Appendix G
Sediment Assessment Methodology

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ATTACHMENT A

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Appendix G
Sediment Assessment Methodology

1.0 BACKGROUND

In 1997, the Oregon Department of Environmental Quality (DEQ) and the United States Environmental Protection Agency (EPA) undertook sampling of sediments in Portland Harbor (the 6-mile segment of the lower Willamette River between river mile (RM) 3.5 and RM 9.5; also referred to as the Harbor or Harbor Area). Data from the sampling show that sediments in discrete areas of the Harbor contain contaminants such as metals, polychlorinated biphenyls (PCBs), pesticides, herbicides, dioxins/furans, tributyl tin, and polycyclic aromatic hydrocarbons (PAHs). EPA is considering Portland Harbor for potential inclusion on the National Priority List (NPL) for cleanup under the federal Superfund program. DEQ, however, believes that it can expedite the assessment of sediment contamination and implementation of any actions necessary to protect human health and the environment in Portland Harbor, without placement on the NPL. To support this, DEQ is developing the Portland Harbor Sediment Management Plan (PHSMP) consisting of a number of elements, including development of a comprehensive and uniform approach to sampling, analyzing, and assessing risks posed by contaminated sediments in the Harbor - the "Sediment Assessment Methodology" (SAM).

This SAM provides a scientifically defensible basis for making appropriate environmental management decisions for Portland Harbor. It identifies the most applicable available options for assessing sediments. The SAM can be viewed as a "tool box" of the most appropriate sediment assessment tools that will meet with the approval of DEQ. The specific selection of sampling methods, sediment tests, and sediment analyses will be determined by the Sampling and Analysis Plans (SAPs) developed for individual sites and the harbor-wide study. The test and characterization procedures identified in those subsequent SAPs will be consistent with the testing options and interpretation guidelines presented in this SAM. Because the SAM presents a range of tests and analyses, it should be understood that, in many cases, not all of the tests and analyses will be required in each of the SAPs prepared as part of PHSMP implementation. In addition, many of the interpretation guidelines identified in the SAM are in the early stages of development and will require additional development throughout the implementation of the PHSMP. Examples of such issues include: developing sediment and tissue quality guidelines (SQGs) and target tissue levels (TTL), bioassays and bioassay data evaluation procedures, and benthic evaluation procedures.

The SAM is applicable both to the entire Harbor (a shore-to-shore, 6-mile segment of the river) and specific sites within the Harbor. It delineates methods for generating and interpreting environmental data for the purpose of: (a) determining the nature and extent of contamination, including its spatial extent both horizontally and vertically, (b) interpreting the significance of contaminant levels, considering site-specific differences in chemical bioavailability, physical and chemical sediment characteristics, and exposure pathways, and (c) supporting decisions about ecological and human health protection, injury, restoration, and protection of trust resources, dredging and open water disposal of sediments, source control, and the need for remediation of contaminated sites. The SAM is intended to bring consistency and predictability to the sediment

assessment process. However, the SAM does not supersede State statutory or regulatory requirements and authorities, nor does it commit the federal regulatory agencies or natural resource trustees to a specific method or approach where deviations from the SAM may be appropriate in the judgment of those agencies.

This SAM embodies scientific or technical information that was readily available at the time of its preparation. Where possible, a preferred method, as well as an acceptable alternative method (or methods) is described. Where production schedules or a lack of information did not allow identification of a method or approach, a recommendation is offered as to how this "data gap" will be filled at some point in the immediate future (e.g., by convening a specialty technical workgroup or conference, additional literature research, or conduct of a highly focused investigation, etc.). The SAM may also acknowledge, where appropriate, that some desired approaches are currently beyond the state-of-the-science or can not meet reasonable value-of-information criteria.

1.1 Environmental Management Framework

One of DEQ's environmental management mandates is to protect the present and future public health, safety, and welfare, and the environment in the event of a release or threat of a release of a hazardous substance. This requires protecting against a variety of potential impacts, regardless of whether they are evaluated as impairment of beneficial uses, unacceptable levels of risk, or adverse effects on natural resources. Risk is the probability that a contaminant will produce an adverse event under specified conditions. Adverse effects refers to a measurable adverse change in either the chemical or physical quality, or viability of a natural resource. Impairment of beneficial uses means exceeding criteria established for toxic substances, which if exceeded, could cause harm or produce adverse affects.

Environmental management goals are the desired characteristics of a value or values that the public wants to protect from impairment, risk, or adverse effects (EPA, 1998b). The following environmental management goals were established for Portland Harbor to meet DEQ's overall environmental protection mandate of protecting against adverse impacts in the Harbor:

> *Reestablish and maintain sediment quality in Portland Harbor to: (1) protect the benthic community, (2) allow human (recreational, subsistence, occupational) use of the Harbor; (3) provide a safe pathway for migratory fish; (4) prevent harm to individual threatened, endangered, and other special status species; and (5) protect endemic fish and water-dependent fish and wildlife populations.*

To interpret this environmental management goal for development of specific aspects of the SAM, it was converted into five management objectives that defined what must be true in the Harbor for it to be achieved and to provide the foundation for environmental management decisions, as follows:

(1) Benthic communities are not exposed to toxic levels of contamination in water or sediment.
(2) Persons using the Harbor for recreational or occupational purposes (boating, swimming, recreational and subsistence fishing, diving, etc.) are not exposed to unacceptable risks from contact with, or incidental ingestion of, sediment or through consumption of fish or shellfish exposed to sediment.
(3) Migratory fish transiting the Harbor are not impact, either directly or indirectly, by contaminated sediment.
(4) Individuals of threatened, endangered, or other special status fish species, as well as resident fish populations, are not adversely affected, either directly or indirectly, by contaminated sediment.
(5) Individuals of threatened, endangered, special status, or indicator (surrogate) water-dependent wildlife species, as well as resident water-dependent wildlife populations, are not adversely affected, either directly or indirectly, by contaminated sediment.

Objective (1) would typically be evaluated on a site-specific, as opposed to a harbor-wide, basis. While some aspects of Objectives (2) - (5) may be addressed at specific sites, they are generally approached on a harbor-wide scale. These include evaluation of risks to fish and wildlife, whose forage or migration range may encompass the entire Harbor, or an even larger area. Threatened and endangered species evaluations fall into this category, as they are largely concerned with piscivorous birds in the Harbor area. Risks to people from consumption of fish may be most easily assessed on a harbor-wide basis; however, risks from dermal contact or incidental ingestion of sediment will be assessed at specific sites and in other Harbor locations with human use.

Environmental management is the process of identifying, evaluating, selecting, and implementing environmental management decisions (i.e., actions to achieve these goals and objectives). The desired outcomes are scientifically sound, cost-effective, integrated actions that reduce or prevent impacts while taking into account social, cultural, ethical, political, and legal considerations. This SAM is a framework for determining whether each of these objectives is being achieved and, if not, for providing information in support of environmental management decisions.

It is important for environmental managers to realize that evaluating impacts is intended to be an internally consistent process. Or, more succinctly: ask a question about an environmental condition, set criteria for how you will differentiate “adverse” from “not adverse,” take measurements, compare the results to the criteria, and state whether the situation is “acceptable” or “unacceptable” (along with the degree of confidence in the answer). When evaluation criteria have been established through discussions with stakeholders, it is vitally important that the resulting assessment clearly connects questions asked and answers provided and adheres faithfully to agreed upon evaluation criteria.

The SAM begins with problem formulation (Section 2.0), or the gathering and consideration of existing information on the nature and extent of contamination (locality of the facility), land and water uses at and near the Harbor, receptors potentially present, physicochemical properties of

the contaminants of interest, potential exposure pathways, and beneficial uses of the waterway that may be impacted. Problem formulation leads to development of a conceptual model containing the assessment endpoints (Section 2.5.1), testable problem statements (Section 2.5.2), and measures (Section 2.5.3) that are appropriate for the Harbor or for specific sites within the Harbor. Details of the assessment framework for each objective are described in Section 3.0.

1.1.1 Consideration of Beneficial Uses

The *State-Wide Water Quality Management Plan; Beneficial Uses, Policies, Standards, and Treatment Criteria for Oregon* (OAR 340-41) is an important set of regulations governing in-water actions, including sediment cleanups. The primary purpose of the Water Quality Management Plan is to set out beneficial uses that must be maintained in water bodies of the state, and to identify water and sediment quality conditions that support these beneficial uses. These beneficial uses and associated water quality standards are legally applicable to in-water site cleanups and are referenced in the cleanup regulations in several places:

- OAR 340-122-072(4)(i)(B)(vii), Preliminary Assessments
- OAR 340-122-080(3)(f) and (6), Remedial Investigations
- OAR 340-122-085(5), Feasibility Study
- OAR 340-122-090(1)(a)(C), Selection or Approval of the Remedial Action
- OAR 340-122-114(9), (31), and (50), Definitions

Water bodies that do not meet their designated beneficial uses must be listed on the Clean Water Act 303(d) list of impaired water bodies, and states are then required to develop Total Maximum Daily Load (TMDL) Plans to improve conditions in the impaired water bodies.

Although TMDL plans typically focus on source control measures to improve water quality, an increasing number of water bodies are being listed due to poor sediment quality, and TMDL plans are beginning to be prepared that include sediment cleanup components.

Designated beneficial uses for waters of the state vary by basin and are listed in Tables 1-19 of OAR 340-41. These beneficial uses are established by regulation and cannot be modified on a project-specific basis. They apply to the entire basin, regardless of uses that may actually be occurring. The designated beneficial uses for the Willamette River (including the Harbor Area) are:

- Public and private domestic water supply
- Industrial water supply
- Irrigation and livestock watering
- Anadromous fish passage
- Salmonid fish rearing
- Resident fish and aquatic life
- Wildlife and hunting
- Fishing
- Boating

- Water contact recreation
- Aesthetic quality
- Hydropower
- Commercial navigation and transportation

To support these beneficial uses, the Water Quality Management Plan sets out criteria for dissolved oxygen, temperature, turbidity, pH, bacteria and bacterial pollution, deleterious or odorous dissolved gases, fungi and other growths, tastes and odors, bottom or sludge deposits, discoloration, scum, oil, floating solids, and films, radioactivity, over-saturation of dissolved gases, total dissolved solids, and toxic substances. Both narrative and numeric criteria exist and are applicable to the site cleanup process.

The toxicants criteria are the most relevant to cleanup of contaminated sediments. However, sediments with sufficient oxygen demand may cause overlying water to fall below dissolved oxygen standards. Water-soluble chemicals such as ammonia and sulfides and gases such as hydrogen sulfide or methane may be produced in sediments and released to overlying waters, causing exceedance of water quality criteria. In addition, wastes deposited in aquatic areas of the site may violate sheen, residue, and sludge deposit criteria. Finally, the water quality standards provide DEQ with the authority to regulate many aesthetic conditions in surface waters.

In addition to the criteria discussed above, sediment quality guidelines have been interpreted by EPQ as water quality criteria. For example, in Washington State, the Sediment Management Standards, SQS, and CSL values have been approved by EPA Region 10, and are considered equivalent to water quality criteria. Once sediment quality guidelines for Portland Harbor are developed, should the State wish to upgrade guidelines to criteria, and be in compliance with the Clean Water Act, the State would need to seek EPA approval at that time.

In developing a conceptual model for Portland Harbor and for individual sites within Portland Harbor, the potential for beneficial uses of the water body to be impaired and applicable water quality criteria to be exceeded should be considered. The conceptual model should include not only risk-based pathways and impacts, but any other beneficial use impairments that may result from the presence of contaminants. In some cases, this may require site investigation components over and above the risk-based components required by Oregon cleanup laws. This is consistent with EPA's sediment management strategy, which focuses on restoration of beneficial uses as the primary cleanup goal for contaminated sediment sites (EPA, 1998a). Finally, the water quality criteria, as applicable, should be included among the remedial action objectives for sites with sediment contamination. It should be noted that cleanup alone may not achieve full restoration of beneficial uses, but may be an important contribution to an overall program incorporating other actions, including source control, habitat restoration, and other watershed-wide activities.

