RECONTAMINATION OF WATERWAY CAP THEA FOSS WATERWAY, TACOMA, WASHINGTON

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ABSTRACT

A hybrid cap was constructed as part of a Remedial Action at the Head of the Thea Foss Waterway, pursuant to the Thea Foss and Wheeler/Osgood Waterways Problem Areas of the Commencement Bay Nearshore/Tideflats (CB/NT) Superfund Site located in Tacoma, Washington. The purpose of the cap was to contain contaminated sediments and a seep of coal tar derived dense non-aqueous phase liquid (DNAPL). Primary contaminants of concern (COCs) included metals, polycyclic aromatic hydrocarbons (PAHs), phthalate esters, pesticides and polychlorinated biphenyls (PCBs). The cap was completed in February 2004. Sediment quality monitoring began soon after the cap was installed according to the EPA approved Operations, Maintenance and Monitoring Plan (OMMP). OMMP sampling was completed in April 2004 (Year 0), May 2005 (Year 1) and May 2006 (Year 2). The monitoring program consisted of visual observation and collection of three types of sediment samples including early warning, "*top-down*" recontamination samples (0 to 2 cm), compliance samples (0 to 10 cm) and, "*bottom-up*" core samples. Soon after the cap was installed, fine grained sediment began to accumulate on the granular cap surface and contaminant concentrations in surface sediment began to increase. Physical observations and core sampling indicated that the DNAPL seep had been controlled and that the cap was functioning as intended. Sampling completed in Year 2 indicated that contaminant concentrations, predominately bis (2-ethylhexyl)phthalate, within the compliance interval (0 to 10 cm) had exceeded the Sediment Quality Objectives (SQOs) established by the CB/NT Record of Decision (ROD). Available data indicate the sources of recontamination were top-down in nature, especially stormwater that discharges to the head of the waterway.

Keywords: DNAPL, HPAHs, phthalates, stormwater, monitoring

INTRODUCTION

Sediment remediation, either by dredging removal or containment with an engineered cap, can be effective if sources of contamination have been identified and controlled to a degree where sediment recontamination will not occur. Recontamination sources, should they exist, can generally be divided into bottom-up and top-down sources. An example of a bottom-up source would be underlying contaminated sediment, if a capping remedy is implemented. Potential top-down sources include shoreline erosion and runoff from industrial properties, municipal stormwater discharges and other facilities that discharge directly to a water body. In the case of the Thea Foss Waterway, multiple contaminant sources, including both bottom-up and top-down sources were potentially present. These sources needed to be considered in both the design of the monitoring program and interpretation of the monitoring data.

The Thea Foss Waterway (formerly called the City Waterway) is one of several recreational/commercial/industrial use waterways that lie within the Commencement Bay/Near Shore Tideflats (CB/NT) Superfund site near Tacoma Washington (Figure 1). The waterway extends in a generally north to south direction along approximately 2.4 kilometers (k) of the downtown Tacoma shoreline and was initially constructed in 1905. The upper (south) 305 meters (m) is the "*Head of Thea Foss Waterway Remediation Project*" and is the focus of this paper.

In 1983, the CB/NT area was designated as a Superfund site. A Remedial Investigation (RI) completed in 1985 identified polycyclic aromatic hydrocarbons (PAHs) as contaminants of concern, among a number of other constituents such as metals and PCBs (TetraTech 1985). The primary potential sources of contamination identified in the RI included stormwater outfalls and a manufactured gas plant (MGP) that operated near the head of the waterway to about 1926. Subsequent research indicated that a portion of the PAHs were contributed to the waterway by a chemical plant that operated on the west shoreline in the early 20th century rather than the MGP.

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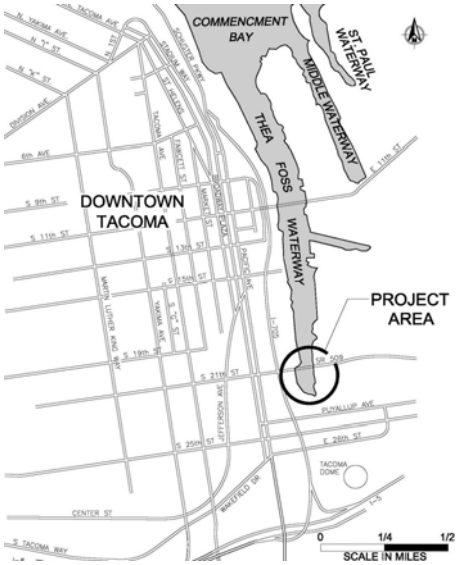

Figure 1. Vicinity map.

CONTAMINANTS AND SOURCES

Contaminants of Concern

Sediment sampling in the Thea Foss waterway identified a number of indicator contaminants of concern (TetraTech FW and DOF, 2003). Selected contaminants and the range of surface (0 to 10 cm) sediment concentrations (prior to remediation) are summarized in Table 1 (Hart Crowser 1995, 1997; Dalton 1999). HPAHs are the sum of high molecular weight polycyclic aromatic hydrocarbons including benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, benzofluoranthenes and pyrene.

Table 1. Contaminants of concern in surface sediment.

Contaminant	Concentration Range
Phenanthrene (ug/kg)	250 – 539,000
HPAHs (ug/kg)	1,780– 2,732,900
Phthalates - bis(2-ethylhexyl)phthalate (ug/kg)	<1,100 – 20,000
p,p'-Dichlorodiphenyltrichloroethane (DDT) (ug/kg)	<4.1 - 13
Polychlorinated biphenyls (PCBs) (ug/kg)	<41 - 170
Lead (mg/kg)	141 – 1,160
Zinc (mg/kg)	105 – 4,230
Mercury (mg/kg)	0.05 – 1.9

Contaminant Sources

A multitude of sources including shipyards and marinas, a chemical plant that produced products from coal tar, stormwater, and other industries and facilities that operated on the waterway contributed to historic sediment contamination. The number of potential sources and the commonality of the sources in contributing similar contaminants made it challenging to differentiate contributions. For example, polycyclic aromatic hydrocarbons (PAHs) are common to coal tar, creosote and particulates (e.g. street dust) found in stormwater. Post-remediation sediment quality monitoring provided an opportunity of assessing the impacts of potential sources, such as stormwater discharges.

Coal Tar Derived Deposits

Sediment sampling discovered a surface and buried coal tar derived deposit (dense non-aqueous phase liquid or DNAPL deposit) in the waterway. The source of the deposit was traced to the Standard Chemical Company (previously called the Standard Creosote Company) that operated on the west bank of Thea Foss between about 1916 and 1926. The company produced industrial chemicals, fertilizers and spray materials from distilled coal tar and gas pipe drip oil (TSL 1919; DOF 1999).

