Appendix C
Analysis of Appropriate Sediment Background and Reference Area for Port Angeles Harbor, Washington
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Introduction

As part of public comment on the Port Angeles Harbor Sampling and Analysis Plan (SAP), questions have arisen regarding reference and background areas for the Harbor. The terminology and regulatory uses of the various kinds of background and reference areas are often complex, and the kinds of information needed to select appropriate background and reference areas are different. This paper addresses the types of background and reference areas that may be used and how they will be defined and the rationale for selection for the Port Angeles Harbor sediment investigation.

Definitions and Uses of Background and Reference Areas

Three types of areas are defined and used by various regulatory programs:

- **Natural Background –** Natural background is defined by the Model Toxics Control Act (MTCA) at WAC 173-340-200. It includes concentrations of chemicals that are naturally occurring, as well as concentrations of man-made chemicals that are globally distributed at low levels, such as PCBs, dioxins, and some radioactive isotopes.

  Natural background concentrations are used for a variety of purposes. For example, if a bioaccumulative chemical has a risk-based concentration that is below natural background, the cleanup standard for that chemical under the Sediment Management Standards is set at natural or "nonanthropogenic" background. Because risk-based standards for dioxin are typically below background, this is particularly important for Port Angeles Harbor and the Rayonier site.

- **Area Background –** Area background is also defined by the Model Toxics Control Act at WAC 173-340-200. It includes somewhat higher levels of contaminants "consistently present in the environment in the vicinity of a site which are the result of human activities unrelated to releases from that site."

  Area background can be used under MTCA as a cleanup standard if it can be demonstrated that area background is higher than natural background, and that cleanup to natural background cannot be achieved. Institutional controls and monitoring may be required if area background is used to set cleanup levels. There is no equivalent concept in the Sediment Management Standards.

- **Reference Area –** Reference areas are not defined in the Model Toxics Control Act or the Sediment Management Standards by rule. Reference areas were originally identified by the Puget Sound Estuary Program (1991) for the purposes of identifying clean comparison areas for bioassay testing. While few specific areas have been agreed upon in the scientific community, several important characteristics of potential reference samples have been agreed on (MMC 1988; Ecology 1988; Michelsen & Striplin 2000; SEA 1996, 2003). These include:

1. The site should be located away from significant anthropogenic activity
2. Anthropogenic chemicals of concern should be below the Washington State SQS
3. The physical characteristics of the reference site must be similar to that seen in the test area (e.g., points, headlands, water depth, currents, wave action)
4. The sediment grain size and organic carbon content at the reference site must be similar to that at the test site

While reference areas have not been established or defined in the SMS, a definition of a reference sediment sample corresponding to the above four points is included in the definitions section at WAC 173-204-200(22).

Identification of Natural and Area Background Concentrations for Port Angeles Harbor

Natural and area background concentrations are critical for understanding the distribution of and setting cleanup standards for dioxins/furans and other bioaccumulative compounds in Port Angeles Harbor. These two types of background will be assessed as follows:

- **Natural Background.** By definition, natural background is not a site-specific or area-specific concentration. It includes only natural concentrations (such as dioxins from forest fires) or globally distributed concentrations (such as those carried atmospherically from other areas of the world). A group of federal and state agencies (Ecology, DNR, EPA, Corps, and the Puget Sound Partnership) are currently working together to collect all existing dioxin/furan data, and are conducting a field sampling effort in August, 2008 to collect 70 additional dioxin/furan/PCB congener samples (as well as other standard chemicals of concern) from reference areas and non-urban areas of Puget Sound. These efforts will provide a data set that will assist in defining non-urban, reference, and background concentrations in Puget Sound and the Strait of Juan de Fuca.

- **Area Background.** As part of the Port Angeles Harbor Sampling and Analysis Plan (SAP), stations have been placed along the outer edge (eastern part) of the harbor, as well as in the reference areas described above, to evaluate area-wide concentrations of dioxins/furans and other CoCs. These stations will help determine whether there are area-wide elevations of these compounds above the natural background concentrations being developed as described above, or whether concentrations outside the Harbor and localized site sources approach natural background levels.

Selection of a Reference Area for Port Angeles Harbor Studies

The current issue is whether Dungeness Bay, Freshwater Bay, or Sequim Bay would provide the best reference site for Port Angeles Harbor. It should be noted that reference areas are used for **bioassay testing only**. They are not relevant to bioaccumulative compounds such as dioxins/furans, which are assessed through tissue concentrations and risk assessments rather than bioassay tests. Dioxins/furans in particular are not toxic to benthic invertebrates, which lack the Ah receptor through which dioxin/furan toxicity is expressed, and therefore the concentrations of dioxins in these bays is not an issue for selection of a reference area for bioassay testing.