1.2 Coordination with Natural Resource Trustees

While recognizing that a natural resource damage assessment (NRDA) is the sole responsibility of the Natural Resource Trustees, the SAM does envision conducting sediment assessments in

such a manner as to supply useful information to the both the ecological risk assessment and NRDA processes to the extent practicable. It may be possible to partially or completely define natural resource injury issues during the sediment assessment by coordinating with trustees to ensure that mutually useful data are collected. The ecological risk assessment portion of the SAM may help to determine whether: (1) a discharge or release has occurred, (2) trust resources have been affected, (3) injury has occurred or is likely, and (4) planned remedial responses will or will not be sufficient to protect or restore the resources. In addition, it can provide the natural resource trustees with information to use during their evaluation of possible injuries to trust resources. It is important to emphasize, however, that an ecological risk assessment conducted as part of a sediment assessment is not intended as preliminary work toward a NRDA and does not constitute a NRDA. Nonetheless, performance of an ecological risk assessment may go a long way toward resolving questions that might otherwise require lengthy NRDA-related proceedings and delay or prevent a comprehensive settlement with responsible parties.

2.0 PROBLEM FORMULATION

Problem formulation is a process for generating and evaluating testable problem statements ("risk hypotheses") about why adverse effects in humans or the environment have occurred, or may occur, from human activities. It provides the foundation for the entire assessment. Early in problem formulation, objectives for the assessment are refined. Then the nature of the problem is evaluated and a plan for analyzing data and characterizing adverse effects is developed. Any deficiencies in problem formulation will compromise all subsequent work on the assessment.

Establishing a multi-party dialogue between assessors and environmental managers (decision-makers), the regulated community, and the affected community during the problem formulation phase is essential to achieving societal, regulatory, and scientific goals. Environmental managers can ensure that the assessment will provide answers for questions related to protection of societal values, selection of remediation technologies, policy concerns and cost, whereas, the assessor ensures that the assessment addresses important scientific concerns. Both perspectives are necessary to efficiently utilize resources to produce scientifically sound assessments that are relevant to management decisions and public concerns.

The outcome of problem formulation is a conceptual model describing how sediment contaminants might affect human and ecological receptors and beneficial uses in and near the Harbor. The conceptual model traces contaminant physical-chemical fate and transport, including food chain transmission, and defines potential adverse effects. It allows the assessor to evaluate the exposure pathway to potential receptors, particularly related to the assessment endpoints, to ensure that the exposure pathway is complete. Further, it describes the relationship among assessment endpoints (Section 2.5.1), testable problem statements (Section 2.5.2), and measures (Section 2.5.3) and is used to confirm that the selected measures are in the same exposure pathway as the assessment endpoints.

Development of a conceptual model also identifies data requirements, methodologies needed to analyze the data (assessment design), and assumptions involving the greatest degree of uncertainty. By identifying these conservative assumptions, assessment design efforts can focus on addressing information gaps or sources of uncertainty, thereby utilizing harbor-specific information to minimize over- or underestimation of actual risks. Typically, this translates into direct field evaluation of contaminant concentrations at exposure points and of bioavailability or toxicity of contaminants in sediments.

2.1 Site Description

The Willamette River basin lies entirely within the State of Oregon, occupying a total area of about 12,000 square miles. The Willamette Valley forms a north-south trough through the northwestern portion of the state, with a width of about 75 miles from the crest of the Coast Range on the west to the crest of the Cascade Range on the east and a length of about 150 miles.

The Willamette River originates in the Cascade Mountain Range and flows approximately 187 miles north through the central part of the Willamette Valley before discharging into the

Columbia River at river mile (RM) 101. The Columbia River then flows an additional 100 miles westward to the Pacific Ocean. The confluence of the Willamette and Columbia Rivers denotes Willamette River RM 0. In the upper 133 miles, the Willamette River flows northward in what once was a braided, meandering channel. Studies conducted through the Willamette River Technical Advisory Steering Committee have shown that the river is no longer as braided as it was historically. Its bed has been greatly augmented, straightened and channelized by various human activities (e.g., navigation, dredging activities, diking, clearing logs and woody debris from the river). Through most of the remaining 54 miles, it flows between higher and more well defined banks unhindered by falls or rapids, except for the basaltic intrusion which blocks the valley at Oregon City and creates Willamette Falls. The stretch below the falls is subject to ocean tidal effects which are transmitted through the Columbia River. Portland Harbor is located in the lower Willamette River from its mouth upstream to approximately RM 14.

The Willamette River contributes a mean annual discharge of about 38,490 cubic feet per second (cfs) to the lower Columbia River. Peak flows, with a range of 20,800 to 130,000 cfs, occur in the high rainfall months of November through January; low flows, with a range of 5,000 to 7,100 cfs, occur in the lesser rainfall months of July through September. Flooding in the lower Willamette Basin occurs frequently with an average of one or two floods in the winter season and with severe floods occurring about every ten years. Flows in the Willamette River are significantly regulated by reservoirs and hydroelectric dams located on the tributaries.

The hydrology of the lower Willamette River area is very complex. Hydrologic conditions are influenced by three primary variables: (1) upstream reservoir regulation on the Columbia and Willamette Rivers, (2) natural stream flows on the Columbia River, Willamette River, and local tributaries such as the Sandy, Washougal, and Clackamas Rivers, (3) tidal effects. Each of these three variables will seasonally influence river stage to a greater or lesser degree. For example, upstream reservoir regulation on the Columbia and Willamette Rivers has resulted in reducing peak winter and spring stages and correspondingly increasing late summer and fall stages. Natural stream flows have a strong influence on stages during extreme events when reservoir regulation cannot completely control downstream stream flow, be it high or low. Tidal effects are noticed at river stages less than 12 feet, and are pronounced at stages less than 5 feet which are common in the summer and fall. The combined effect of these three interacting variables is what makes the hydrology of the lower Willamette River complex.

During the winter period, with high flows coming out of the Willamette River, the Portland Harbor stage tends to be 0.2 to 0.5 feet greater than Vancouver. Conversely, in the spring when the Columbia River flows are high, the Vancouver stage tends to be a few tenths higher than Portland. The harbor area is especially sensitive to harbor stages below 0.0 feet on the Portland-Vancouver gages. Occasionally harbor stages can change substantially due to heavy rain in the harbor area. In February of 1982 an intense rain event hit northern Oregon and southern Washington causing an increase of 3 to 4 feet in the harbor area over a 12-hour period.

Most development along the Willamette River has occurred within Portland Harbor, which has been dredged to provide a shipping channel generally 300 feet wide and 40 feet deep from the mouth of the Willamette River upriver to the Broadway Bridge (RM 11.8). Channel depths

currently range from 10 to 140 feet, with an average depth of 45 feet. In this reach, the river is deep, slow moving, and tidally influenced. During periods of medium and low flows, tidal effects are evident to RM 26.5 (Willamette Falls); reverse flow has been measured as far upstream as Ross Island (RM 15) during low flow periods. River flow from 1987 to 1989 averaged between 685 and 825 cubic meters per second (cms) with a high of over 4,814 cms during January 1988 and a low of 198 cms during August 1988.

Many of the upland areas adjacent to the Willamette River within Portland Harbor are heavily industrialized, and marine traffic within the river is considered to be intensive. The shoreline of the river near Portland has been altered to accommodate urban development and a growing shipping industry. Shoreline features include steeply sloped banks covered with riprap or constructed bulkheads, with manmade structures such as piers and wharves extending out over the water. Because of dredging, many portions of the riverbed are steeply sloped and maintain substrates composed mainly of silts and sands.

2.2 Contaminants of Interest

For human health and ecological risk assessments, where various toxicity screening processes may be applied, chemicals that have been screened-in without considering toxicity (i.e., by using frequency of detection or comparison to background) are designated "contaminants of interest" (COIs), while those that have been screened-in with regard to their toxicity are designated "contaminants of potential concern" (COPCs, for humans) or "contaminants of potential ecological concern" (CPECs, for ecological receptors). If no toxicity screening is applied, any chemical detected above background (for inorganics only) and with sufficient frequency (≥ 5%) is classed immediately as a COPC and/or CPEC. Following completion of the risk assessment, those contaminants that pose unacceptable risks are designated as "contaminants of concern" (COCs).

2.2.1 Toxicity

Contaminants of interest for benthic toxicity were determined by reviewing existing sediment chemistry data (available data are described in Section 6.3). Together these studies include over 550 samples at more than 500 stations. Most of these studies analyzed for a full suite of metals, semivolatile organics, pesticides, and PCBs. Many of the studies also include volatile organics, butyltin compounds, and dioxins/furans.

Various levels of screening were applied to these data sets to determine which contaminants should be of interest during sediment investigations, and which subset of those contaminants would be appropriate for development of benthic criteria. The first level was to identify those chemicals that were detected in any of the studies, and differentiate between those that were frequently detected and those that were infrequently detected and may only be associated with one or two sites. Various crustal metals and ions (Al, Ba, Be, Ca, Co, Fe, Mg, Mn, K, Se, Na, Th, Ti, and V) were detected but not included on the contaminant list. To ensure that this elimination was appropriate, their distributions were reviewed and no indications of unusual elevations within the Harbor were found. The list of detected chemicals and their frequency

shown in Table G-1 forms a basis for identifying COIs in Portland Harbor.

Table G - 1: Identification of Portland Harbor Contaminants of Interest

Analyte	Frequency of Detection	Percent% Detectedion	COI?
Metals			
Arsenic	409/551291/475	7461	Y
Antimony	108/343	31	Y
Cadmium	382/456369/420	848	Y
Chromium	546-551472/472	99100	Y
Copper	537/546475/475	98100	Y
Lead	486/51419/420	95100	Y
Mercury	389/449380/420	8790	Y
Nickel	450/456411/411	99100	(Y)
Silver	357/449344/411	8084	N
Zinc	524/524475/475	100	Y
Butyltins			
Tetrabutyltin	15/11311/86	13	(Y)
Tributyltin	200/260116/135	7786	Y
Dibutyltin	62/15416/86	4019	(Y)
Monobutyltin	39/12616/86	3119	(Y)
PAHs			
Naphthalene	371/566298/452	66	Y
Acenaphthylene	199/565169/452	357	Y
Acenaphthene	365/565296/452	65	Y
Fluorene	372/566298/452	66	Y
Phenanthrene	505/566418/452	8992	Y
Anthracene	393/565316/452	70	Y
Fluoranthene	514/566427/452	914	Y
Pyrene	516/566426/452	914	Y
Benz(a)anthracene	482/566400/452	858	Y
Chrysene	498/565415/452	8892	Y
Benzo(b)fluoranthene	380/438398/448	879	Y
Benzo(k)fluoranthene	343/411370/430	836	Y
Benzo(a)pyrene	480/564399/448	859	Y
Benzo(e)pyrene	57/83	67	(Y)
Indeno(1,2,3-cd)pyrene	430/566351/448	768	Y
Dibenz(a,h)anthracene	266/562214/448	478	Y
Benzo(g,h,i)perylene	449/561383/448	805	Y
Other Semivolatile Organics			
Dibenzofuran	194/430132/303	454	Y
2-Methylnapthalene	226/449182/352	502	Y
Carbazole	122/279109/255	443	Y
Nitrobenzene	1/249	<1	N
Chlorobenzene	7/69	10	(Y)
1,2-Dichlorobenzene	2/28703	<1	N
1,3-Dichlorobenzene	2/284	<1	N
1,4-Dichlorobenzene	10/2861/203	4<1	N
Hexachlorobenzene	3/3412/253	<1	N
Hexachlorobutadiene	4/3512/258	<1	N
Hexachloroethane	5/2494/198	2	N
Benzoic acid	18/265198	79	(Y)