Oily sheens were intermittently observed within a portion of the intertidal area where Standard Chemical formerly operated and on the water surface in a subtidal portion of the waterway underlain by the DNAPL materials (Hart Crowser 2002). The DNAPL had a measured density of 1.1396. For comparison purposes, seawater has a density of approximately 1.020 to 1.029 depending on salinity. The estimated extent of the DNAPL deposits and locations of the visible seeps are illustrated on Figure 2. Sheens in the subtidal area became evident during periods of falling tides when oily globules rose to, and spread on, the water surface. Subsequent investigations discovered that DNAPL was being discharged in two ways: oily globules that migrated upward to the mudline where they became entrained in sediment and oily globules that rose to the water surface where they became visible as sheens.

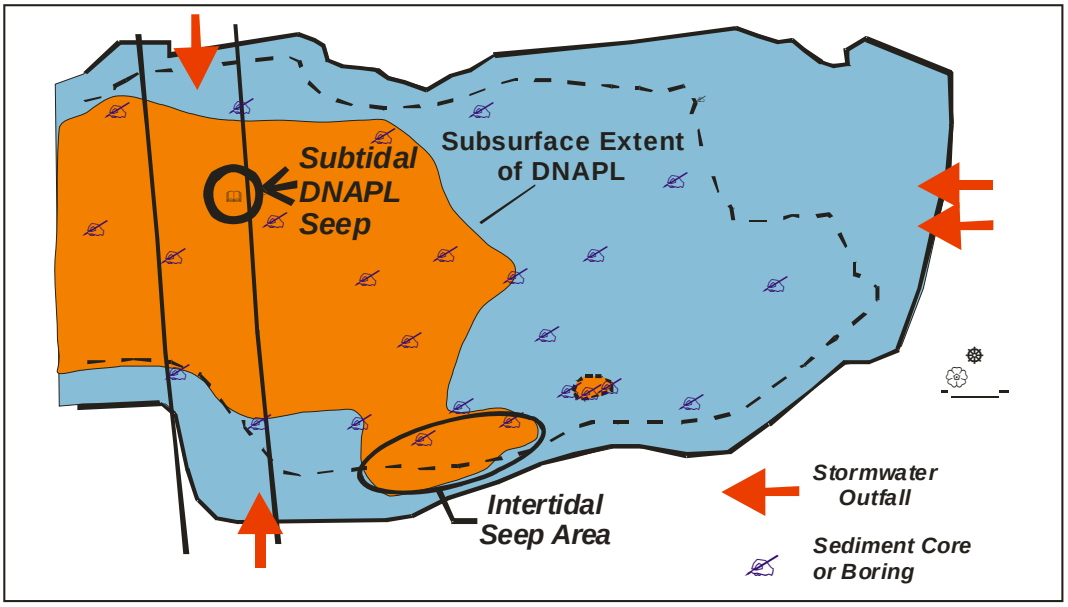

Figure 2. Extent of buried DNAPL in Head of Thea Foss Waterway.

Sediment coring and testing indicated that the DNAPL deposit was being contained by fine grained sediment that had accumulated in the waterway since the last dredging in the 1940's, except in one localized portion of the waterway. Available data indicated the cause of the subtidal DNAPL seep to be the pulling of timber piles and other construction activities that occurred in the waterway as part of the construction of a bridge (Dalton 1999; Dalton et al. 2007). These activities appear to have created preferred pathways through the fine grained sediment. While upward ground-water gradients are present beneath the waterway, they were not considered high enough to be the cause of the upward migration of DNAPL. As the tides fall, degassing of the organic rich sediments occurs and gas bubbles are released. The release and upward migration of the gas bubbles likely facilitated the upward transport of DNAPL. The relationship between the tides and visible oily seepage (globules per fifteen minutes) based on data collected by Hart Crowser (2002-Appendix G) is illustrated on Figure 3.

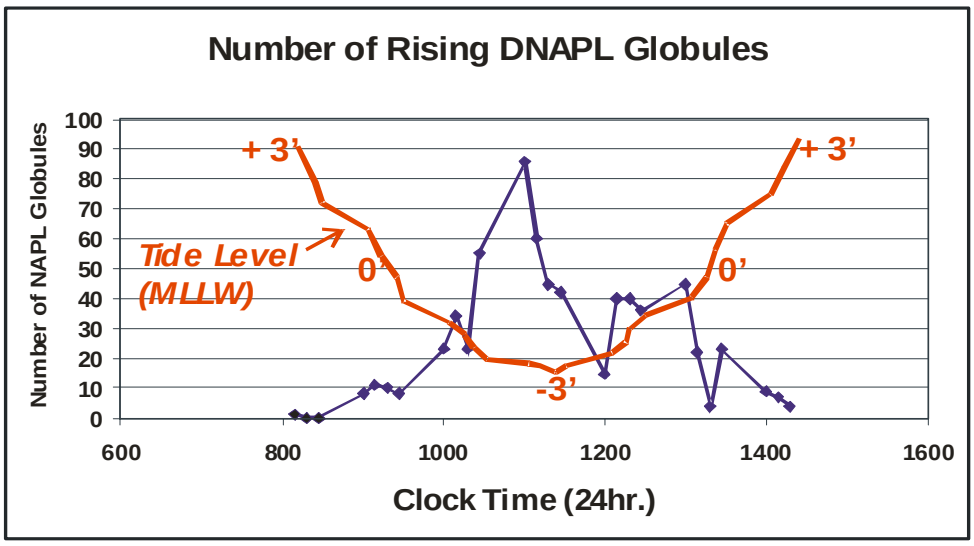

Figure 3. Tidal level impact on subtidal seepage (MLLW – Mean Lower Low Water).

Stormwater

A number of stormwater outfalls discharge into the head of the waterway as illustrated on Figure 2. The outfalls drain a combined area of approximately 1,960 hectares (4,840 acres). Drainage basin sizes and general land uses within each basin are summarized in Table 2 (Tacoma 2006). The largest outfalls are situated at the end of the waterway and are locally known as the Twin 96-inch outfalls.

Table 2. Stormwater basin sizes and general land uses.

Outfall Designation	Area (hectares)	Area (acres)	Land Use
237A	1130	2794	Residential, commercial and industrial
237B	737	1821	Residential
235	73	181	Residential, commercial and industrial
243	18	45	Industrial

Vactor truck waste solids from stormwater settling basins within the central portion of the Puget Sound Region (King and Snohomish Counties) contain a variety of contaminants including metals (especially zinc, lead, chromium, cadmium, copper, nickel and arsenic) (Sedar 1993). The most commonly detected organic contaminants in vactor waste sediment included PAHs, total petroleum hydrocarbons (TPH) and several phthalates [especially bis(2-ethylhexyl)phthalate]. These contaminants were detected, for the most part, in the solids phase rather than in the decant water, indicating that transport would most likely occur in the solids particulate phase as compared to being dissolved and migrating in water.

