Appendix A-1. Puget Sound Sediment Monitoring Program findings

Findings from the Puget Sound Sediment Monitoring Program's Historical, Long-term, Spatial, and Urban Waters Initiative elements, from the program's inception in 1989 through 2015, are summarized below. Full reference to all documents and their associated web links can be found in Appendix A-2.

Historical Monitoring, 1989-1995 (Llansó, et al., 1998a,b)

Sediments were collected and tested for a suite of Sediment Quality Triad parameters at 76 stations throughout Puget Sound; 34 sampled annually, 42 sampled on a three-year rotational schedule in north, central, and south Puget Sound. The majority of these stations were intentionally located at a distance from known sources of contamination (Striplin et al., 1988).

Findings included:

- **Chemical concentrations generally low, highest in urban bays**
  - **Low detection:** Chemical contaminant concentrations were generally low and below Washington State sediment regulatory standards.
  - **Mercury standards exceeded in Sinclair and Dyes Inlets**: Mercury concentrations were above standards in Sinclair and Dyes Inlets for each of the seven years.
  - **Urban influence:** Highest metal and organics concentrations were found in stations located in urban and industrial centers. Low metals concentrations were found in some rural and deep depositional areas.
  - **No trends:** No obvious trends in sediment quality were detected over the seven years examined.
- **Sediment toxicity with no patterns, data compromised**
  - **No trends:** A 10-day amphipod bioassay indicated significant mortality at some urban and rural stations, but no consistent patterns were observed.
  - **Problems with test:** Compounding environmental variables (e.g., grain size) were not controlled for, and may have contributed to the test's sensitivity.
- **Benthos broadly distributed**
  - **Habitat influence:** Benthos community composition was primarily related to sediment composition and water depth, secondarily to geographic location.
  - **Broad species distribution:** The majority of organisms were not restricted to one substrate, but were broadly distributed with peaks of abundance in sand, mixed sediment, or mud.

- **Terminal inlets and bays:** Some stations, located in upper reaches of inlets, semi-enclosed bays, and depositional locations associated with river plumes, displayed consistently low species richness and abundance. These locations have the potential for low dissolved oxygen episodes in bottom waters and accumulation of sulfide in sediments.

- **Lack of Sediment Quality Triad correspondence**

  - **Low correspondence between parameters:** Spatial patterns in species abundance and composition appeared to be unrelated to contaminant concentrations at most sampling locations.

Long-term Monitoring, 1989-2000 (Partridge et al., 2005), 1989-2016 (Partridge et al., 2018)

Ten of the 76 Historical Monitoring stations were selected for continued monitoring from 1997 through the present. They were selected because they represent unique habitat types and benthos assemblages throughout Puget Sound, and because many are co-located with the PSEMP Marine Waters and the Toxics in Biotic Systems monitoring programs. Chemical testing occurred annually through 1996, then on a roughly five-year cycle, including 2000, 2005, 2010, and 2016. Toxicity testing was dropped from these analyses. Benthos were sampled annually (Dutch et al., 2009). Findings for 28 years of monitoring, summarized in Partridge et al., 2017, include:

- **Chemical concentrations**

  - **Low detection:** Other than metals and polycyclic aromatic hydrocarbons (PAHs), few contaminants were measurable above detection limits.

  - **Urban influence:** Four of the ten long-term stations are located in urbanized bays and have higher chemical contaminant concentrations than the six stations which are more removed from urban influences.

  - **Standards exceeded:** Sediment contaminant concentrations exceeded Washington Sediment Management Standards (SMS) for mercury at Sinclair Inlet and PAHs at Thea Foss Waterway.

- **Sediment-dwelling invertebrate community composition**

  - **Benthos relatively stable:** Sediments and the invertebrate communities inhabiting them have largely remained stable over time, though with some drift and cycles in species composition and abundance. Distinct assemblages were found at each of the ten stations.

  - **Localized benthos shifts have occurred:** Some communities, including those sampled in urban Sinclair Inlet and the Thea Foss Waterway, and the more rural Anderson Island and the Strait of Georgia experienced profound shifts in species composition at specific points in time. These changes may have been in response to cleanup activity in the urban locations or influence from pressures such as river flow, changes in grain size, or other habitat characteristics at specific points in time.