Table G - 1: Identification of Portland Harbor Contaminants of Interest

Analyte	Frequency of Detection	Percent% Detectedion	COI?
Benzyl alcohol	6/2632/198	21	N
Phenol	14/38817/327	45	N
4-Methylphenol	177/387160/315	4651	Y
2,4-Dimethylphenol	1/387	<1	N
2-Chlorophenol	1/34301	<1	N
4-Chloro-3-methylphenol	1/343	<1	N
2,4-Dichlorophenol	2/4171/356	<1	N
2,4,5-Trichlorophenol	2/4191/66	<12	N
2,4,6-Trichlorophenol	1/419	<1	N
2,3,4,6-Tetrachlorophenol	2/861/66	22	N
Pentachlorophenol	29/46224/364	67	(Y)
2,4-Dinitrotoluene	1/249	<1	N
2,6-Dinitrotoluene	1/249	<1	N
Bis(2-ethylhexyl)phthalate	239/401212/301	6070	Y
Butylbenzyl phthalate	131/40096/301	332	Y
Diethyl phthalate	6/402	1	N
Dimethyl phthalate	20/40123/301	58	(Y)
Di-n-butyl phthalate	110/39988/301	289	Y
Di-n-octyl phthalate	63/40161/301	1620	(Y)
N-nitrosodiphenylamine	1/267	<1	N
Volatile Organics			
Tetrachloroethylene	4/64	6	(Y)
Benzene	2/52	4	N
Ethylbenzene	8/64	13	(Y)
Toluene	7/52	13	(Y)
Xylene	15/64	23	(Y)
Acetone	8/49	16	(Y)
2-Butanone	1/52	2	N
Pesticides/Herbicides/PCBs			
4,4'-DDD	117/20896/176	565	Y
4,4'-DDE	104/20776/175	5043	Y
4,4'-DDT	99/20989/176	4751	Y
2,4-D	4/7	57	(Y)
Endosulfan I	1/1962/152	<1	N
Endosulfan II	3/1963/152	2	N
Endosulfan sulfate	2/1964/152	13	N
Gamma-Chlordane	1/2506/152	<14	N
Alpha-BHC	26/196	13	(Y)
Delta-BHC	7/181	4	N
Gamma-BHC (Lindane)	18/1814/152	310	N(Y)
Aldrin	16/20810/152	86	(Y)
Dieldrin	14/2508/152	65	(Y)
Endrin	5/1962/152	31	N
Endrin aldehyde	5/1939/152	36	N(Y)
Heptachlor	5/2081/152	2<1	N
Heptachlor epoxide	8/196	4	N
Aroclor 1232	1/268	<1	N
Aroclor 1242	8/3147/271	3	N
Aroclor 1254	93/314109/272	3040	Y
Aroclor 1260	105/314271	339	Y

Table G - 1: Identification of Portland Harbor Contaminants of Interest

Analyte	Frequency of Detection	Percent% Detectedion	COI?
PCDDs/PCDFs			
TECs, undifferentiated by congener	29/2914/14	100	(Y)

A variety of additional chemicals were analyzed at more than 50 stations, and were undetected, including various chlorinated benzenes and phenols, methylphenols, nitrophenols, nitrotoluenes, nitrobenzenes, nitroamines, other miscellaneous semivolatiles included in the 8270 analysis, volatile organics, and a variety of additional pesticides, herbicides, and Aroclor formulations. With the exception of the Corps of Engineers data, these sampling locations were generally biased toward contaminated areas. It is reasonable to assume that these additional analytes are not likely to occur within Portland Harbor sediments unless there is a history of use and discharge at a specific facility or source area. Summary statistics for detection limits used in these historical studies are provided in Table G-23 at the end of this appendix.

The detected chemicals were further evaluated to determine which might be contaminants of interest for Portland Harbor. Chemicals that were analyzed at least 20 times and detected 20-100% of the time were classified as contaminants of interest, as they are relatively widespread in areas of Portland Harbor that have been sampled. These include 7 common metals, butyltins, low and high-molecular weight PAHs and associated compounds, several phthalates, 4-methylphenol, DDT and derivatives, Aroclors 1254 and 1260, and dioxins/furans. It should be noted that the studies reviewed here were heavily biased toward contaminated areas of the Harbor. Therefore, the detection percentages listed above were developed only for the purpose of establishing a COI list for sites in the Harbor area, and should not be considered as representative of overall detection frequencies for other areas of the Harbor.

Chemicals detected 5-20% of the time, and chemicals detected more often but analyzed at only one or two sites, may be COIs at certain sites or limited locations within the Harbor (indicated by a Y in parentheses). These include tetrabutyltin, chlorobenzene, benzoic acid, pentachlorophenol, dimethyl phthalate, di-n-octyl phthalate, tetracholoethylene, toluene, ethylbenzene, xylene, acetone, 2,4-D, alpha-BHC, gamma-BHC, aldrin, and dieldrin. These analytes should be included in site investigations if there is reason to believe they might be present. Sediment quality guidelines for benthic toxicity cannot be developed at this time for these potential COIs, as there are not enough data to perform the calculations. It is unlikely that benthic toxicity associated with these chemicals will drive cleanup at any site, however, sediment quality guidelines could be developed on a site-specific basis if needed, pending collection of additional data.

Chemicals detected less than 5% of the time are not considered harbor-wide COIs, however, they may be important at specific sites. In addition, metals were subjected to further evaluation because they are naturally occurring in sediments and detected concentrations may not be indicative of anthropogenic sources. Nickel was retained as a COI at a few sites due to one or two elevations over ambient levels, defined as widespread, lower concentrations of chemicals

that may be naturally occurring (e.g. metals) or associated with non-point sources, such as upstream contributions, boat traffic, stormwater, and sediments redistributed from other areas. Silver was eliminated from the list because there were no apparent elevations above ambient levels in the data set.

The list of COIs above should be considered a "default" analyte list for site and harbor-wide investigations in Portland Harbor. However, chemicals should be added to this list on a site-specific basis if there is reason to believe they might be present (e.g., known use and release, documented presence in other environmental media, etc.). Similarly, chemicals may be dropped from the list if there is reason to believe they would not be present at a specific site, based on a comprehensive review of chemical use at the site, and/or existing analytical data for upland areas and potential sources to sediments. However, since most of these chemicals are widely distributed in Portland Harbor, care should be taken in dropping analytes from the list. COIs will also be carried through for development of sediment quality guidelines for benthic toxicity. During that process, it may become apparent that some of these COIs are not present at high enough levels to cause adverse effects, and the list will be further refined at that time to identify contaminants of concern for Portland Harbor.

2.2.2 Bioaccumulation

COIs for bioaccumulation were identified through an evaluation of their presence in Portland Harbor sediments and tissues, and potential for bioaccumulation. An overall list of COIs for Portland Harbor is provided in Section 2.2.1 above. Because this list was based solely on elevations above ambient levels (metals) or detection in sediments (organics), it serves as an appropriate starting point for identification of bioaccumulative COIs. Bioaccumulative metals are limited to those that have organic forms which may be taken up, concentrated, and/or passed up the food chain by aquatic receptors, including arsenic, mercury, and butyltins.

Organic chemicals were further screened by their octanol-water partitioning coefficient (K_{ow}), which is considered a good indicator of the potential for a chemical to partition into tissues. Organic chemicals with log K_{ow}s greater than 3.5 were retained as bioaccumulative COIs, consistent with other regional cleanup and dredging programs (WDOH, 1995; DMMP, 1998). Of the COIs identified in sediments (both Harbor-wide and limited distribution), the following have the potential to bioaccumulate in fish and higher trophic levels:

- Arsenic
- Mercury
- Butyltins
- Pentachlorophenol
- Bis(2-ethylhexyl)phthalate
- Butylbenzyl phthalate
- Di-n-butyl phthalate
- Di-n-octyl phthalate
- DDT and derivatives
- 2, 4-D

- Alpha-BHC, gamma-BHC (Lindane)
- Aldrin and dieldrin
- PCBs
- Dioxins/furans

Although many PAHs have K_{ow}s greater then 3.5, they are not retained on this list because they are quickly metabolized by fish and do not generally present a risk to higher trophic level consumers. However, during the metabolization of PAHs, adverse effects to fish are known to occur which cannot be addressed through tissue guidelines. Impacts to fish, especially juvenile salmonids, have been identified from exposure to various PAH mixtures. Impacts can include DNA adducts or immunosuppression. PAH metabolites can be identified in the bile of fish and this could be used as a biomarker for exposure. These types of effects cannot be assessed through this approach.

Because the development of tissue guidelines for fish and wildlife is research-intensive, COIs were further screened to identify which have been detected in fish or shellfish tissues in Portland Harbor. The following studies were reviewed:

- McCormick & Baxter Remedial Investigation Report (PTI, 1992). 6 fish and 6 crayfish samples were collected and analyzed for a limited list of compounds (four metals including arsenic but not mercury, PAHs, pentachlorophenol, and PCDDs/PCDFs). Four stations were near the site, one was upstream, and one downstream.
- Willamette River Toxics Study (DEQ, 1994). Several fish samples were collected at two station in Portland Harbor in each of three years and analyzed for chlorinated pesticides, PCBs, and metals.
- Data tables for mercury in fish tissue analyzed in 1997, provided by DEQ Water Quality Program (DEQ, 1999).
- Fish tissue samples collected by Oregon State University and DEQ at various sites in the Willamette River, including one station in Portland Harbor (six individual fish samples), analyzed for organochlorine pesticides, PCBs, PAHs, and PCDDs/PCDFs (Curtis et al., 1993).
- Fish tissue samples collected by USGS (USGS, 1999; Bonn, 1998)

In these studies, detection frequencies in tissues are listed in Table G-2 below:

Table G-2: Contaminants of Interest With Respect to Bioaccumulation Potential

Analyte Contaminant	Frequency of Detection Frequency	Detection Percentage Detected	Detection Limit Range	COI?
Arsenic	0/17	0	0.03-0.22 mg/kg	N
Mercury	21/21	100	always detected	Y
Butyltins	0/0	NA	NA	(Y)
Pentachlorophenol	0/12	0	100 µg/kg	N
Bis(2-ethylhexyl) phthalate	0/0	NA	NA	(Y)
Butylbenzyl phthalate	0/0	NA	NA	?
Di-n-butyl phthalate	0/0	NA	NA	?
Di-n-octyl phthalate	0/0	NA	NA	?
DDT	3/17	18	2-6 µg/kg	Y
DDD	6/17	35	2-6 µg/kg	Y
DDE	13/17	76	2-6 µg/kg	Y
2,4-D	0/0	NA	NA	?
Alpha-BHC	1/19	5	2-6 µg/kg	Y
Gamma-BHC (Lindane)	0/19	0	2-6 µg/kg	N
Aldrin	0/197	0	2-6 µg/kg	N
Dieldrin	0/197	0	2-6 µg/kg	N
Aroclor 1254	1/17	6	3-25 µg/kg	Y
Aroclor 1260	10/17	59	5-30 µg/kg	Y
PCDDs/PCDFs	2318/2318	100	always detected	Y

Chemicals that have even been detected in Portland Harbor tissues are retained as COIs for criteria development. Based on this review, mercury, DDT and derivatives, alpha-BHC, PCBs, and PCDDs/PCDFs are confirmed as COIs in tissues. No data are available for butyltins and phthalates in fish tissue, and a harbor-wide study will be recommended to fill this data gap (see Section 6.3.2). However, because TBT and bis(2-ethylhexyl) phthalate were frequently detected in sediments (>70%), these chemicals will be included for the purposes of the Harbor area fish study and for guideline development. Once the fish tissue study has been completed, additional chemicals may be added to the COI list.

2.3 Potential Receptors

Identification of potential receptors depends, in part, on the habitat and contaminant. An assessment should consider all receptors potentially exposed to sediment contaminants either directly or indirectly. For sediment assessments, the benthic invertebrate community is identified as the primary receptor along with demersal fish species. If COIs have a potential for transfer from sediments via food webs (e.g., chlorinated pesticides, PCBs, certain mercury compounds), then pelagic fish species (e.g., steelhead) and other wildlife (e.g., piscivorous birds and mammals) should be considered. Typically, wading birds and mammals that feed on benthic invertebrates or may be exposed directly to sediments are considered for shallow water sediments. Plants may also be considered as potential receptors, as might periphyton, plankton and *Corophium* or similar mid-water invertebrates. The process of characterizing receptors

usually involves a combination of reconnaissance survey work (site visits) together with natural history information; additional data on receptors will be gathered at later stages of the evaluation.