In the early to mid-1990s, the Washington State Department of Ecology (Ecology) recognized that particulates are a major source of sediment contamination in some receiving waters (Wilson and Norton 1996). Ecology completed a pilot study to collect and analyze stormwater particulates using sediment traps deployed in a number of stormwater structures. Using the results of the pilot study, Ecology deployed sediment traps in stormwater pipes that discharge to the Thea Foss Waterway (Norton 1997). Based on the Ecology results, the City of Tacoma implemented a program, with Ecology and EPA oversight, to monitor stormwater quality discharging into the Thea Foss Waterway using sediment traps, and whole and dissolved water analyses (Tacoma 2006). The average of contaminant concentrations detected in particulate samples collected from in-line sediment traps deployed in discharge pipes that drain the basins listed in Table 2 are summarized in Table 3 for the period 2001 to 2006.

Table 3. Average concentrations in sediment trap samples collected in discharges to Thea Foss Waterway (2002 to 2006).

Contaminant	Basin 237A	Basin 237B	Basin 235	Basin 243
Phenanthrene (ug/kg)	3,192	2,202	1,360	1,788
HPAHs (ug/kg)	27,450	17,505	8,624	10,736
Bis(2-ethylhexyl)phthalate (ug/kg)	11,340	8,180	11,660	28,200
DDT (ug/kg)	12	7.6	<8	<19
PCBs (ug/kg)	79.8	70	57	195
Lead (mg/kg)	86	75	144	479
Zinc (mg/kg)	279	217	304	727
Mercury (mg/kg)	0.06	0.08	0.06	0.84
TPH (heavy oil) (mg/kg)	2,320	1,910	2,400	5,680

DESCRIPTION OF REMEDY

Overall construction of the Head of Thea Foss Remedy was completed in February 2004 (DOF 2004). The selected remedy was containment of contaminated sediments over an area of approximately 3.6 hectares (nine acres). The major components of the remedy are shown on Figure 4 and included the following:

- Installation of a sheet-pile wall near the lateral end (north end) of the DNAPL deposits. The primary purpose of the wall was to delineate the end of the navigation channel located to the north of the remediation area described in this report. The joints between the sheet pile wall were also sealed to prevent the lateral migration of residual DNAPL deposits.
- Placement of a fine to medium sand cap over contaminated sediments. The cap was designed to physically and chemically contain the underlying sediment. The cap was augmented with organic material to achieve a total organic carbon content of 0.5% to assist in chemical containment.
- Placement of a relatively coarse-grained material on side slopes for erosion protection.
- Installation of a scour protection apron at the head of the waterway, to prevent erosion by stormwater discharges from the Twin 96" outfalls. Placement of the apron required that approximately 3,000 cubic meters of sediment be dredged from the waterway.
- Installation of a hybrid cap over the intertidal seep (DOF 2004; Dalton, et al. 2007). The hybrid cap consisted of placing an HDPE sheet ("hard cap") over the seep area and placing one to two meters of sand over the hard cap. The hybrid cap was installed in January 2004.
- Congressional deauthorization of the navigation channel (pending) for the south 1,000 feet of waterway and implementation of an Institutional Control Plan (ICP).
- Implementation of an EPA approved Operations, Maintenance and Monitoring Plan (OMMP).

The intertidal seep on the west bank of the waterway was remediated by the Washington State Department of Ecology in 2002 and 2003 (Geoengineers 2003). The remedy consisted of excavating contaminated sediment and filling the excavation with uncontaminated fine grained material. Additional capping material was placed over the intertidal remediation area as part of the overall remediation within the head of the waterway.

After construction of the remedy described above was completed and after confirmation sampling (April 2004), significant surface recontamination of the northern portion of the cap occurred. The sediment contamination was traced to dredging on the north side of the sheet pile wall in September 2004 that caused the suspension and spreading of contaminated sediment, some of which accumulated on the sand cap. This contaminant source was temporary in nature. Remediation of the dredging contamination was accomplished by placing an additional 6 to 18 inches of sand capping material in the area most impacted by the recontamination. However, dredging recontamination complicated interpretation of the monitoring data.

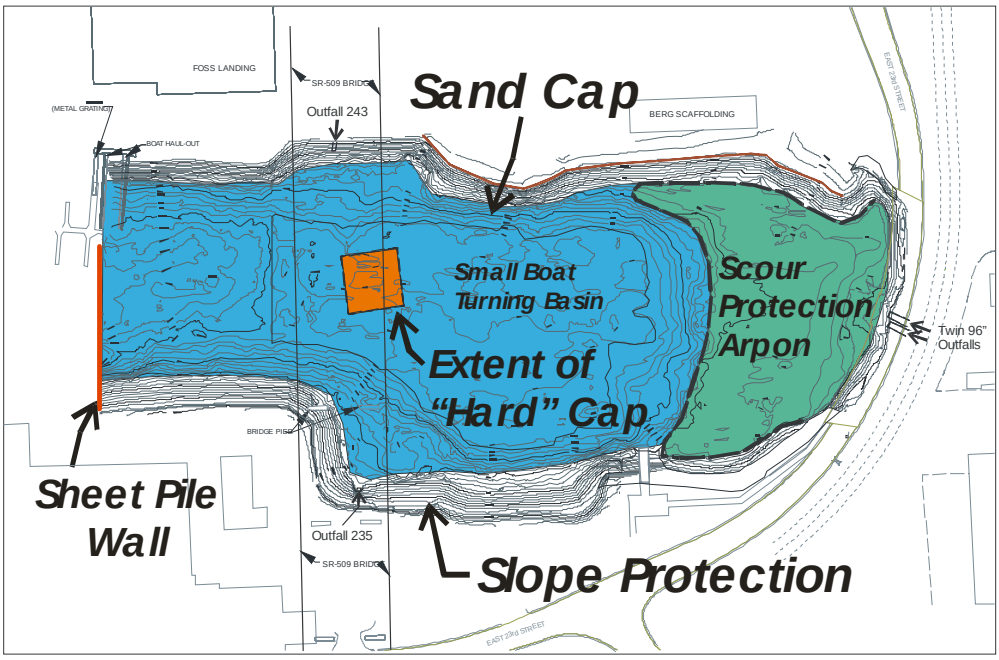

Figure 4. Remedy features.