Comparing the sites to the first criterion it is clear that both Freshwater and Dungeness Bays are located away from significant anthropogenic activity, and both locations have large rivers that empty into the surrounding marine environment. Sequim Bay, while not influenced by industrial activity, receives road runoff, is surrounded by private homes that are serviced by onsite septic systems, and is the location of the John Wayne Boat Marina. While Sequim Bay has been used as a site to collect reference sediment for toxicity testing in the past, the presence of the marina, non-point sources, and on-site septic systems, and the restricted flow of seawater at the entrance to the Bay, suggest that it is not an optimal sediment reference location for Port Angeles Harbor. In addition, the existence of mats of the filamentous bacteria *Beggiatoa* spp. has been reported in Sequim Bay. These bacterial mats tend to grow in nutrient rich sediments where low dissolved oxygen levels have led to the formation of sulfide compounds that could confound toxicity testing results.

The third criterion suggests that the reference and test areas have similar physical characteristics. Dungeness Bay is physically very similar to Port Angeles Harbor. Both embayments are protected by a spit of land from the strong currents in the Strait of Juan de Fuca and both have inputs of water and organic rich sediment from creeks and rivers. While Freshwater Bay also has a source of sediment from the Elwha River, the sediment tends to be coarse and the fines that are present are carried away by the longshore current into the Strait of Juan de Fuca. Sequim Bay is a semi-enclosed embayment with no rivers or creeks entering it, thus recent sediment arrives through runoff from the surrounding hillsides. Due to poor water circulation, portions of the Bay periodically experience low dissolved oxygen, unlike Freshwater and Dungeness Bays.

The fourth criterion calls for the test and reference locations to have similar grain size and organic carbon content. This is perhaps the most important criterion, because benthic invertebrate communities are highly structured by sediment type and the amount of organic material available as a food source. The ultimate goal of a reference area is to provide samples/data that may be protective of these benthic invertebrate communities and the demersal fish populations which use them as a food source. These groups, which represent two of the lowest trophic levels, may be the first to be affected by anthropogenic activity, thus the reference area should reflect the condition of the test area prior to the introduction of the activity that caused the impact. While no quantitative data are available to characterize the sedimentary environment in Port Angeles Harbor prior to its industrialization, inferences can be made by examining its physical characteristics and those of the proposed reference sites and then by examining sediment grain sizes and organic carbon content to find similarities among the proposed locations.

Statistical Comparison of Conventional Parameters in Potential Reference Areas

To this end, data from sediment sampling stations in Port Angeles, Freshwater, Sequim, and Dungeness Bays were examined to determine whether there are statistically significant differences in the percent fines (combined percent of silt and clay) and in the total organic carbon content of the sediment (Zar 1984; MS Excel 2003; Systat 2004).

To reduce the inherent variability in the data, each station in an embayment was considered to be a replicate sample from that embayment and summary statistics were calculated accordingly. This enables us to generally characterize a large area with a greater certainty than the variability is being accounted for. A similar approach was used to characterize the chemical and biological conditions at potential reference areas in Puget Sound (SEA 1996); by the Capital Regional District of the City of Victoria, B.C. to identify reference areas for comparison to chemical and biological conditions at their sewage outfall in the Strait of Georgia (SEA 2001, 2002); and is currently being used by the Department of Ecology's Sediment Ambient Monitoring Program to characterize benthic infaunal communities over large areas in Puget Sound.

The stations within each study area were not located based on a random sampling design, but were located to specifically identify areas were chemicals of concern may be located or to characterize sediment conditions for a potential reference site. However the spatial distribution of these stations encompassed large portions of their respective study areas, allowing a better characterization of the areas as a whole. The exceptions to this were the samples from Sequim Bay. The majority of data for sediments from Sequim Bay were taken from an area that was specifically located to act as control sediment for fine grained sediment toxicity tests. Thus the use of the Sequim Bay data would unduly bias the results of any analysis in favor of Sequim Bay. Even though these sediments have been used as control sediments there have been SQS hits and toxicity test control failures in Sequim Bay sediments (Michelsen 2008). For this reason and the presence of the marina, on-site septic systems, the restricted seawater circulation at the entrance to the Bay, and the presence of mats of the filamentous bacteria *Beggiatoa* spp. it was decided to remove Sequim Bay from further consideration as a potential reference site.