2.3.1 Benthic Community

There is a lack of information on the nature and extent of benthic communities in and near Portland Harbor. This is a significant data gap that will be proposed for a harbor-wide study.

A sediment profile imaging (SPI) survey and a benthic community survey were conducted at and near the Portland Shipyard (P. Quinn, Port of Portland, *personal communication*). Neither survey found a diverse, deep-dwelling benthic community to be present. The lack of a diverse, deep-dwelling benthic community is not necessarily due to industrial activities. These Shipyard data indicate no significant difference in benthic population indices between Shipyard sediments and upstream sediments. Thus, there are likely other non-industrial influences such as sediment texture, sediment deposition, years of combined sewer overflows, and ship/boat traffic that needs to be considered. It is critical that whether or not the Harbor did or would support a diverse benthic community were it not for contaminated sediments be understood.

2.3.2 Fish

Recent studies have identified 39 species of fish in the Willamette River within the Harbor area (Farr and Ward, 1993). The lower Willamette River upstream to Willamette Falls provides a juvenile and adult migratory corridor, and juvenile rearing habitat, for several anadromous fish species. Three runs of chinook, two runs of steelhead, and individual runs of coho and sockeye salmon occur in the area. In general, chinook and steelhead populations are the largest and most widespread of the salmonids found in the Willamette River basin. Cutthroat trout are also present in the Willamette River, but their abundance is low (Bennett and Foster, 1991).

Several of the anadromous fish runs (considered evolutionarily significant units - ESU) in the area are either listed or proposed for listing under the Endangered Species Act (50 CFR 17.11 and 17.12). Steelhead from Willamette River tributaries downstream of Willamette Falls are included in the Lower Columbia River ESU, listed as a threatened species in March, 1998. Steelhead from Willamette River tributaries upstream of Willamette Falls are included in the Upper Willamette ESU, proposed as a threatened species in March, 1998. Spring chinook salmon from Willamette River tributaries downstream of Willamette Falls are included in the Lower Columbia River ESU, proposed as a threatened species in March, 1998. Spring chinook salmon from Willamette River tributaries upstream of Willamette Falls are included in the Upper Willamette River ESU, proposed as a threatened species in March, 1998. Coho salmon from Willamette River tributaries downstream of Willamette Falls are included in the Lower Columbia River ESU, a candidate species for listing. Sea-run cutthroat in the Willamette River are part of the West Coast population considered a candidate species for listing. Final listing determinations for proposed ESUs are expected by March, 1999. Listing assessments for candidate species are expected by mid-1999.

A threatened species is one that is likely to become endangered within the foreseeable future. Pacific lamprey are also present in the river and are currently classified as a species of special concern by the U.S. Fish and Wildlife Service (USFWS). The USFWS defines species of special concern as those organisms whose conservation status is of concern to the USFWS, but for which further information is needed. Pacific Lamprey are also classified by the Oregon Department of Fish and Wildlife (ODFW) as a sensitive specifies (OAR 635-100-040). The state of Oregon defines sensitive species as naturally reproducing native vertebrates that are likely to become threatened or endangered throughout all or a significant portion of their range in Oregon. The Sensitive Species List is for the express purpose of encouraging actions that will prevent further decline in species' populations and/or habitats and thus avoid the need for listing.

Chinook: Spring chinook and fall chinook, differentiated by their time of entry into freshwater, use the Willamette River. The runs are genetically distinct from one another. During their annual migration, Willamette River spring chinook begin entering the Columbia River during January. Peak densities occur in late March, with entries tapering off by mid-May. Spring chinook migrate past the site, bound for upstream tributaries. Spawning takes place in the early fall. Wild juvenile spring chinook reside in fresh water from 3 to 18 months following egg deposition. Emigration from natal streams occurs during one of three periods: (1) a movement of fry in late winter and spring soon after emergence (sub-yearlings); (2) a movement of yearlings in late fall and early winter; and (3) an emigration of smolts the following spring (Howell et al., 1985). Based on the number and small size of juveniles caught at collection facilities at Leaburg Dam on the McKenzie River, it is evident that many of the naturally produced spring chinook in Willamette sub-basins emigrate to the lower reaches of tributaries and the main-stem Willamette River for completion of rearing before smoltification (Howell et al., 1988; ODFW, 1990). They spend anywhere from 1 to 5 years in the ocean (Bennett and Foster, 1991).

Five large hatcheries currently produce approximately 5 million smolt-size spring chinook for release into the Willamette River each year, plus additional fingerling salmon to seed underused reservoir and tributary streams. Current hatchery practices include the release of one-third the annual production as sub-yearlings in November and two-thirds as moderate sized yearlings (smolts) in March. Sub-yearlings are released into streams or reservoirs for further rearing. Most of the smolts are released near the adult collection sites, but some are also trucked to areas within the lower Willamette River to increase survival.

Fall chinook were introduced to the Willamette River in 1964. This sub-species spawns and rears in the main-stem of the upper Willamette River and lower reaches of east-side tributaries upstream of the site. Fall chinook begin entering the Columbia and Willamette Rivers in late August and runs taper off by mid-October. The spawning period typically occurs from mid-September to late October. Wild fry begin emerging in late December. The migration of wild juveniles peaks the first week of June at Willamette Falls. Fall chinook juveniles migrate to the Columbia River estuary as sub-yearlings (Howell et al., 1985). Fall chinook generally spend 2 to 5 years in the ocean before returning to the Willamette. Runs are supplemented by the addition of 5 to 7 million smolts each year. Knutsen and Ward's (1991) study of the behavior of juvenile salmonids migrating through the Portland Harbor area found that yearling chinook salmon appeared to be actively migrating through the area. Even during periods of low river flow, they

did not spend more than a few days in the harbor area. Information on the migratory behavior of sub-yearling chinook is limited. Sub-yearling chinook were found in the Harbor area over a longer period than other species or races of salmonids, probably because they actively fed during migration. There was little certainty to what extent they were actively migrating. Electrofishing catches from 1987 indicated that some juvenile salmonids may over-winter in the lower Willamette River.

Juvenile (sub-yearling) chinook salmon are potential receptors for contaminants in the lower Willamette, and information regarding their migration patterns and residence times is important for risk assessment. Juvenile chinook salmon from a contaminated urban estuary in Puget Sound, exposed to PCBs and PAHs, were reported as having exhibited immunosuppression (Arkoosh et al., 1991). Immunosuppressed fish may be more susceptible to disease and ultimately experience an increase in mortality. Juvenile salmon from a contaminated estuary in Puget Sound, challenged with the marine pathogen *Vibrio anguillarum*, were reported as showing a higher cumulative mortality after exposure to the pathogen than salmon from hatcheries or a non-urbanized estuary (Arkoosh et al., 1998). Factors that affect health in the early life stages may affect recruitment to adults. Therefore, mortality during estuarine and early ocean life of juvenile salmon from increased disease susceptibility induced by immunotoxic compounds may be a factor in year-class strength for populations with polluted estuaries (Arkoosh, et al., 1998). See Section 3.4.2.2 for further discussion of this issue.

Steelhead: Two races of steelhead are present on the Willamette River - winter run and summer run, each named for the time period in which spawning runs begin. The Willamette River winter steelhead run occurs during the late winter to spring with adults migrating upstream from February through May. Spawning occurs from March through May. Naturally-spawned juveniles generally spend two years in freshwater before smolting; out-migration begins in early April and extends through June. Juvenile steelhead appear to actively migrate through the Portland Harbor area, spending less time in the area than other juvenile salmonids (Knutsen and Ward, 1991). Runs have been supplemented by hatchery stocks since the 1960s; in 1991, approximately 565,000 winter steelhead smolts were released in the Willamette River basin as age 1+ smolts (Bennett and Foster, 1991).

Summer steelhead begin entering the Willamette River starting in early March migrating to spawning grounds above Willamette Falls. Peak migrations occurs from mid-May through June. Adult fish remain in the river through the fall and spawn during the winter months. The majority of returning adults spend two years in saltwater. Summer steelhead were introduced above Willamette Falls in the late 1960's for sport fishing. Natural production is low and is monitored closely by the Oregon Department of Fish and Wildlife to ensure populations are sustained by hatchery releases and angling regulations. In 1991, approximately 750,000 summer steelhead smolts were released in the Willamette River basin.

Coho: This species migrates up the Willamette from late August through early November with peak numbers beginning in mid to late September. Spawning occurs from September through December and juveniles out-migrate the following spring. Coho return to freshwater as age-3

adults and age-2 jacks (precocious male adults). Due to concerns regarding competition between coho salmon and other game fish and a lack of contribution to Willamette River fisheries, the management of coho runs has been de-emphasized (Bennett and Foster, 1991).

Sockeye salmon: These are not indigenous to the Willamette River. Experimental releases were conducted 1966 and 1967 with 143,000 Columbia River sockeye and 243,000 Adams River (British Columbia) sockeye introduced into up-river reservoirs. Adults from these releases returned in 1970 and 1971 and were allowed to spawn naturally. No further releases were made as natural reproduction has continued. Since the first introduction, the population of sockeye salmon in the Willamette has decreased considerably (Bennett and Foster, 1991). The Willamette River Basin Fish Management Plan proposes to eliminate the sockeye run from the river.

American shad: These are also not indigenous to the Willamette River, but were introduced to the Columbia Basin early in the century. Shad enter the lower Willamette River and migrate upstream to Willamette Falls from mid-May to mid-July, peaking in June. Shad rarely use the Willamette Falls fishway due to structural limitation that inhibit the species from proceeding upstream. Data for sport catch indicate that shad are abundant in the Willamette River. Shad are broadcast spawners, releasing eggs in open water. The eggs are slightly heavier than water and non-adhesive; they settle to the bottom and are carried along by the current, larvae hatch in 8 - 12 days and spend their first summer in fresh water. Juveniles drift downstream and enter the ocean in autumn (Scott and Crossman, 1973).

White sturgeon: These are plentiful throughout the lower Willamette River and transplants have established a small resident population above Willamette Falls. Most white sturgeon spawn immediately below Willamette Falls, upstream of the site, during the late fall and winter. Juveniles are present in the river year round and congregate in the Portland area in the vicinity of the Harbor. Sturgeon have been stocked in limited numbers (approximately 1,000 to 2,000 per year) above the falls from 1989 - 1992 (Bennett and Foster, 1991).

2.3.3. Birds and Mammals

Numerous piscivorous birds, migratory waterfowl, and raptors utilize the lower Willamette River during various times of the year. Great Blue Heron, Cormorant, Osprey, Merganser, Kingfisher, and Bald Eagle routinely forage within the Harbor area. Both Great Blue Heron and Osprey nest sites are located in the vicinity of the Harbor and represent significant potential receptors. There is an active Great Blue Heron rookery on Ross Island at RM 15. All of these species are protected under the Migratory Bird Treaty Act. River otter, nutria, raccoons, and other small mammals may also utilize the Harbor area.

2.3.4 Human Populations

No commercial fisheries for anadromous salmonids are present on the Willamette River. Commercial fishing in the Willamette River within the Harbor is limited to a small Pacific lamprey fishery. In contrast, recreational fishing is extremely popular throughout the lower

Willamette basin. Resident species such as largemouth bass, black crappie, white crappie, and walleye support a significant year-round recreational fishery. Species most desired are spring chinook, steelhead, coho, shad, and white sturgeon. Spring chinook contribute substantially to the mainstem Columbia River sport fishery and consistently supports the largest recreational fishery in the lower Willamette River. The chinook fishery in the Willamette River occurs between Oregon City and the confluence of the Willamette and Columbia River and throughout the Multnomah Channel. The Harbor is located within this 75-krn reach and recreational angling may occur in the general vicinity. Angling is conducted primarily from anchored or slow-moving boats. Recently a bank fishery has developed popularity along the Multnomah Channel and there is an active crayfish fishery in the Harbor. Recreational and subsistence fisher-persons, beach users, swimmers, and boaters (both adults and children) are currently thought of as the human populations most likely to have sediment-related exposures. Dockyard workers and maintenance personnel, work boat and marine equipment operator, and divers may also have some limited potential for contact with Harbor sediments.