MONITORING PROGRAM

Sediment Quality Objectives

As part of the Superfund cleanup of the CB/NT, including the Thea Foss Waterway, Sediment Quality Objectives (SQOs) were established by the CB/NT Record of Decision (1989). The SQOs include both chemical and biological criteria. Chemical SQOs are listed in Table 4 for the primary COCs associated with the Thea Foss Waterway. If a chemical SQO is exceeded, biological assay testing may be completed to assess whether the contamination has the potential to cause adverse biological effects. The results of bioassay testing supersede the chemical test results. Bioassay testing protocols are contained in PSEP (1995).

Table 4 - Comparison of May 2006 compliance sample concentrations with SQOs.

Contaminant	Maximum Concentration	SQO	Location
Phenanthrene (ug/kg)	1500	1500	WC-05
HPAHs (ug/kg)	21481	17000	WC-02
Bis(2-ethylhexyl)phthalate (ug/kg)	7700	1300	WC-02
DDT (ug/kg)	<12	34	-----
PCBs (ug/kg)	160	300	WC-02
Lead (mg/kg)	92	450	WC-02
Zinc (mg/kg)	269	410	WC-01
Mercury (mg/kg)	0.22	0.59	WC-02
TPH (heavy oil) (mg/kg)	5100	none	WC-01

Monitoring Approach

Monitoring consists of both physical observation and sediment quality sampling. The conceptual framework on which the monitoring program was based is illustrated on Figure 5.

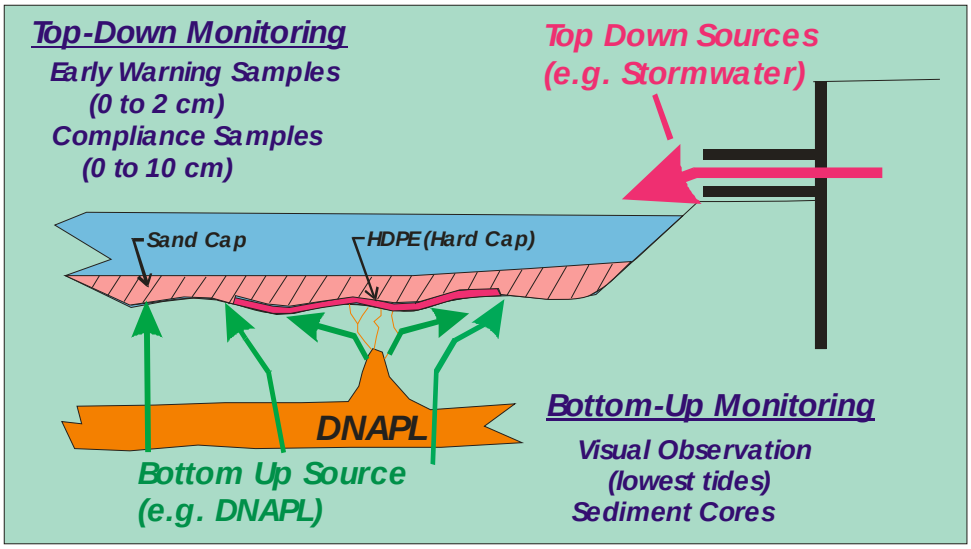

Figure 5. Conceptual framework of contaminant sources.

The types of monitoring and samples are briefly described below. Sediment sampling locations are shown on Figure 6.

- Physical monitoring was conducted to generally assess the condition of the scour protection apron and waterway side slopes during seasonal low tides. Observation of the former subtidal DNAPL seep area during the lowest tides of the year was also conducted to confirm that the hybrid cap continues to be effective in preventing visual sheens. These observations are typically made when tidal levels are lower than approximately 0-feet mean lower low water (MLLW).

- Sediment quality sampling was completed to assess the performance of the sand and hybrid caps and was designed to monitor both top-down and bottom-up recontamination sources. Sediment samples were obtained as follows:

    - Compliance Samples (0 to 10 cm) – To compare to the sediment quality performance criteria (SQOs).
    - Early Warning Samples (0 to 2 cm) – To assess possible recontamination from top-down sources.
    - Core Samples (0 to 1 m) – To assess possible recontamination from bottom-up migration through the sand cap.

Sediment quality monitoring was completed in April 2004 (Year 0), May 2005 (Year 1) and May 2006 (Year 2). Visual observations of the former subtidal seep area were also made in January 2007. Sediment sampling was completed using standard methods. Surface samples were collected using a standard 0.1 m^2 van Veen stainless-steel grab sampler while core samples were collected using a VibraCore sampler. During collection of the sediment samples, the samples were visually logged to assess the depth of sediment that had accumulated on top of the sand cap after placement.

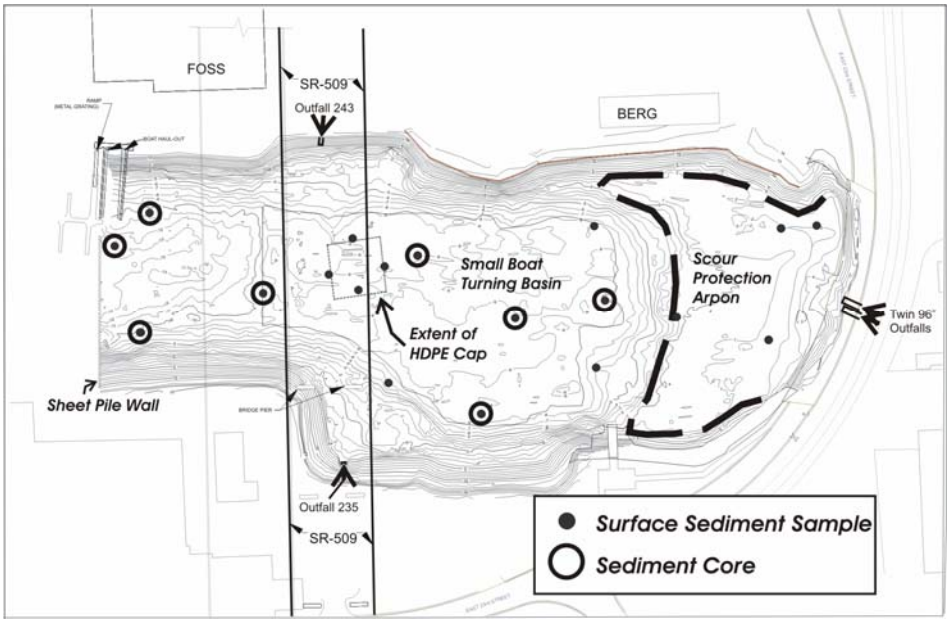

Figure 6. Sediment sampling locations.