- **Benthos function impacted by shifts:** In stable conditions, such as at the bottom of the deep Central Basin of Puget Sound, the feeding guilds were essentially constant proportionally, even though the species and abundances in each guild varied from year to year. In impacted communities, such as Sinclair Inlet, however, there was considerable variability in the feeding guilds over time.

- **Sediment Quality Triad relationships**

  - **Low correspondence between parameters:** Little to no relationship was found between sediment contaminant levels and the benthic communities for most stations. For two stations with persistent contaminant concentrations higher than the SMS, those particular contaminants were weakly correlated with the benthos.

  - **Benthos structure tied to habitat characteristics and season:** The primary determinants of invertebrate communities are habitat variables such as depth and grain size. The date of sampling also had a small effect on community composition.

Spatial Monitoring

- 1997-1999 Regional, Strata, Puget Sound-wide Baseline (Long et al, 2003, 2005)

Surficial sediments were collected from 300 randomly chosen locations throughout Puget Sound as part of joint monitoring between the Sediment Program and the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends (NS&T) program. The sampling frame encompassed a 2363 km^2 area extending from the U.S./Canada border to the inlets of southern Puget Sound and Hood Canal. The study was designed to characterize the severity, spatial patterns, and spatial extent of sediment quality degradation as measured with the Sediment Quality Triad parameters. A sediment quality spatial baseline was established for these parameters and this time period for a nested set of sampling frames, including six geographic regions, five strata defined by their geomorphology and degree of anthropogenic use, and a Puget Sound-wide sampling frame (Dutch et al, 2009).

Puget Sound-wide sediments were characterized as follows:

- **High quality (68%):** Sediments with high quality (as indicated by no toxicity, no contamination, and the presence of a relatively abundant and diverse infauna) occurred in samples that represented a majority (68%) of the total study area.

- **Intermediate quality (31%):** Sediments in which results of the three kinds of analyses were not in agreement were classified as intermediate in quality and represented about 31% of the total area.

- **Degraded quality (~1%):** Degraded sediment quality, as indicated by a combination of high chemical concentrations, significant toxicity, and adversely altered benthos, occurred in samples that represented about 1% of the total area. These conditions occurred in samples collected within urbanized bays and industrial waterways, especially near the urban centers of Everett, Seattle, Tacoma, and Bremerton.

- ***2002-2003 Additional Regional Baseline (Long, et al., 2008)***

The spatial survey was continued in 2002 and 2003 to establish a sediment quality baseline for two additional regions, the bays and inlets of the San Juan Islands and the Eastern Strait of Juan de Fuca, and to augment the Admiralty Inlet regional sampling frame.

The Sediment Quality Triad of chemistry, toxicity, and benthos measurements indicated sediments with:

- **High quality (67% in Admiralty Inlet):** Highest sediment quality was measured in Admiralty Inlet (67% of area).

- **Intermediate quality (70%, 71% San Juan Islands, Eastern Strait of Juan de Fuca):** The majority of the sediments measured in the San Juan Islands and the Eastern Strait of Juan de Fuca (70 and 71% of each area, respectively) were of intermediate quality.

- **Degraded quality (0%):** No sediments were of degraded quality in any of the three regions.

- ***2004-2014 Regional, Strata, Puget Sound-wide Second Round (Weakland et al., 2018a,b)***

A second round of sediment quality spatial characterization was conducted between 2004 and 2014. A different region was sampled in each of eight years during this time span. A refined set of sediment chemistry, toxicity, benthos, and SQT index classifications and thresholds (Appendix B - Dutch et al., 2014; Long et al., 2012) was used to reclassify sediment condition for comparison with the 1997 – 2003 Baseline. Changes over time were identified for the nested set of eight regions, five strata, and the full Puget Sound sampling frame.