2.4 Potential Exposure Pathways

For an exposure pathway to be complete, a contaminant must be able to travel from the source to receptors and to be taken up by the receptors via one or more exposure routes. Identifying complete exposure pathways prior to a quantitative evaluation of toxicity allows the assessment to focus on only those contaminants that can reach receptors. If an exposure pathway is not complete for a specific contaminant (i.e., receptors cannot be exposed to the contaminant), that exposure pathway does not need to be evaluated further.

Fate and transport processes may link land-based contamination or in-place sediments with other areas where exposure may occur. The following processes are important to consider at this stage: (a) surface erosion and bulk transport of contaminants present in surface soils at a site, (b) seep discharge of non-aqueous phase liquids (NAPL) present at a site or along the bank of a water body which may be denser than water (DNAPL) or lighter than water (LNAPL), which could enter the aquatic environment by migrating along geological features or on ground water and contaminate sediments, (c) contaminated groundwater from a site which could discharge to an adjacent water body and result in exposure to benthic organisms or result in contamination of sediments, and (d) resuspension of contaminated sediments at or below the sediment-water interface (sometimes by infrequent storm or flood events, or by bottom disturbing activities such as dredging and shipping), such that they become exposed to the surface or are transported to other areas.

2.4.1 Sediment Sources and Transport

The Harbor represents the final reach of the Willamette River just prior to its confluence with the Columbia River. Before settlement along the Willamette River began in the 1830s, stream flows varied dramatically, with frequent floods during major rainfall events and spring snowmelt. At that time, the Willamette River channel was braided and shallow. Settlers cleared forests,

drained marshes, and made the river narrower, deeper, and straighter (Tetra Tech, 1995a). Development of the Harbor resulted in significant alterations to the morphology of the lower Willamette River. The main river channel was deepened and widened by dredging. Numerous structures were built to receive and service large commercial vessels. Some of the areas of natural shoreline were replaced by riprap or by bulkheads. Today, the Harbor is characterized by a relatively stable channel, due primarily to shoreline development throughout downtown Portland, and in some locations, rock outcrops along the shoreline. The Harbor is heavily developed, with many docks and marine facilities. The Willamette River from RM 0.0 to 11.8 is generally confined to a single channel that varies in width from 1,300 feet to 2,000 feet. Multnomah Channel splits from the Willamette at RM 3 to form Sauvie Island (COE, 1997a).

Stream flow throughout the Willamette River basin, with the exception of some flow regulation from the basin's 11 major reservoirs, is dominated by seasonal patterns of rainfall. The low-flow period is from July through September; a period that typically accounts for 2 to 5 percent of stream flow for unregulated streams in the basin (Anderson et al., 1996). In contrast, the high-flow period from November to April generally accounts for 80 to 90 percent of the annual flow in streams unaffected by reservoir regulation and 60 to 80 percent in regulated streams (Anderson et al., 1996).

Between October 1, 1950, and September 30, 1994, inflows to the Harbor exceeded 7,000 cfs approximately 99 percent of the time. Inflows exceeded 100,000 cfs approximately 5 percent of the time (Anderson et al., 1996). The COE estimates that the average annual discharge into the Harbor (as measured at the USGS Willamette River gauging station at Portland) is 33,000 cfs. High river stages can occur in the winter due to Willamette River flood discharges or in the spring as a result of backwater from the Columbia River during spring snowmelt (COE, 1997a).

Water surface elevations in the Harbor fluctuate on a daily basis, mainly due to daily tidal fluctuations in the Columbia River. These tidal fluctuations result in a reversal of water movement in the lower portion of the Harbor and stagnation points where water velocities are zero. During times of medium to low flow in the Willamette River, tidal effects are evident as far upstream as Willamette Falls (RM 26.5). Flow reversal has been observed as far upstream as Ross Island (RM 15) during low-flow periods.

Tidal fluctuations also result in movement of Columbia River water into the Willamette River. A wedge of cooler Columbia River water periodically migrates upstream under the warmer Willamette River water. This phenomenon was observed near Multnomah Channel at RM 3 during an August 1994 investigation by the USGS of sediment oxygen demand. Columbia River water has been detected as far upstream in the Willamette River as RM 12.8 (Caldwell and Doyle, 1995). The transport of Columbia River sediments and associated contaminants into the Harbor is expected to be limited because water velocities are low and Columbia River sediment tends to be sand that settle rapidly and require higher velocities for transport.

As water moves downstream through the Harbor it slows as the river widens (particularly downstream of RM 10.3) and as the hydraulic gradient flattens near the mouth of the Willamette River. During a 1994 study, maximum water velocities reached 0.5 foot per second (fps) during

both rising and falling tides (Caldwell and Doyle, 1995). In a 1992 study of the effects of waterway development on anadromous and resident fish in the Harbor, water velocities at the surface ranged from 0.16 to 0.56 fps and averaged 0.33 fps during a flow of 62,200 cfs in April 1989. Water velocities ranged from 0.13 to 0.26 fps and averaged 0.2 fps during a flow of 9,900 cfs in June 1989 (Port of Portland, 1992). In addition, water velocities in the Harbor are very low compared to those measured upstream and in major tributaries to the Willamette River. Between RM 141 and RM 157 in the Willamette River, time-of-travel and dye dispersion studies determined river velocities ranging from 2.7 to 3.6 fps; water velocities in the Clackamas River were 1.1 to 3.1 fps (Lee, 1995).

The amount of suspended sediment transported by the Willamette River as it enters the Harbor varies seasonally. The available data indicates that a significant percentage of the total amount of sediment transported enters after major storm events or during spring snowmelt when suspended sediment concentrations are relatively high. Relatively little sediment enters during the rest of the year, because suspended sediment concentrations are very low. During low flow periods the sediment load is about 1,000 tons per day or less. During flood events the load increases, to as high as 30,000 to 50,000 tons per day. At flow rates below 50,000 cfs for the period of 1973 to 1982, suspended sediment concentrations typically ranged from 10 to 20 mg/L. Suspended sediment concentrations increase substantially as discharge increases above 50,000 cfs.

The COE estimates that the Willamette River's average annual suspended sediment load is 1.7 million cubic yards per year. Less than 20 percent, or about 0.3 million cubic yards per year, of that material is sand, the rest is silt or clay (COE, 1997a). The Tualatin and Clackamas Rivers, both upstream of the Harbor, represent significant sources of sediment for the lower Willamette River (Tetra Tech, 1995). A high percentage of the suspended sediments entering the Harbor is transported through and into the Columbia River. Most of the suspended sediments carried into the Harbor by the Willamette River are fine-grained silts and clays, as opposed to the coarse-grained sands that are commonly found in the Columbia River. Numerous samples have been analyzed by the Port, COE, USGS, and others to determine the grain-size distribution of Portland Harbor bed sediments.

A more comprehensive evaluation of Harbor navigation channel bed sediment physical characteristics was conducted by the COE during their 1997 sampling program (COE, 1997b). With the exception of one sample collected at RM 11.5, surface sediments in the uppermost 0.5 mile of the navigation channel (between RM 11.55 and 11.1) consist mainly of sands (i.e., there is a low percentage of fines). In this reach, the Harbor is relatively narrow, making water velocities high enough to carry fines into the next reach. Surface bed sediments in this next reach (downstream of the Fremont Bridge to approximately the Burlington Northern Railroad Bridge; from RM 10.3 to RM 6.7) are generally 30 percent or more of fines; the exception being a sample collected at RM 6.9 with approximately 11 percent fines. The channel widens in this reach, allowing water velocities to decrease to the point where fines can settle to the bottom. Between RM 6.5 and RM 5.1, where the river and navigation channels narrow and water velocities increase, the percentage of fines decreases to < 6 percent. Fine sediments that make it into this reach tend to get carried further downstream. Between RM 5.1 to the mouth, the river and navigation channels again widen, water velocities slow, and the percent fines again

increases, ranging from > 40 percent to approximately 80 percent.. This is the reach most affected by flow reversal and stagnation in response to Columbia River tidal fluctuations.

In 1997, the COE also measured two other key physical characteristics of Harbor navigation channel bed sediments: percent solids and percent total organic carbon. Percent solids ranged from 60 percent to 93 percent; percent total organic carbon from 0.07 percent to 2.26 percent (COE, 1998). In an earlier COE study, a 2- to 4-foot layer of loam to silty loam fluff was discovered in the channel near Swan Island (RM 9) and a 3-foot layer at the Burlington Northern Railroad Bridge (RM 7) (COE, 1979b).

There is only one natural point source discharge of sediment into the Harbor: Columbia Slough. No data on suspended sediment concentrations or loadings from the Columbia Slough into the Harbor were found (Port of Portland, 1998). According to recent river bathymetric maps prepared by the COE, as part of the proposed channel deepening project, a small delta exists at the mouth of the Slough and it may act as a source of suspended sediments into the Harbor.

There are a number of outfalls that discharge suspended solids from public and industrial sources into the Harbor. Two major wastewater point source discharges are Elf Atochem and Rhone-Poulenc. According to Tetra Tech (1992), the Elf Atochem discharge does not contribute additional total suspended solids (TSS), if a correction is made for the TSS content of the intake water. TSS loadings from Rhone-Poulenc ranged from 0.17 pound per day to 2.3 pounds per day. Thus, the two major point source discharges to the Portland Harbor are negligible sources of sediment even during periods of low flow.

Stormwater point source discharges include City of Portland outfalls for combined sewer overflows (CSOs). These outfalls carry suspended sediments from nonpoint sources that drain to the Harbor. Limited available data suggest that suspended sediment concentrations in some CSO discharges range from 0.3 to 74 mg/L (CH2M Hill, 1992). Relatively little information is available on suspended sediment concentrations in other stormwater discharges. According to data compiled by the USGS (Harrison et al., 1995), monitoring of an outfall that collects runoff from Interstate 84 detected suspended sediment concentrations that ranged from 17 to 233 mg/L during 1994 (Port of Portland, 1995). This outfall discharges to the Willamette River beneath the Burnside Bridge.

The sediment transport capacity of the Willamette River within the Harbor is relatively low because of low water velocities and flow reversals in the lower portion of the Harbor. Despite the low transport capacity of the Willamette River, sedimentation rates during most of the year tend to be low because suspended sediment concentrations in the Willamette River and in nonpoint source discharges to the Portland Harbor are low. In addition, suspended sediments tend to be silts and clays, which have a tendency to remain in suspension. Sedimentation rates increase during high-flow events when the transport capacity of the Willamette River is still relatively low and suspended sediment concentrations are high. The accumulation of up to 6 inches of sediment at certain locations during the February 1996 flood event illustrates increased sedimentation during high flows.
Bathymetric mapping by the COE as part of the proposed channel deepening project indicates

that most of the sediment deposition occurs in a few locations: (a) just downstream of the Fremont Bridge, (b) north side of the navigation channel across from Swan Island, (c) near the Burlington Northern Railroad Bridge, (d) west side of the navigation channel near Terminal 4, (e) west side of the navigation channel between the Multnomah Channel, and (f) at the mouth of the Willamette River.

The Port and other facility operators report the location of historic depositional areas consistent with the areas mapped by the COE (Ogden Beeman and Associates, 1996): (a) from RM 3.25 to RM 7.3 shoaling occurs in the navigation channel and (b) from RM 7.3 to RM 11.35 shoaling occurs in the navigation channel, particularly on the west bank across from Swan Island upstream to Terminal 2 and on the east bank upstream from Swan Island (approximately 82 percent of the Port's projected facility dredging is from this reach, including 27 percent from Terminal 2 and 55 percent from the Portland Ship Yard).

If suspended sediment concentrations are low, most sediments entering the Harbor would remain suspended and be carried through and into the Columbia River. The COE estimates that the average annual suspended load entering the Portland Harbor is 1.7 million cubic yards (COE, 1997a). The average annual volume of navigation channel and Port facility dredging in the Harbor is 0.17 million cubic yards. Assuming that other parties dredge another 30,000 cubic yards each year on average, it is estimated that there is an average annual discharge of 1.5 million cubic yards of sediments into the Columbia River from the Harbor. Most of the suspended sediments discharged into the Columbia River are carried downstream and either settle in the lower estuary or remain suspended and are carried across the river delta to the Pacific Ocean (COE, 1979a).