Monitoring Results

Subtidal Seep – Visible Observations

Visible observations of the former subtidal seep area were completed on several occasions in 2004, 2005 2006 and, most recently, in early January 2007. The visible observations made as part of the OMMP were completed when tidal levels were below 0-feet MLLW. While gas bubbles were observed throughout the head of the waterway during the lowest tides, including in the area of the former subtidal seep, no visual sheens were observed. These observations indicate that the hybrid cap continues to be effective in preventing the upward migration of DNAPL into overlying sediment, three years after the cap was installed.

Fine Grained Sediment Accumulation

After the sand cap was installed, fine grained sediment began to accumulate on the cap. Between February 2004 and May 2006, approximately 6 to 19 cm of fine grained sediment had accumulated on the sand cap generally south of the bridge. The greatest thicknesses were near the north edge of the scour protection apron and declined in a northward direction. Lower sediment thicknesses (0.5 to 2 cm) were observed north of the bridge in the area where re-capping occurred because of the dredging recontamination. The source of fine grained sediment is interpreted to be particulates being discharged from the stormwater outfalls.

The sand capping material had a fines content (defined as particle sizes less than 62.5 microns) less than 4%. Grain size analyses of early warning samples (0 to 2 cm) indicated that the fine grained material that had accumulated on the cap had a fines content of approximately 30% to 58% (DOF 2006). The early warning samples (0 to 2 cm) were predominately composed of fine grained sediment while the compliance samples (0 to 10 cm) generally consisted of varying proportions of fine grained and coarser grained capping material, depending on when the sample was obtained and location.

Compliance Samples – May 2006

The maximum compliance sediment sample (0 to 10 cm) concentrations are compared to the SQOs in Table 4. This comparison indicates that HPAHs and bis(2-ethyhexyl)phthalate exceeded their respective SQOs. There were also exceedances of individual PAHs in sample WC-02 (fluoranthrene, pyrene, total benzofluoranthenes, benzo(a)pyrene and benzo(ghi)perylene) and WC-05 (fluoranthrene). Where SQOs were exceeded, PAH exceedance factors (concentration divided by the SQO) ranged between 1.1 and 1.7 while the BEHP exceedance factors ranged between 1.4 and 5.9.

While the other contaminants of concern did not exceed their respective SQOs in any of the compliance samples, they were elevated as compared to the underlying sand capping material. DDT, PCBs and TPH were not detected in confirmation samples of the sand capping material (DOF 2004). Metals are naturally occurring however, concentrations of metals in sand capping material were generally below the concentrations detected in post-construction monitoring early warning samples (Table 5). In Table 5 natural metal concentrations are for Puget Sound soils (Ecology 1994).

Table 5. Comparison of metal concentrations in capping sand and May 2006 fine grained sediment.

Constituent	Natural Background (mg/kg)	Maximum in Capping Material (mg/kg)	Range in Fine Grained Sediment (mg/kg)
Antimony	Not Available	<10	<10
Arsenic	7	<10	<8 to 10
Cadmium	1	<0.5	<0.2 to 1.0
Chromium	48	25	Not Analyzed
Copper	36	45	24 to 88
Lead	24	3	13 to 97
Mercury	0.07	<0.05	<0.04 to 0.28
Nickel	48	20	18 to 59
Silver	Not Available	<0.8	<0.8
Zinc	85	41	52 to 287

SOURCE IDENTIFICATION BASED ON MONITORING DATA

Recontamination of the Head of Thea Foss Waterway sand cap surface began soon after the cap was constructed in February 2004 based on Year 0 sampling (April 2004). Chemical SQOs and bioassay criteria were exceeded in several samples collected in May 2006. Interpretation of the monitoring data indicates top-down sources were the cause of the surface recontamination and that the sand and hybrid caps are functioning as designed and intended. The top-down sources included short-term dredging adjacent to the sand cap and stormwater discharges. These conclusions were based on the following lines of evidence:

- Sampling and analysis of sediment cores
- Fine grained sediment accumulations and chemical quality
- HPAH and BEHP concentration correlations and trends

Sediment Cores

In November 2004, several sediment cores were advanced near the north edge of the project area to assist in assessing the cause of surface recontamination that was detected after dredging on the north side of the capped area was completed. Core samples were taken approximately one year after the sand cap was constructed. The results of Core UA-01 located near the north edge of the sand cap are illustrated on Figure 7. The concentration pattern of total HPAHs, BEHP and lead indicate a top-down source of recontamination. Concentrations of HPAHs, BEHP and lead in 0 to 10 cm sediment on top of the cap were substantially higher than in underlying sand cap material.

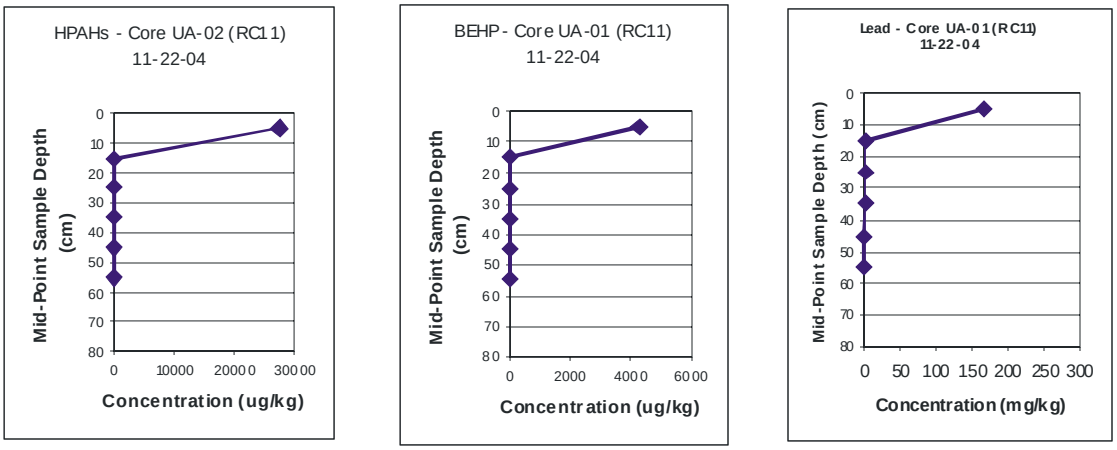

Figure 7. Sediment core UA-01 (RC-11) to assess 2004 dredging recontamination.

In May 2006, sediment cores were obtained from a number of locations within the project area (Figure 6), approximately 2.5 years after the cap had been constructed. The results of a core located in the central portion of the waterway south of the bridge are illustrated in Figure 8, and include the 0 to 2 cm and 0 to 10 cm samples and a composite sample of capping material from a depth interval of approximately 9 cm to 46 cm. The concentration patterns of core RC/WC-5 were consistent with other cores. Contaminant concentration increases were detected in fine grained sediment that had accumulated on the cap after construction. At core RC/WC-05, approximately 10 cm of fine grained sediment was observed at the time the core was collected. There was no evidence of upward migration of contamination through the sand cap.