Reports for each of the eight monitoring regions were generated, including:

- *1999, 2004 Hood Canal (Long et al., 2010)*

- *1997, 2006 Strait of Georgia (Partridge et al., 2012)*

- *1997, 2007 Whidbey Basin (Partridge et al., 2013)*

- *2008-2009 Central Sound (Partridge et al., 2013)*

- *2011 South Puget Sound (Partridge et al., 2014)*

- *2012 San Juan Islands (Partridge et al., 2014)*

- *2013 Eastern Strait of Juan de Fuca (Weakland, 2015)*

- *2014 Admiralty Inlet (Weakland, 2016)*

Data for regions, strata, and the Puget Sound sampling frames are summarized in Weakland et al., 2018. The following was observed:

- **Toxic chemicals in low concentrations and declining:** The Chemistry Index indicated that the majority (94%) of the Puget Sound study area had *minimum* exposure to the 39 chemicals incorporated into the index. Sediments with *moderate* to *maximum* exposure were generally confined to Harbor and Urban strata. Toxic chemicals monitored in sediments generally declined in concentration and occurrence between the Baseline and Second Round surveys.

- **Toxicity increased, but not in response to chemistry:** The Toxicity Index indicated that the majority (80%) of the sediments Puget Sound-wide were non-toxic. Increases in *low* and *moderate toxicity* were observed with the Toxicity Index. Sediment with *moderate* and *high* toxicity were located near the heads of terminal inlets and areas known to have poor water circulation in both urban and non-urban locations. Toxicity responses were generally not in correspondence with the chemical parameters measured in this survey.

- **Benthos condition declined:** The area of Puget Sound with benthic communities considered *adversely affected* by natural or anthropogenic stressors has significantly increased (35% to 44%) since the 1997–2003 Baseline survey. Additionally, the abundance of taxa sensitive to disturbance has declined while tolerant taxa have increased.

- **Sediment Quality Triad - Majority of sediments unimpacted/likely unimpacted, but quality declining:** Sediment quality was characterized by the Sediment Quality Triad Index as *unimpacted* or *likely unimpacted* by anthropogenic or natural pressures in the majority (86%) of sediments Puget Sound-wide in the Second Round survey. This was a significant decline from 95% measured during the Baseline survey. These changes were due primarily to increases in sediment toxicity and degraded condition of the benthos as reflected in declining Benthic and Toxicity indices.

- **Lack of Triad correspondence:** Benthos declines do not appear to be strongly correlated to changes in measured chemical concentrations or toxicity test results.

- **Impacts in terminal inlets and bays:** The SQT indices suggest a spatial gradient of improving sediment quality from inner to outer bay or inlet. Impacted sites are primarily confined to terminal inlets and bays of Puget Sound, in areas with sluggish water circulation and known low dissolved oxygen and high sulfide conditions. These findings are similar to conclusions drawn during Historical Monitoring, 1989-1995 (Llansó, et al., 1998a,b).

Urban Bay Monitoring, 2007-present

From 2007 through the present, sediment quality monitoring has been conducted in six urban bays on an annual rotational cycle as an extension of the Spatial Monitoring element. As with Regional monitoring, the Urban Bay monitoring is designed to characterize the severity, spatial patterns, and spatial extent of sediment quality degradation as measured with the Sediment Quality Triad parameters. These Urban Bay sampling frames are nested within Regional and Puget Sound-wide frames, allowing comparison between frames. Spatial characterization is generated annually, and changes over time are compared over approximately six-year intervals when each bay is resampled. Urban Bay data are also compared with Baseline data when enough stations were sampled within a bay during Baseline monitoring (Dutch et al, 2009).

Reports summarizing findings for each of the six urban bay sampling frames were generated, including:

- *Elliott Bay - 1998, 2007, 2013 (Partridge et al., 2009; Weakland et al., 2016)*
- *Commencement Bay – 1999, 2008, 2014 (Partridge et al., 2010; Weakland et al., 2016)*
- *Bainbridge Basin – 1998, 2009, 2015 (Weakland et al., 2013; Weakland et al., 2017)*
- *Bellingham Bay – 1997, 2006, 2010 (Weakland et al., 2013)*
- *Budd Inlet – 2011 (Partridge et al., 2014)*
- *Port Gardner/Everett Harbor - 2012 (Partridge et al., 2014)*

Characteristics for urban bays based on the Sediment Quality Triad indicators are captured below.

