Ecology. Bellevue, Washington.

Elliott Bay/Duwamish Restoration Program (EB/DRP). 1997. *Pier 53-55 Sediment Cap and Enhanced Natural Recovery Area Remediation Project, 1996 Data.* Panel publication 17. Prepared by King County Water and Land Resources Division.

Erickson, G. 2004. Personal communication. Polaris Applied Sciences, Inc. Kirkland, Washington.

King County. 1995. *The Denny Way Sediment Cap, 1990-1992 Data*. Department of Metropolitan Services, Water Pollution Control Division. Seattle, Washington.

King County. 1996. *The Denny Way Sediment Cap, 1994 Data*. Department of Natural Resources, Water Pollution Control Division. Seattle, Washington.

King County. 1999. *The Denny Way Sediment Cap, 1996 Data*. Department of Natural Resources, Water Pollution Control Division. Seattle, Washington.

King County. 1999. Sediment Management Plan, Prepared by Anchor Environmental and Herrera Environmental Consultants. Seattle, Washington.

King County. 2005. *The Denny Way Sediment Cap, 2000 Data*. Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington.

Norton, D. 1996. *Results of sediment trap monitoring during pier maintenance along the Seattle waterfront at Pier 62/63*. Publication No. 96-334. Washington State Department of Ecology. Olympia, Washington.

Parametrix, Inc. 1994. *Pier 64/65 thin-layer cap; Habitat mitigation plan and monitoring program.* Prepared for the Port of Seattle. Parametrix, Inc. Kirkland, Washington.

Polaris Applied Sciences, Inc. 2002. *Pier 64/65 thin-layer sediment cap; Sediment chemistry monitoring report.* Prepared for the Port of Seattle. Polaris Applied Sciences, Inc. Kirkland, Washington.

Polaris Applied Sciences, Inc. 2003. *Pier 64/65 thin-layer sediment cap; Sediment chemistry monitoring report; Addendum on PCB issues*. Prepared for the Port of Seattle. Polaris Applied Sciences, Inc. Kirkland, Washington.

Polaris Applied Sciences, Inc. 2004. Port of Seattle Pier 66 (*Pier 64/65) thin-layer sediment cap; Supplemental Report; Contingency plan sediment investigation March 2004.* Prepared for the Port of Seattle. Polaris Applied Sciences, Inc. Kirkland, Washington.

Romberg, P, D. Healy, K. Lund. 1887. *Toxicant Reduction in the Denny Way Combined Sewer System*. Municipality of Metropolitan Seattle. Seattle, Washington;

Romberg, P., C. Homan, and D. Wilson. 1995. *Monitoring at two sediment caps in Elliott Bay*. Pp. 289-299 in: Puget Sound Water Quality Authority. 1995. Proceedings; Puget Sound Research "95; Volume L. Conference held January 12-14 at Maydenbauer Center, Bellevue, Washington. Puget Sound Water Quality Authority. Olympia, Washington.

Sumeri, A. and P. Romberg. 1991. *Contaminated bottom sediment capping demonstration in Elliott Bay*. Pp. 507-520 in: Puget Sound Water Quality Authority. 1991. Proceedings; Puget Sound Research "91; Bolume2. Conference held January 4-5, 1991 at the Washington State Convention and Trade Center, Seattle, Washington. Puget Sound Water Quality Authority. Olympia, Washington.

Symonds, A. 2005. *Reducing Combined Sewer Overflows at Denny Way*. 2005 Puget Sound Georgia Basin Research Conference, held March 29-31, 2005 at the Washington State Convention and Trade Center, Seattle, Washington.