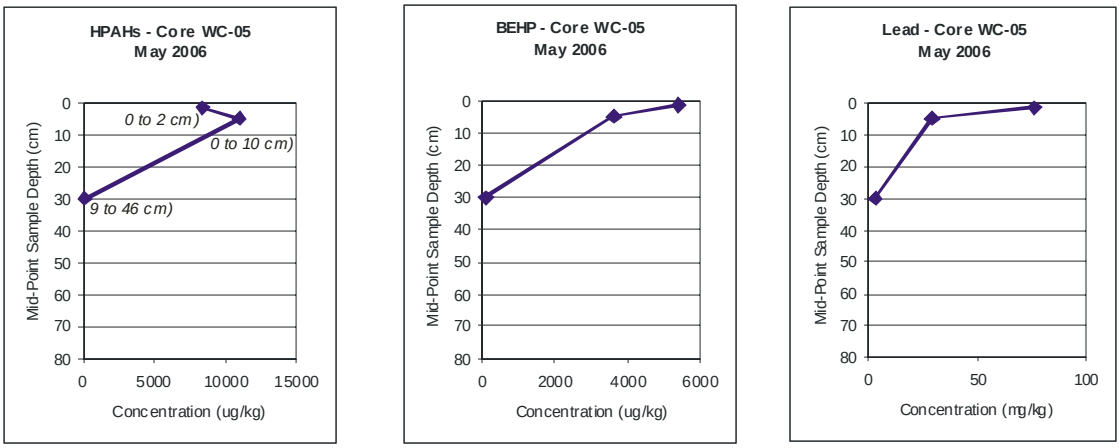

Figure 8. Sediment core to assess sand cap performance – May 2006.

HPAH and BEHP Correlations and Trends

The site specific relationship between HPAH and BEHP can be used to assess the sources of top-down recontamination. Figure 9 shows a regression line fit plot of HPAH and BEHP concentrations for April 2004 (Year 0), May 2005 (Year 1) and May 2006 (Year 2) early warning samples, not including May 2005 samples collected north of the bridge that were most impacted by dredging recontamination. The plots show a high correlation ($R>0.95$) and the line fit plots account for most of the sample variability ($R^2>0.90$). This relationship is interpreted to represent the impacts of stormwater.

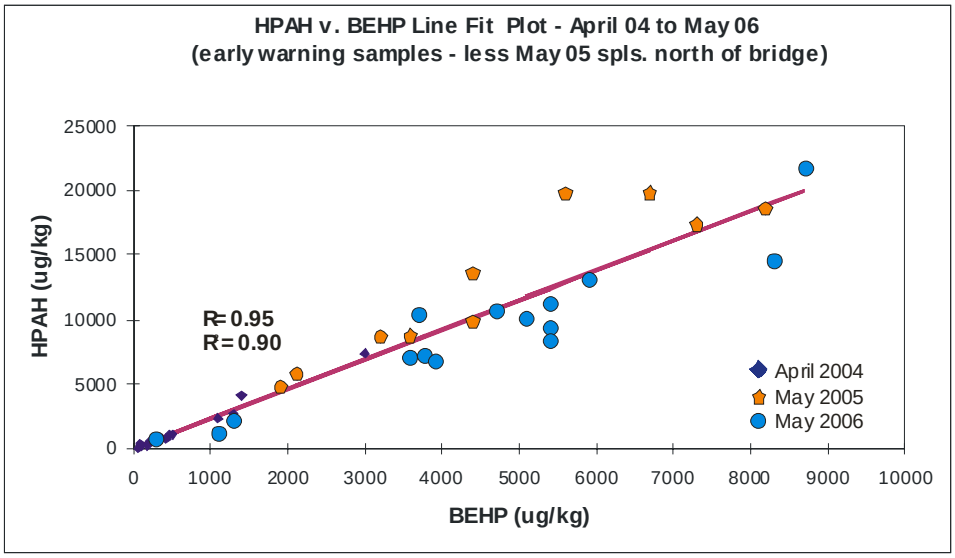

Figure 9. HPAH v. BEHP stormwater relationship.

Figure 10 shows a combined plot for data collected in April 2004, May 2005 and May 2006. Most of the samples trend in a similar manner as illustrated on Figure 9, however, three to five of the samples are enriched with HPAHs as compared to the other samples. These samples were collected during the May 2005 monitoring round within the northern portion of the project area after the dredging recontamination occurred. The dredging disturbed and resuspended deeper sediment deposits that contained coal tar derived DNAPL with relatively higher concentrations of PAHs as compared to stormwater.

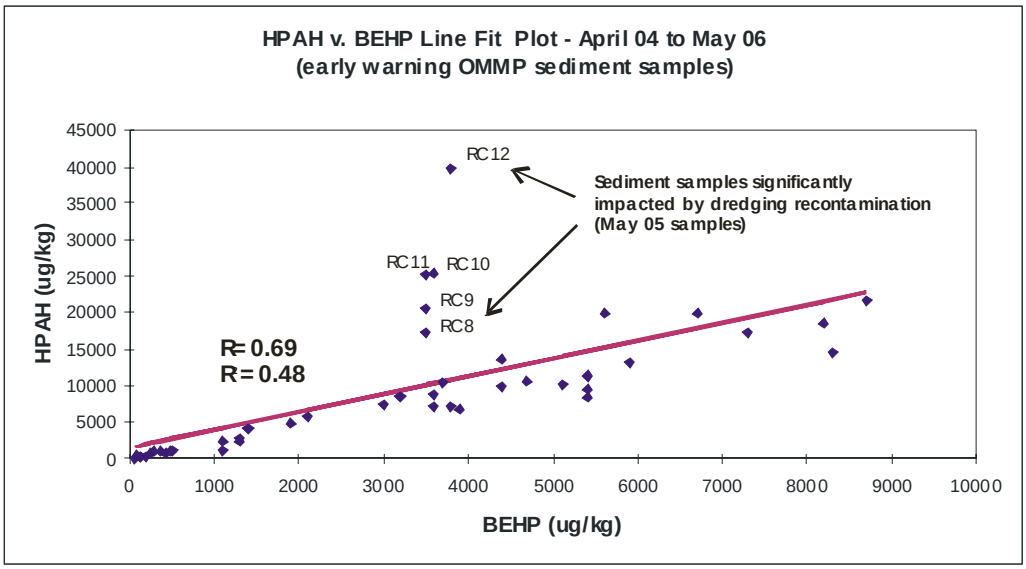

Figure 10. HPAH v. BEHP combined dredging impact and stormwater relationship.