If the Willamette River has a low transport capacity, sediments that deposit on the bottom will not be transported to other locations unless dredged or disturbed by high seasonal flows. Although bed load transport in the Harbor may be limited because of channel dimensions and the type of bed material (COE 1997a), the issue is not yet fully resolved. Mean water velocities in the Harbor are generally less than the critical velocity required for initiation of sediment motion supports this conclusion. The critical velocity is at least 0.45 to 0.60 fps for sediments that contain a relatively high percentage of silts and clays (Hjulstrom (1935) as described in ASCE (1975)). Based on a mean sediment size of 0.02 to 0.03 millimeter, the calculated critical velocity is actually in the range of 0.3 to 1.5 fps. For most of the year, observed mean water velocities in the Harbor are only 0.2 to 0.3 fps, suggesting that water velocities may usually be too low to scour sediments that have settled to the bottom. However, during flood and other high flow events, velocities may exceed 2-4 times the critical velocity (c. Anderson, USGS, personal communication), raising the possibility for significant out-of-Harbor transport of contaminated sediment. In addition, localized resuspension and transport may occur because of prop wash or wakes created by ships and boats or from dredging activities.

2.4.2 Contaminant Sources and Transport

Contaminant source definition is important because: (a) from a legal perspective, it establishes linkages to potential contributors (i.e., to the problem) who might participate in the investigation or remediation of the site; and (b) from a scientific perspective, it identifies the form of discharge and hence the fate and transport processes linking land-based contamination to aquatic systems, including sediments at one location with other areas where exposure could occur. In addition, source identification may help to focus the analyses for contaminants or limit the number of contaminants of concern if historical information about the site is available. The identification of sources of sediment contamination generally involves an examination of the operational histories of private or public facilities that may have contributed directly to contaminated sediments or to land-based contamination that has or might migrate to the sediments. The process can become complicated by the presence of many different historical or current sources. Sediments themselves represent a source as well as a receptor, as some types of contaminants tend to strongly sorb to particulate matter, may accumulate over time, and may be re-released to the water column via disturbance or dissolution during transport.

There are considerable data on potential sources of contaminants that enter the Willamette River upstream of the Harbor area. These sources and their resultant water quality impacts have been and are the topic of several basin-wide studies. Despite the many water and sediment quality studies that have been conducted over the years on the Willamette River basin and in the Harbor area, very little data exists on contaminant concentrations on suspended sediments carried into the Harbor area. Most of the past studies focused on bulk water quality or contaminant concentrations in bottom sediments, rather than on suspended sediments. In those studies where suspended sediment samples were collected, only a few samples were collected immediately upstream of the Harbor area and many contaminants were not detected. Available sediment and water quality data do indicate that some of the contaminants found in bed sediments in the Harbor area likely originated from sources upstream of the area.

The USGS conducted two phases of sampling throughout the Willamette River basin as part a comprehensive water quality study (Harrison et al., 1995). Analyses were made of bulk (i.e., unfiltered) water samples, filtered water samples, suspended sediment samples, and bed sediment samples during 1992 - 1993 (Phase I sampling) and in 1994 (Phase II sampling). One of the sampling points was located just upstream of the Harbor at the Portland USGS Willamette River gauging station. Another sampling point was located within the Harbor at the Linnton gauging station. Samples were analyzed for a broad range of constituents, including metals, organochlorine compounds, volatile organic compounds, semi-volatile compounds, and dioxins/furans. Very few contaminants were detected in unfiltered and filtered water samples or suspended sediment samples. Thus, few data exist for use in estimating the concentration of contaminants on sediments carried into the Harbor area.

An indirect indicator of contaminant contributions from upstream sources is to compare contaminant concentrations in navigation channel depositional areas removed from near-shore sources with those in near-shore areas closer to potential local sources. To this end, the

concentrations of selected constituents detected in navigation channel samples collected by the COE (1998) in historic deposition areas were compared to those collected near potential sources by EPA and DEQ (EPA, 1998d).

EPA samples collected near RM 7.3 show an increase in DDT concentrations, likely due to a source or sources in the Harbor area. All of the COE samples collected in historic depositional areas contained DDT concentrations below 100 µg/kg (Port of Portland, 1998). This suggests: (1) that upriver sources contribute DDT to suspended sediments being carried into the Harbor area by the Willamette River and (2) that concentrations <100 µg/kg represent an anthropogenic "background" for DDT in the Harbor. For naphthalene (a representative LPAH) and benzo(a)pyrene (a representative HPAH), the historical depositional areas contained naphthalene concentrations below 100 to 200 µg/kg and benzo(a)pyrene concentrations below 1,000 µg/kg. In several locations, the EPA near-shore, near-source samples contained higher concentrations, likely from a source or sources within the Harbor area. For cadmium and zinc, these data suggest that suspended sediments entering the Harbor may contain cadmium concentrations below 0.5 to 1 mg/kg, whereas sources in the Harbor cause higher cadmium concentrations. Zinc concentrations on sediments entering the Harbor appear to have concentrations below 100 to 200 mg/kg. Thus, the available data indicates that upstream contaminant sources are, at least in part, responsible for "ambient" concentrations of metals and PAHs found throughout the Harbor bed sediments. Upstream sources do not, however, appear to be responsible for the higher, localized contaminant concentrations apparently associated with intra-Harbor sources.

Within the 6-mile Harbor area, a number of industrial operations have been identified (see Sections 2.2 and 2.3) as potential sources of contamination to sediment in the Willamette River. Historical or current industrial operations include hazardous waste storage; marine construction; bulk petroleum product storage and handling; oil fire fighting training activities; oil gasification plant operations; wood-treating; agricultural chemical production; battery processing; liquid natural gas plant operations; chlorine production; ship loading and unloading; ship maintenance and repair (i.e., sandblasting, scaling, repair, painting, refueling); and rail car manufacturing.

Sediment sampling results from five stormwater discharge locations in the Harbor area found that arsenic, chromium, copper, lead, zinc and bis(2-ethylhexyl)phthalate were some of the more commonly detected contaminants. Maximum detected sediment contaminant concentrations at these five locations equal or exceed the maximum detected contaminant concentrations reported by EPA in 1997 (EPA, 1998d).

Monitoring at a discharge location draining an industrial land use in downtown Portland at Harbor Way found a suspended sediment concentration of 42 mg/L with copper at 45 µg/L, cadmium at 7 µg/L, and zinc at 290 µg/L in unfiltered water (Anderson et al., 1996). Monitoring at the Interstate 84 runoff site which discharges into the Willamette River underneath the Burnside Bridge, detected a large variety of organic compounds despite the fact that this site represents a single land use (downtown Portland freeway). In addition to trace metals and volatile organic compounds, several organochlorines (DDT, dieldrin, heptachlor, and lindane), 16 different pesticides (including atrazine, metolachlor, simazine, diuron, chlorpyrifos, and others), and PCBs were also detected (Anderson et al., 1996).

Another form of potential nonpoint source of contaminants for the Harbor is the subsurface migration of contaminated groundwater or NAPLs into the river. No data were found in the information reviewed as part of this study to quantify the contribution from these types of nonpoint sources. This information is expected to become available through remedial investigations at specific clean-up sites.

The transport of contaminants that have a tendency to adsorb to sediment particles will be controlled by the transport, deposition and resuspension of sediments within the Harbor. Water velocities in the Harbor are thought to be usually low, suggested that sediments (and associated contaminants) that have settled to the Harbor bottom would not tend to be resuspended and transported within or outside the Harbor. An example of this is the Portland General Electric Station L site in downtown Portland, where a spill from a failed transformer resulted in the release of PCBs into the Willamette River. This site is located near the Marquam Bridge on the east side of the Willamette River. Spill records discovered many years later indicated that the release occurred in the early 1970s. Sediment sampling conducted almost 17 years after the release found that PCBs were detected within only 50 to 100 feet of the original point of release. Data have not been collected on additional transport of PCBs from the site.

Because the transport of contaminants from one location to another in the Harbor is expected to be limited, it is unlikely that contaminants from one local source will become commingled with those from other local sources, particularly where the sources are widely separated. Localized commingling of contaminants is possible, however, where several sources are located in close proximity to each other and where ship and boat traffic or dredging activities have caused localized disturbance of sediments.

2.4.3 Exposure Routes

The number of routes of exposure considered is limited to those that are deemed to be important for the assessment endpoints. The following points should be considered:

Benthic invertebrates are exposed to sediment pore water and whole sediment. The evidence is strong that some benthic invertebrates are significantly exposed to a variety of chemicals by ingestion of sediment particles. Therefore, it is important to characterize risks due to both modes of exposure through analysis of bulk sediment (containing pore water) or toxicity tests.

Fish are assumed to be exposed to contaminants in water, through dietary exposures, and through direct contact with the sediment (especially true for flatfish and suckers that spend a good deal of time in and on the bottom sediments). It has generally been assumed that dietary exposures are negligible and that is likely to be true for most chemicals. This is reasonable given the relatively high rate of exposure of organisms to chemicals in the water that pass their respiratory surfaces and the fact that most chemicals are not highly bioaccumulative and do not biomagnify. However, dietary exposures are important for a few long-lived and biophilic chemicals such as DDE, DDT, and metabolites and may be important for a wider variety of chemicals than is

currently recognized. Fish body burdens integrate dietary, contact, and direct aqueous exposures.

Human exposure routes (Figure G-1) include at sediment sites are nearly always focused on consumption of contaminated fish and shellfish. Other significant pathways are occasionally present, such as dermal exposure and incidental ingestion during recreational use (particularly clam-digging or other similar activities) and exposure to contaminated sediments during fishing (primarily methods in which nets are used that drag along the bottom and bring up sediment into fishing boats).

Wildlife exposure routes (Figure G-2) usually include ingestion of food, drinking water, and incidental sediment ingestion. Sediment ingestion rates have been calculated for a number of terrestrial species and can be a major transport route for exposure (e.g., swans consuming sediment containing lethal levels of lead in Idaho). Thus sediment ingestion is nor being excluded for species such as osprey and bald eagle, as these species can ingest sediment when consuming carp whose stomachs contain plant matter and sediment. Birds such as herons feeding in shallow areas may also consume sediment attached to their prey items.

2.5 Conceptual Model

A conceptual model is a written description and visual representation of predicted relationships between receptors and the contaminants to which they may be exposed. Conceptual models consist of two main components: (1) a set of testable problem statements (i.e., “risk hypotheses”) that describe predicted relationships among contaminant, exposure, and assessment endpoint response, along with the rationale for their selection and (2) a diagram that illustrates the relationships presented in the problem statement. A conceptual model is more than the typical exposure pathway diagram, in that it attempts to anticipate where, how, when, and to whom effects may occur.

As a final check to ensure that the assessment is proceeding in the right direction, the assessor should verify with the environmental manager and stakeholders that the proposed conceptual model will provide the information needed to support the manager in making appropriate environmental decisions. When agreement has been reached on the conceptual model and on the plan of action to carry out the assessment, the problem formulation phase is terminated and assessment design begins.