- **Toxic chemicals below target in Elliott Bay and Commencement Bay, but improved over time:** Of the six urban bays monitored for sediment quality, chemical contaminant measurements were highest in Elliott Bay and Commencement Bay. The weighted mean Chemistry Index calculated for each bay in 1998 and 1999, respectively, did not reach the Puget Sound Partnership recovery target value of 93.3. Each bay, resampled twice, has shown significant improvement over time, with Commencement Bay reaching the recovery target value in both 2008 and 2014. The Chemistry Index calculated for sediments from the four other urban bay sampling frames, Bainbridge Basin, Bellingham Bay, Budd Inlet, and Pt. Gardner/Everett Harbor, met recovery targets with 66-80% of the survey area characterized as having sediments with minimum exposure to toxic contamination.

- **Toxicity increased and highest in terminal bays with poor circulation and water quality problems:** The Toxicity Index indicated that 79 to 93% of the study area in Elliott Bay, Commencement Bay, and Pt. Gardner/Everett Harbor was non-toxic, with an increase in low toxicity over time. A lower percentage of the study areas in the Bainbridge Basin (66%), Bellingham Bay (37%), and Budd Inlet (27%) were characterized as non-toxic. Toxicity in these three bays did not correspond with chemical contamination; instead toxicity seemed to correspond with patterns of sluggish water circulation and suspected areas of low dissolved oxygen and high sulfide conditions in these enclosed terminal inlets.

- **Benthos condition varied among bays and over time; poor in terminal bays with poor circulation and water quality problems:** The Benthic Index indicated condition of the benthos varied with 30-53% of the Elliott Bay study area having *adversely affected* (i.e., by natural or anthropogenic stressors) benthos between 1998 and 2013 with no significant change over time. A significant increase from 14 to 34% of area was observed in Commencement Bay (1999-2014) and 9 to 29% in the Bainbridge Basin (1998-2009). 33% of the Pt. Gardner/Everett Harbor area had adversely affected benthos, primarily in the mouth of Ebey Slough and in the Snohomish Delta. Adversely affected benthos were characterized in 79% and 100% of Budd Inlet and Bellingham Bay, respectively.

In some cases, poor benthic condition occurs in areas of highest chemical contamination (Elliott Bay, Commencement Bay, Sinclair Inlet in the Bainbridge Basin), but more often, as with toxicity, benthos patterns do not correspond with chemical measures. Instead, correspondence occurs with patterns of sediment disturbance such as fine grain sediment deposition in the Snohomish Delta and sluggish water circulation and suspected areas of low dissolved oxygen and high sulfide conditions in enclosed terminal inlets including Bellingham Bay and Budd Inlet.

- **Sediment Quality Triad – Varied among bays and over time; influenced by increasing toxicity and declining condition of the benthos:** The weighted mean Sediment Quality Triad Index calculated for each bay during Baseline and subsequent surveys reach the Puget Sound Partnership recovery target value of 81 for Elliott Bay (significant increase over time), Commencement Bay, Bainbridge Basin, and Pt. Gardner/Everett Harbor. Values calculated for Bellingham Bay and Budd Inlet fall far under the target value, influenced heavily by the poor condition of the benthos and detection of toxicity. The percent of area in these two bays with impacted sediments was 63% and 70%, respectively, as compared with Pt. Gardner/Everett Harbor (4%), Commencement Bay (6%), Elliott Bay (12%), and the Bainbridge Basin (24%).

- **Lack of Triad correspondence:** Benthos declines do not appear to be strongly correlated to changes in measured chemical concentrations or toxicity test results.

- **Impacts in terminal inlets:** The SQT indices suggest a spatial gradient of improving sediment quality from inner to outer bay or inlet. Of the six bays that were monitored over time, the two that displayed the highest percentage of area of impacted sediment quality were two terminal inlets with poor water circulation and high nutrient input.