A stormwater source for much of the surface contamination detected during the first 2.5 years of monitoring is also supported by comparing the HPAH v. BEHP stormwater relationship with that of the sediment trap samples. The stormwater relationship shown on Figure 9 is superimposed on a plot of the 2002 to 2005 sediment trap data for the outfalls that discharge to the head of the waterway on Figure 11. This comparison shows that the major outfalls are the primary contributors of stormwater HPAHs and BEHP. Outfalls 237A and 237B drain approximately 95% of the area that contributes stormwater to the project site. The plot of the data also indicates that the smaller outfalls

are enriched with BEHP, as compared to HPAHs, although the data would suggest that their overall contribution to sediment contamination is relatively small.

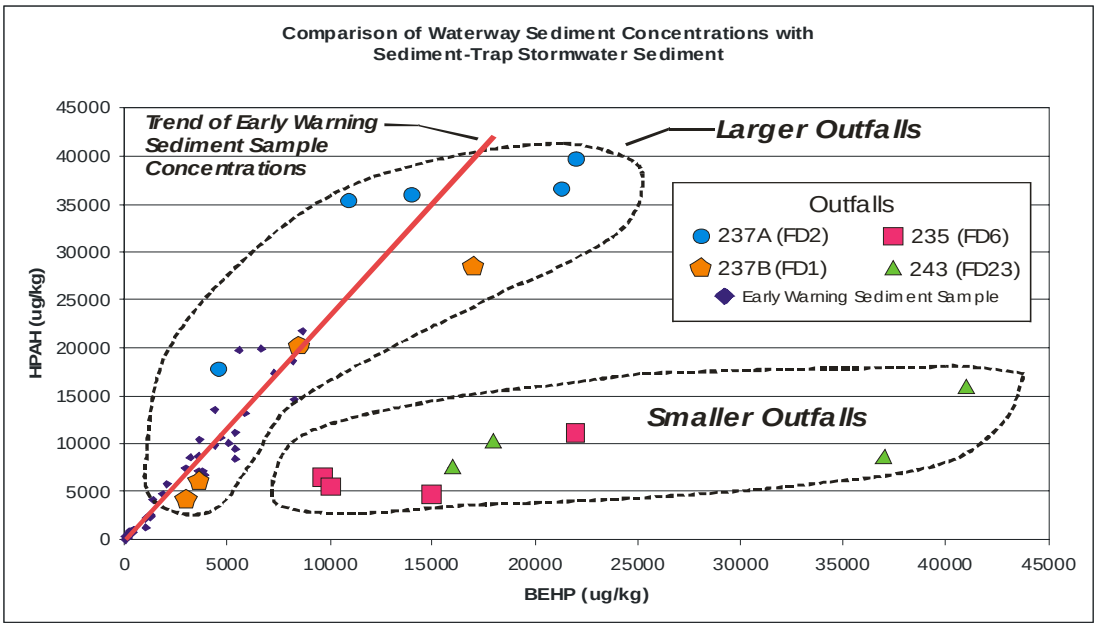

Figure 11 – Comparison of surface sediment and sediment trap - HPAH v. BEHP relationship.

The stormwater relationship between HPAHs and BEHP discussed above is based on data collected between 2004 and 2006. Figure 12 shows the relationship for just the 2004 and 2006, 0 to 2 cm sediment samples. The trend is similar to that shown on Figure 9 and the line fit is a bit better (R^2=0.94 as compared to 0.90) because much of the concentration variability caused by the dredging recontamination has been removed by not including the May 2005 samples. The May 2005 sample set was most affected by the dredging recontamination.

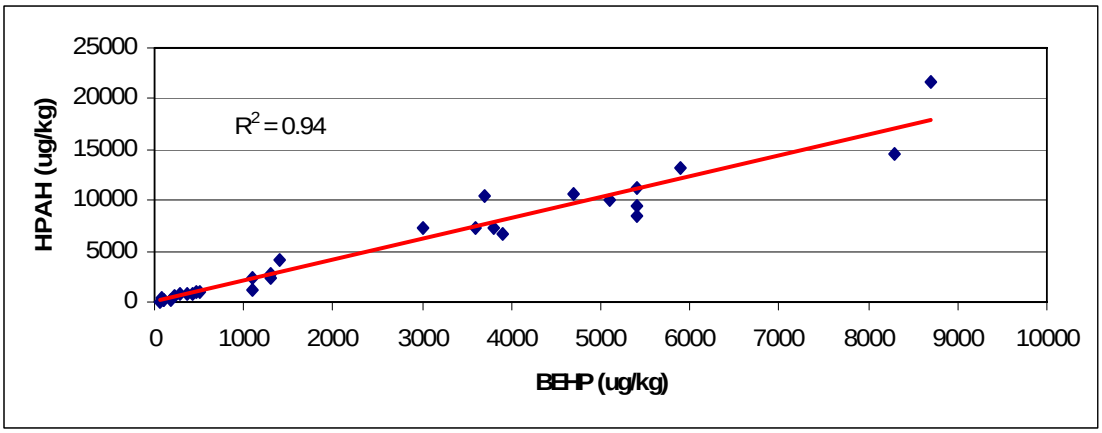

Figure 12. HPAH v. BEHP stormwater relationship -2004 and 2005 sample data.

In 1984 surface sediment samples were collected near the head of the waterway as part of the Commencement Bay remedial investigation (RI) (TetraTech 1985). PAHs and phthalates were analyzed as part of the RI. The results of these analyses are plotted on Figure 13 and show a very similar trend as that shown in Figure 12, using the 2004 and 2006 data. This comparison suggests the primary source or sources contributing HPAHs and BEHP to stormwater have not substantially changed over the past twenty or so years.

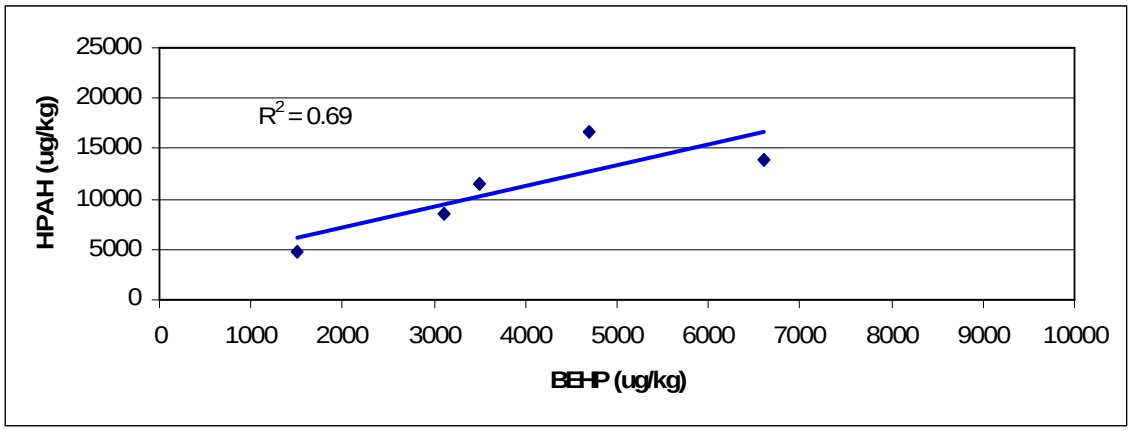

Figure 13. HPAH v. BEHP stormwater relationship - 1984 sample data.