***t*-Test Results**

The tests conducted included a two sample t-test assuming unequal variances between the following categories:

Dungeness Bay versus Port Angeles Harbor
Freshwater Bay versus Port Angeles Harbor
Dungeness Bay versus Freshwater Bay

Table 1 shows the results of the t-test comparing the parameters of interest among the embayments.

Area	Freshwater Bay	Port Angeles		

	Mean	Mean	p (1-tail)	p (2 tail)
Total Organic Carbon	0.36	3.75	0.0000	0.0000
Percent fines	1.75	61.8	0	0
Area	Dungeness Bay	Port Angeles		
	Mean	Mean	p (1-tail)	p (2 tail)
Total Organic Carbon	0.7	3.8	0.0000	0.0000
Percent fines	28.2	61.8	0.006	0.011
Area	Dungeness Bay	Freshwater Bay		
	Mean	Mean	p (1-tail)	p (2 tail)
Total Organic Carbon	0.7	0.36	0.031	0.0621
Percent fines	28.2	1.75	0.017	0.034

The results in Table 1 indicate that Freshwater Bay, located to the west of Port Angeles, has a much coarser sedimentary environment than Port Angeles or Dungeness Bay. The mean TOC at Freshwater Bay was 0.36 percent with a percent fines of 1.75; compared to 0.7 percent TOC and 28.2 percent fines at Dungeness Bay, and 3.8 percent TOC and 61.8 percent fines at Port Angeles. Typically low amounts of TOC and percent fines characterize erosional environments where wave action and tidal currents do not allow fine particulate material to settle from the water column; and greater amounts of each reflect anthropogenic activity at Port Angeles Harbor and the accumulation of organic material and sediment trapped behind the spit at Dungeness Bay.

Regression Analysis

Multiple regression analysis was conducted to examine the relationship between the organic content in the sediment and the percent fine grained material in each study area. A strong regression coefficient indicates a close relationship between the amount of TOC and percent fines. For example, a high coefficient may indicate a thorough mixing of TOC with silts and clays in the environment and that the input of this material is constant/consistent in arrival at the site; while a weak relationship may indicate that the organic material and/or silts and clays arrive in the area sporadically or that the organic material is larger thus physically and chemically difficult to break down. The regression relationship between percent fines and total organic carbon was strongest at Dungeness Bay with an r^2 of 0.865. This indicates that 86.5 percent of the variability in the organic carbon content of the sediment can be explained by percent fines. The regression coefficients at Freshwater Bay and Port Angeles were much lower. The r^2 value at Freshwater Bay was 0.102 and at Port Angeles was 0.026. In Port Angeles Harbor, the lack of correlation between percent fines and TOC may be related to the large amounts of anthropogenic woody debris present in that harbor.

In addition to percent fines the amount of sand at the potential reference sites were examined to further characterize the sites. Freshwater Bay contained a higher percentage of coarse and medium sand than was seen at the other locations, Port Angeles Harbor consisted of fine sand while Dungeness Bay of medium and fine sand.

Table 2 shows the regression relationship between Percent TOC and percent fines.

Regression Statistics	Dungeness Bay	Freshwater Bay	Port Angeles
Multiple R	0.930	0.319	0.454
R Square	0.865	0.102	0.206
Adjusted R Square	0.850	0.002	0.166
Standard Error	0.179	0.287	1.913

Chemicals of Concern

Low concentrations of several metals, PAHs, and PCBs have been detected in both Freshwater and Dungeness Bay sediments (E & E 1998; Malcolm Pirnie 2007). Chemical contaminants adsorb to sediment particles based on the composition of the sediment and on its surface to volume ratio. The smaller a particle, the greater the amount of a chemical that can be adsorbed to its surface based on its volume. This implies that an area with predominantly silt and clay sediments would adsorb larger amounts of a chemical than an area with gravel and sand sediments. Thus it is not surprising that some chemicals of concern were detected in the finer grained sediments at Dungeness Bay.