2.5.1 Assessment Endpoints

Assessment endpoints for sediments at contaminated sites establish the overall direction and focus of the assessment. Assessment endpoints are established through discussions among the assessor, environmental manager, and others (e.g., the public) who may be interested in, or affected by, the outcome of the decisions. Assessment endpoints reflect what human beings are

Figure G-1. Human and Wildlife Exposure Pathway Model for Portland Harbor

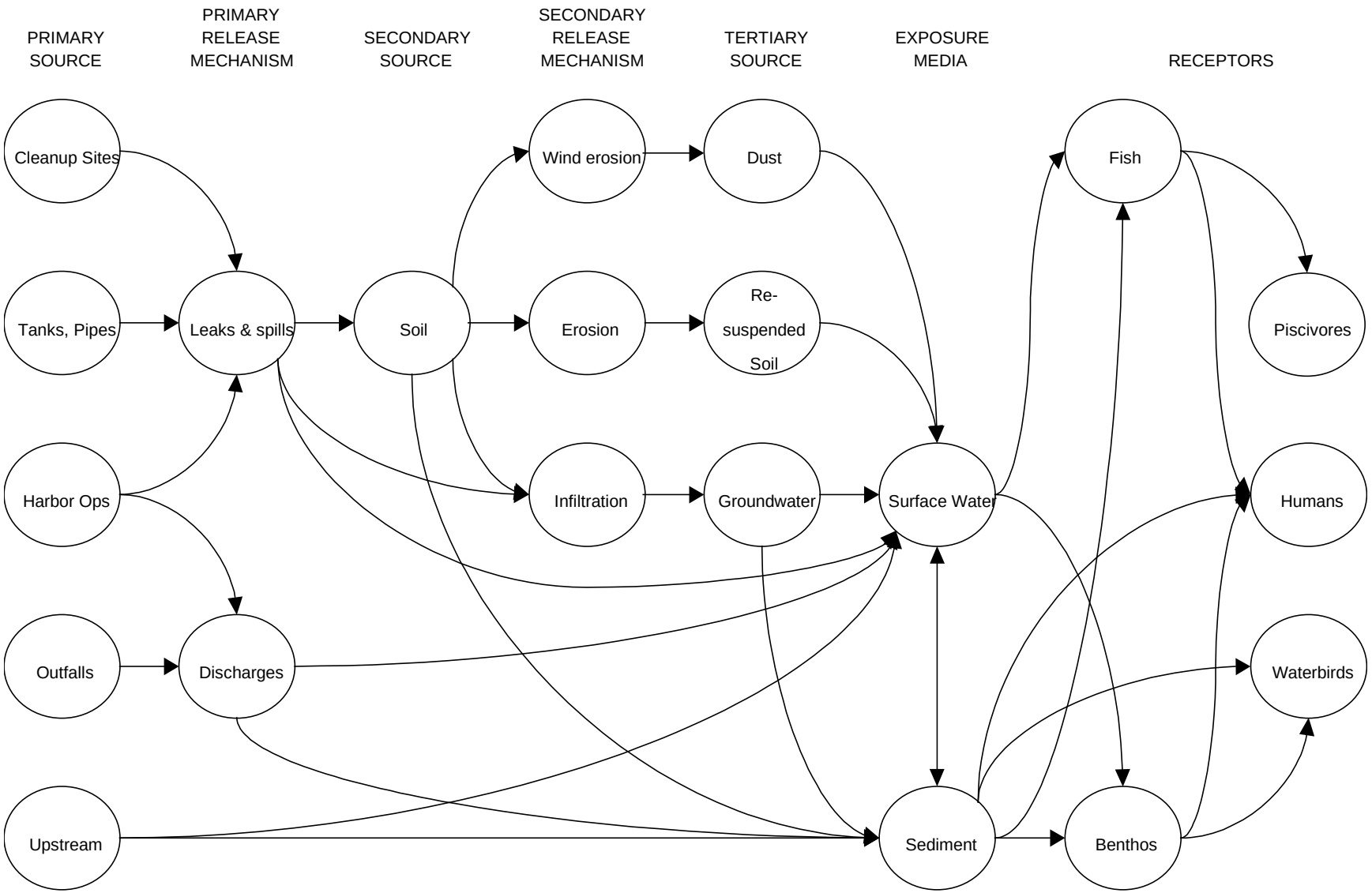
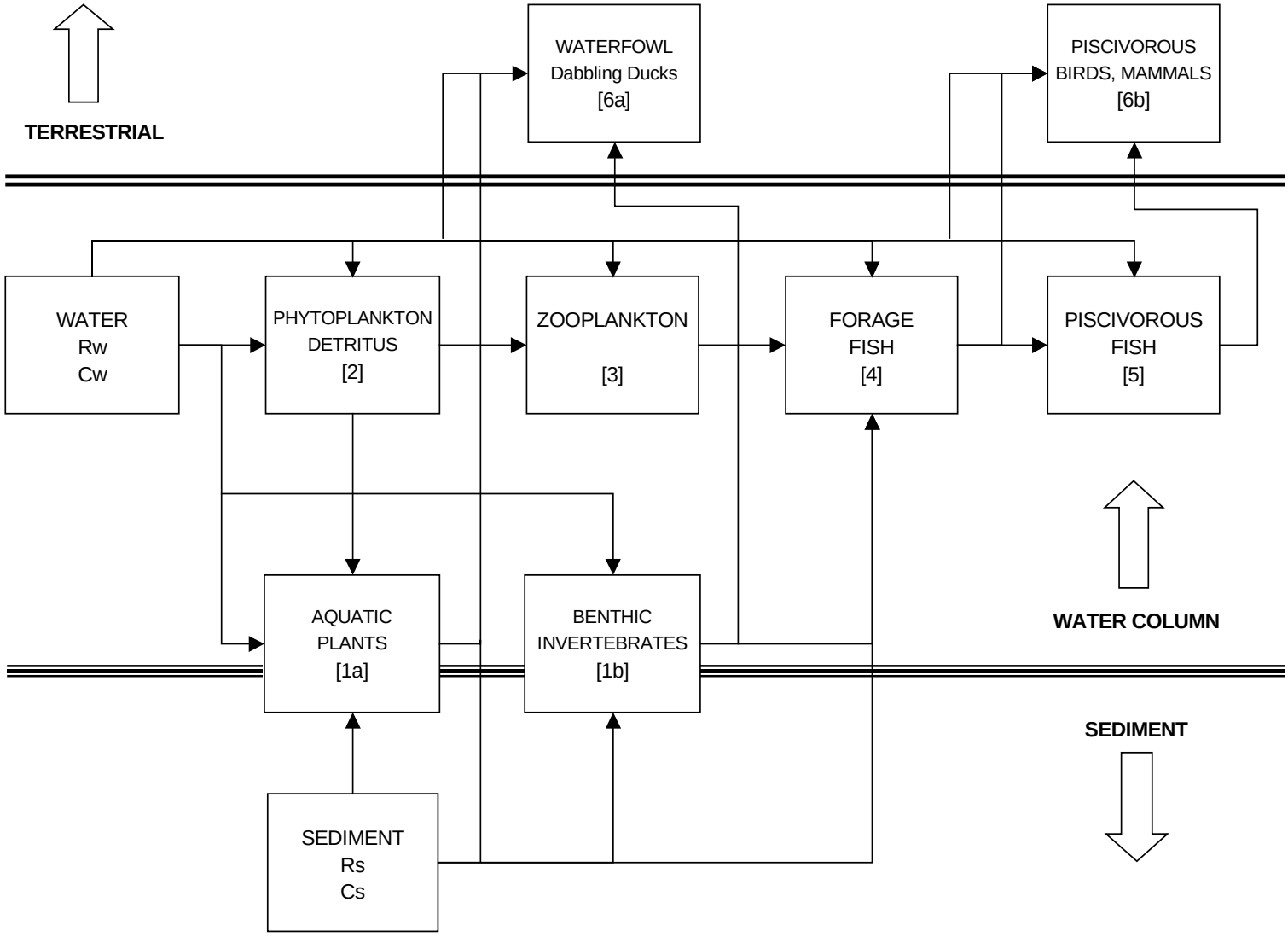


Figure G-2: Wildlife Food Web Model for Portland Harbor



concerned with or care about, expressed in a manner that can be evaluated through an objective scientific process. Such endpoints may include both human health and ecological concerns. The selection of assessment endpoints is a critical communication step among the assessor, environmental manager, and others (e.g., stakeholders) interested in the outcome of the assessment. The objective is to reach a consensus on what the assessment endpoints will be. Assessment endpoints should be defined in terms of: (a) a receptor (species, community, other level of organization) and (b) a characteristic or function *(*e.g., survival, maintenance, reproduction) to be protected. Not all assessment endpoints included in the SAM are risk-based; for example, some endpoints consider whether other beneficial uses may be impaired (e.g., impacts on aesthetics, fisheries, navigation).

2.5.2 Testable Problem Statements

Testable problem statements describe predicted relationships between contaminants, exposure, and assessment endpoint response (i.e., each is a statement of how a given contaminant might affect an assessment endpoint and what the criteria are for judging whether any effect is indicative of adverse effects or not). For example, "…percent survival of benthic invertebrates is not significantly ($p \leq 0.05$) less in Harbor sediment samples than in reference sediment samples…" states a position that contaminants in sediment may cause mortality (adverse effect) in benthic invertebrates (an assessment endpoint) and that an unacceptable condition will be indicated if site sediment is significantly (defined) more toxic than reference site sediment. This statement is tested with an appropriate aquatic bioassay. Testable problem statements clarify and articulate relationships that are posited through the consideration of available data, information from scientific literature, and the best professional judgment of assessors developing the conceptual model. This explicit process opens the assessment to peer review and evaluation to ensure the scientific validity of the work. Testable problem statements are not equivalent to statistical testing of null and alternative hypotheses. However, predictions generated from testable problem statements can be tested in a variety of ways, including standard statistical approaches.

The results of individual problem statement tests ("lines-of-evidence") can be combined using formal weight-of-evidence methods to make a more holistic evaluation of risk in the Harbor for a single receptor type (e.g., benthic invertebrates). The weight-of-evidence analysis generally has its own criteria for judging adverse effects, with each line-of-evidence having its own weight within the evaluation. If this method is employed, it is important that stakeholders be involved in approving the criterion for each problem statement, as well as the criteria for any weight-of-evidence analysis. If stakeholders are involved, it is incumbent on the assessor to remain faithful to these established criteria when reaching conclusions regarding adverse effects.

2.5.3 Measures

There are three categories of measures, each of which may be evaluated either qualitatively and/or quantitatively: (1) measures of exposure are measures of contaminant existence and movement in the environment and their contact or co-occurrence with the assessment endpoint; (2) measures of

effect are measurable changes in an attribute of an assessment endpoint or its surrogate in response to a contaminant to which it is exposed; and (3) measures of characteristics include environmental characteristics that influence the behavior and location of entities selected as the assessment endpoints, the distribution of a contaminant, and life history characteristics of the assessment endpoint or its surrogate that may affect exposure or response to the contaminant. Because measures are the bases for structuring the analysis phase of the sediment assessment, and because they will ultimately be used to estimate adverse effects, they should be related explicitly, either directly or indirectly, to specific assessment endpoints and should include metrics (e.g., toxicity results, tissue levels, and community structure) that can be used for estimating effects.

2.5.4 Uncertainty

Conceptual model development may account for one of the most important sources of uncertainty in a risk assessment. If important relationships are missed or specified incorrectly, risk characterization may misrepresent actual risks. Uncertainty arises from, among other things, lack of knowledge about receptor behavior or functions, failure to identify and interrelate temporal and spatial parameters, omission of contaminants, or overlooking secondary effects. Uncertainty associated with conceptual models can be explored by considering alternative relationships. If more than one conceptual model is plausible, the risk assessor may evaluate whether it is feasible to follow separate models through analysis or whether the models can be combined to create a better model.

2.6 Risk Characterization

This plan uses a combination of effects-based testing and calculated comparisons to applicable criteria (reference doses, cancer potency factors, target tissue levels, tissue screening concentrations, and sediment quality guidelines) to assess risks to both human and ecological receptors. For the benthic community, risk will be assessed using either toxicity testing (a suite of bioassay tests) and or sediment quality guidelines (which are developed with toxicity testing). Target tissue levels, which are allowable tissue concentrations back-calculated (per EPA RAGS Part B) from acceptable levels (reference doses, cancer potency factors), will be used to assess risk to humans through consumption of contaminated fish. For localized human exposures (dermal contact, incidental ingestion of sediment), standard EPA risk characterization protocols, RAGS Part A guidance and IRIS-derived reference doses and cancer potency factors) will be used. Both human target tissue level development and localized human health risk assessments will include: reviewing outputs from the toxicity and exposure assessments, quantifying risks, assessing and presenting uncertainties, summarizing and characterizing risk characterization results. Risk to higher trophic level wildlife consuming contaminated fish will also be assessed using target tissue levels; in this case, allowable tissue concentrations back-calculated from acceptable levels (toxicity reference values based on NOAEL or LOAEL endpoints). Development of wildlife TTLs will include risk estimation, risk description, risk calculation, uncertainty analysis, interpretation of uncertainty and interpretation of ecological significance will be included in the development of wildlife target tissue levels.