COMPARISON OF PARTICULATE CONTAMINANTS AND CONCENTRATIONS

The May 2006 - 0 to 2 cm - maximum concentrations and the average sediment trap concentrations for the major outfalls that discharge to the head of Thea Foss are summarized in Table 6. Contaminants detected in the sediment trap particulate samples provided an indication of the "*suite*" of stormwater contaminants that would be expected to be found in bottom sediment of the receiving water body. This same suite of contaminants was found in fine grained bottom sediment that had accumulated since the containment cap was constructed.

Table 6. Comparison of maximum 0 to 10 cm sediment (May 2006) and sediment trap concentrations (2001 to 2006).

Contaminant	Bottom Sediment	Outfall 237A (average)	Outfall 237A (max)	Outfall 237B (average)	Outfall 237B (max)
Phenanthrene (ug/kg)	1500	3192	4600	2202	3500
HPAHs[2] (ug/kg)	21481	27450	40020	17505	28830
Bis(2-ethylhexyl)phthalate (ug/kg)	7700	11340	22000	8180	17000
DDT (ug/kg)	<12	12.2	28.6	7.6	12.9
PCBs (ug/kg)	160	80	110	70	197
Lead (mg/kg)	92	86	114	75	129
Zinc (mg/kg)	269	279	365	217	277
Mercury (mg/kg)	0.22	0.06	0.12	0.08	0.16
TPH (heavy oil) (mg/kg)	5100	2320	3700	1910	3000

Once stormwater sediment is discharged to the waterway, concentrations may change by mixing, volatilization, solubilization, and degradation. The effects of these processes will depend on the waterway environment (bottom currents, fresh/salt water etc.) as well as on the properties of the contaminants. For example, metals such as lead do not degrade and have very low solubility in most natural environments, while compounds such as benzene are relatively more soluble and degrade readily in many natural environments. With respect to Thea Foss, a relatively large area (almost 2,000 hectares) drains into a small (3.6 hectares), low energy aquatic environment. In the head of Thea Foss, Norton (1993) estimated current velocities of less than approximately 4 cm/sec, 90% of the time.

Figure 14 shows a comparison of the maximum bottom sediment concentrations detected in 0 to 10 cm compliance samples with average sediment trap concentrations for HPAHs, BEHP and lead. The maximum surface sediment concentrations compare well with the average sediment trap concentrations. Bottom sediment concentrations generally declined with increasing distance from the head of the waterway.

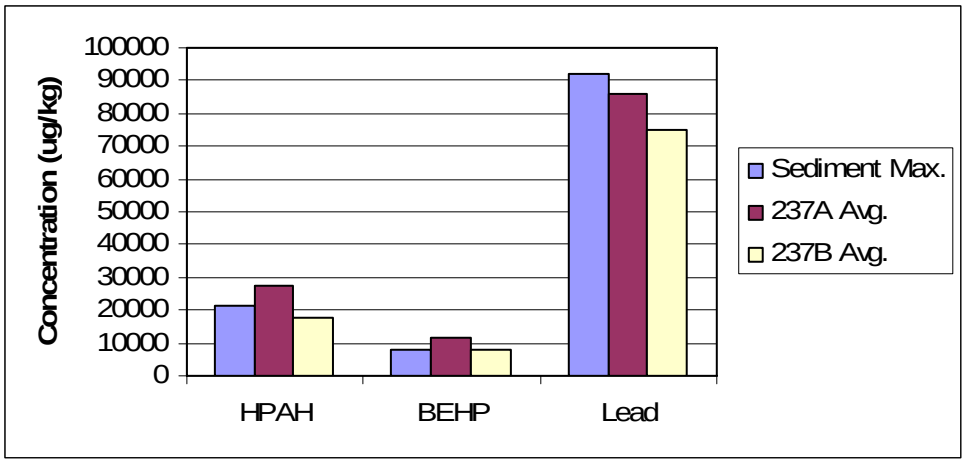

Figure 14. Histogram of bottom sediment and sediment trap concentrations.

CONCLUSIONS

Design of a monitoring system to assess the effectiveness of a sediment remedy needs to consider potential sources as well as the nature of the potential recontamination. In the Thea Foss Waterway, potential sources included a coal tar derived DNAPL seep, contaminated sediment being contained by an engineered cap and stormwater. These sources can generally be classified as bottom-up sources (DNAPL seep and previously contaminated sediment) or top-down sources (stormwater discharges). The contaminants of concern included metals, PAHs, phthalate esters, pesticides and PCBs. These contaminants are hydrophobic in nature and are generally associated with contaminated particulates.

Collection of sediment quality data indicated that recontamination of the engineered cap surface began soon after it was installed and exceeded sediment quality objectives within approximately 2.5 years. The monitoring program included physical observation of the DNAPL seep and collection of surface and core sediment samples. Surface sampling included early warning sediment samples (0 to 2 cm) and compliance sediment samples (0 to 10 cm). Recontamination was detected in the surface sediment samples that consisted of a fine grained sediment that had accumulated on the engineered cap surface. Physical observations and the sediment core samples indicated that the engineered cap was functioning as designed and intended. Sediment core data, the suite of contaminants detected in surface sediment and concentration correlations and trends indicated recontamination from a top-down stormwater source.

Comparison of in-line stormwater sediment trap samples with recontaminated bottom sediment indicated a similar suite of contaminants generally associated with stormwater particulates. The correlation and trends of HPAHs and BEHP concentrations indicate the primary source of recontamination were the primary stormwater outfalls that discharge to the head of the Thea Foss Waterway. Without control of the particulate discharges from these outfalls, recontamination will likely continue.

Sediment trap data provide valuable insights on the potential nature of stormwater recontamination sources. However, the impacts of such discharges will depend on the environment where the discharges occur, and on the number and magnitude of the discharge sources, etc. In situations where particulates are potentially being discharged to a water body, it is recommended that the point of compliance be bottom sediment in the water body.

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