The large particle sizes of sediment found in Freshwater Bay indicate an extremely dynamic environment where levels of chemicals of concern should be undetected. Yet, available data indicate that PCBs and some dioxin compounds have been found there in the past. The herbicide 2,4,5-T (agent orange), which contains dioxin as an impurity, was reportedly used to clear vegetation around facilities associated with the Elwha River dams (Gardner, W. 2008 pers. comm.). In addition, trace concentrations of PCBs have been found in previous investigations around some of the Elwha Dam facilities (E & E 1999) and the Elwha River is listed as an impaired waterway under Section 303(d) of the Clean Water Act for PCBs. This information suggests that the Elwha River is a possible source of PCBs and dioxins to Freshwater Bay. Furthermore, assuming that the plan to remove the Elwha River dam facilities proceeds, the possibility exists that Freshwater Bay could become more contaminated through flushing of river sediment material and therefore, the bay would be lost as a future reference location.

Current Tendencies

To quantify the transport of potential contaminants from sources in Port Angeles Harbor to Dungeness Bay is a difficult undertaking. A simple estimate of transport between these two points requires numerous assumptions about tidal characteristics, freshwater input from large adjacent rivers (Fraser & Skagit), mixing, stratification, wind and waves. Recent research indicates that strong eastward currents are common along the north shore of the Olympic Peninsula, termed the Olympic Peninsula Countercurrent (Thomson et al. 2007). However, there several factors that make efficient transport of concentrated contaminants from Port Angeles Harbor to Dungeness Bay unlikely:

Tidal eddies - Both Port Angeles Harbor and Dungeness Bay exhibit tidal eddies. These eddies have been documented by several earlier studies. These studies have shown that the eddies have a tendency to isolate the waters of the harbor and bay from water in the outer Strait of Juan de Fuca. To transport contaminants from Port Angeles Harbor to Dungeness Bay, contaminated water must leave the Port Angeles Harbor eddy, join the main current in the Strait of Juan de Fuca, and then leave that main current to enter the eddy in Dungeness Bay. While possible, this would require unusual timing of different physical processes. The process of transport between these eddies would coincide with intense mixing, significantly diluting any potential contaminants in the water column.

Geomorphic evidence of westward transport - At depths influenced by waves (depths < 50 feet), transport is dominantly westward at the mouth of Port Angeles Harbor. This condition was observed during the Sediment Trend Analysis fieldwork conducted in April, 2008 for the Port Angeles Harbor sediment investigation, and is consistent with additional observations made by team geomorphologists of sediment transport in the intertidal and shallow subtidal areas of the Harbor.

Reversibility of the current field - The same work that discovered the Olympic Peninsula Countercurrent, also documents the extreme temporal variability in the currents in the Strait of Juan de Fuca. It is not uncommon for the current to reverse its direction or stop altogether. Because the strong eastward current is ephemeral, it would take an unlikely sequence of events to advect water column pollutants the approximately13 miles from Port Angeles Harbor to Dungeness Bay via this mechanism alone.

Strait sill - Finally, the Olympic Peninsula Countercurrent was documented in the Strait of Juan de Fuca west of Port Angeles. The countercurrent encounters a sill (a topographic high) immediately west of Dungeness Bay -- in between Dungeness Bay and Port Angeles Harbor. Thomson et al. (2007) suggest that the current likely changes structure dramatically at or near the sill. For instance, at depths greater than the sill, it is unlikely water-borne contaminants would be transported east of the sill because they would have to ascend in the water column (unlikely given that the Strait of Juan de Fuca is highly stratified). At water depths above the sill, the flow is generally westward as a result of the large freshwater effluent from the Fraser and Skagit Rivers (and other large rivers draining to the Strait of Georgia and Puget Sound). In this case, the contaminants would be mixed with this fresher water and forced west, back towards Port Angeles Harbor.

Conclusions

Dungeness Bay sediment, in conjunction with sediment sample stations in the outer (eastern) part of Port Angeles Harbor are expected to generate appropriate data to characterize area background concentrations. Sequim Bay and Freshwater Bay are less desirable background areas because of documented anthropogenic influences and grain size differences.

The use of Sequim Bay and Freshwater Bay as sediment reference sites would be problematic for the following reasons:

- Sequim Bay has a sediment grain size similar to Port Angeles Harbor; however it is not suitable as a reference location due to its extremely different geomorphology, and the presence of anthropogenic influences in an embayment with poor water circulation.
- The sediment grain size distribution and average TOC levels in Freshwater Bay are significantly different than Port Angeles Harbor.

The physical and geomorphological characteristics of Dungeness Bay, combined with the analysis of long-shore current tendencies along the north Olympic Peninsula, suggest that Dungeness Bay is the most appropriate area background and reference site for Port Angeles Harbor.

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