2.7 Sediment Assessment Design

The sediment assessment design includes pathways and relationships identified during problem formulation that will be pursued during the assessment. Those problem statements considered more likely to contribute to adverse effects are targeted. The rationale for selecting and omitting problem statements is incorporated into the plan and includes acknowledgment of data gaps and uncertainties. It also may include a comparison of the level of confidence needed for the environmental management decision with that expected from alternative analyses in order to determine data needs and evaluate which analytical approach is best. When new data are needed, the feasibility of obtaining them can be taken into account. The assessment design is basically the plan for the collection of field samples, as well as interpretation of resulting data. The assessment design must be critically evaluated to ensure that data generated will fully answer all of the specific questions developed through problem formulation. In particular, the measurement tools must be relevant to the concerns associated with the assessment endpoint.

Details of the sediment assessment design are described in the following sections: Section 3.0 (Technical Evaluation Framework), Section 4.0 (Sampling), Section 5.0 (Analysis), and Section 6.0 (Freshwater Sediment and Tissue Guidelines). These sections describe a variety of tools for assessing risks to the benthic community, fish, wildlife, and humans, as well as methods for assessing injuries to natural resources, impairment of beneficial uses, and potential impacts to endangered species. As noted in Section 1.1, some assessments will be conducted harbor-wide and others only at specific sites.

3.0 TECHNICAL EVALUATION FRAMEWORK

Specific sediment-related objectives derive from the mission statement that guides the overall PHSMP. The SAM, a component of the PHSMP, is designed to assess whether these objectives have been attained. Five objectives are currently listed (Section 1.1). Attainment of each objective is evaluated using an objective-specific technical evaluation framework (TEF), consisting of:

- An introduction that describes the objective being evaluated and its importance,
- Assessment endpoints, testable problem statements, and measures (together, the "conceptual model") associated with evaluation of that objective,
- Exposure and effects estimation "tools" (Sections 4.0, 5.0, and 6.0) with which to collect data necessary for the evaluation, and
- Decision guidelines (including risk characterization protocols) that describe a preferred approach to interpreting those data in order make a supportable recommendation regarding objective attainment.

Objectives, along with their evaluation guidelines, can be removed, or new ones created, in response to changes in the PHSMP. By implementing the specific evaluation guidelines for each objective, it will be possible to determine whether that objective has been "attained" or not. This information is passed to the environmental managers as one factor in their decision-making process.

3.1 Site, Harbor, Reference Area Investigation Coordination

A "site" is a current or future (i.e., "to-be-discovered") DEQ cleanup site as defined by OAR 340-122-115(26). Per OAR 340-122-115(34), a site may extend to any other portion of the river where contaminants released from that site could come to be located. At present, all known sites of interest to the PHSMP are within the "Harbor area", the 6-mile segment of the Willamette River between RM 3.5 and 9.5. "Reference areas" will be identified at locations, within the lower Willamette River (river segment from Willamette Falls (RM 26.5) to the Columbia River confluence at RM 0.0) and, as appropriate, in the Columbia River itself, that are presumably unaffected by site-related contaminants. "Harbor-wide" refers to a combination of Portland Harbor and the reference areas.

To properly evaluate each objective, evaluations must be performed at sites, in the Harbor area, and in reference areas, and the results integrated. There are several benefits attributable to conducting area-wide studies in support of site-specific studies, including: (a) enabling refinement and focusing of methods prior to their application at specific sites, (b) minimization of site-specific testing, (c) placing the focus on COIs that present problems over a wide area, (d) with respect to fish and wildlife issues, reducing the total cost by doing one study, one time and sharing the results, and (e) enabling development of an area-wide biota-sediment accumulation function (BSAF) to simplify calculation of site-specific RAOs.

The potential for adverse effects from toxicity (Objectives (1), (2, contact)) would typically be evaluated on a site-specific, as opposed to a Harbor area, basis. However, information needed for development of the sediment quality guideline (SQG) data base, and for evaluation of risk posed to and by fish, must also be obtained from Harbor and reference area investigations. Similarly, all site-specific toxicity evaluations will initially contribute to development of this SQG data base. The potential for adverse effects from bioconcentration or bioaccumulation of contaminants in food items (Objectives (2, food), (3), (4), (5)), will first be evaluated on a Harbor and reference area basis. This will include evaluation of risks to: (a) fish and wildlife (whose forage or migration range may encompass the entire Harbor, or an even larger, area) and (b) humans from consumption of locally caught fish. Only if these larger scale evaluations suggest a problem will site-specific investigations of bioconcentration or bioaccumulation be performed.

There are a number of additional investigations that would be undertaken across sites, the Harbor area, and reference areas to develop supporting data for each objective-specific evaluation. These supporting investigations would include: (a) determining the nature and extent of fish and wildlife populations and their associated habitats (supporting wildlife target tissue level (TTL) and fish tissue screening concentration (TSC) development), (b) surveying human uses of the area, including attempting to quantify recreational and subsistence fishing activities (supporting human TTL development), (c) considering the effects of non-chemical stressors on assessment endpoints, and (d) determining the nature and extent of the benthic community. To minimize cost and time, many of these supporting studies would be primarily literature surveys corroborated with focused field validation activities.

3.2 Objective (1)) - Benthos

A healthy benthic community is a protected beneficial use. Clean sediment (i.e., those that do not restrict dredging or other commercial activities) can be identified by a lack of response in the benthic invertebrate community to contaminants in sediment. Dredging is a necessity to maintain the commercial viability of Portland Harbor. However, the presence of contaminated sediments in a working, urban harbor can greatly increase the complexity and cost of routine maintenance dredging and may, in extreme cases, prevent dredging all together. Contaminated sediments may also adversely affect dredging for new construction or other capital improvement projects. Contaminated sediment impairs beneficial uses in the Harbor by directly impacting the benthos and by potentially placing restrictions on dredging activities, as well as adding costs to agriculture (e.g., through increased shipping charges for bulk commodities) and industry.

3.2.1 Sites

3.2.1.1 Conceptual Model

Elements of the conceptual model for the benthic community at any given site are summarized in Table G-3.

Table G-3: Objective (1) Conceptual Model Elements - Benthic Community

Assessment Endpoints	Testable Problem Statements	Measures of
Survival, growth, and reproduction of benthic invertebrate species	Contaminant concentrations in bulk sediment or pore water do not exceed contaminant-specific SQGs (Table G-4, Outcome A). **or** Sediment bioassay tests show no adverse effects in test organisms exposed to Harbor sediment [Table G-4, outcome C]	**Exposure:** Contaminant concentrations in pore water and sediment **Effect:** SQGs; Bioassay tests
Maintenance of benthic invertebrate community species diversity and abundance	Same as above	Same as above

Figure G-3: Decision Guidelines for Objectives (1), (2, contact) - Site-Specific

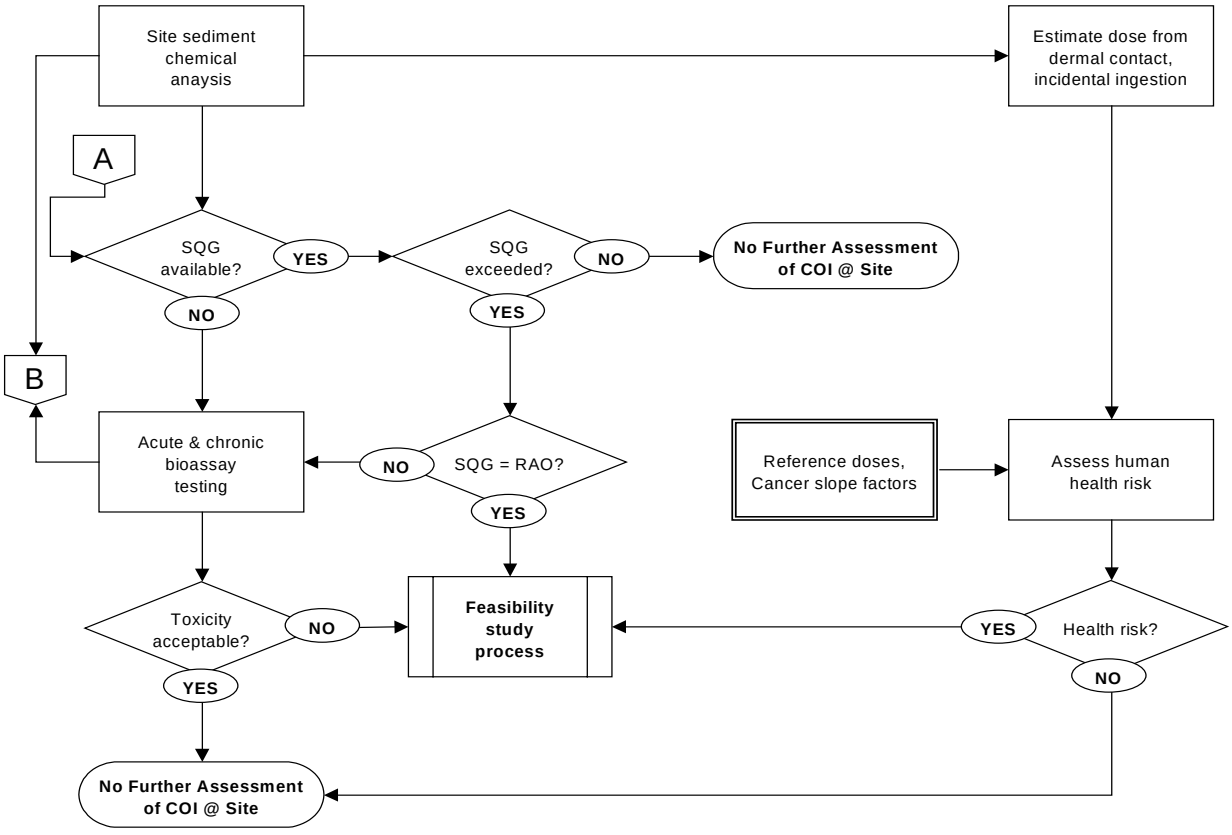


Table G - 4: Interpretation of Chemistry and Bioassay Results

Toxicity	Sediment Chemistry	[Outcome] Possible Interpretation
–	–	[A] Contaminants are not present in sediment and are not toxic to benthic organisms. No further assessment needed.
+	–	[B] Toxicity to benthic organisms due to contaminants without SQGs or unrecognized contaminants. Potential for adverse effects to benthic communities. Additional evaluation may be needed to address uncertainty; remedy selection required.
–	+	[C] Contaminants in sediment are not toxic to benthic organisms. If bioaccumulation is not a factor, no further assessment needed.
+	+	[D] Contaminants in sediment are bioavailable and toxic to benthic organisms. Potential for adverse effects to benthic communities. Additional evaluation needed to address uncertainty; remedy selection required.

To assess toxicity, tests 1, 2, and 3 must be run, or test 3 may be replaced by 4, 5, or 6. Once final protocols for tests 4-6 are available, test 3 may be permanently replaced.

1. Mortality of test organisms in the *H. azteca* 10-day survival test
2. Survival and growth of test organisms in the *C. tentans* 10-day survival test
3. Percent luminescence in the pore water or deionized water extract Microtox test
4. [ADD CHRONIC 28-DAY *H. azteca* TEST]
5. [ADD *Tubifex* TEST]
6. [ADD *Lumbriculus* TEST]

In the short term, bioassay endpoints should be interpreted in accordance with the Lower Columbia River Dredged Material Evaluation Framework (DMEF, 1998). A freshwater bioassay workshop will be convened to develop endpoints for additional bioassays and/or modify existing endpoints in coordination with the dredging program. For sediment chemistry, "+" indicates presence of a contaminant above SQGs, given detection limit < SQG.

3.2.1.2 Decision Guidelines

As shown schematically in Figure G-3, until SQGs are developed, all sites will collect synoptic sediment chemistry and toxicity bioassay data. These data will be entered into the SEDQUAL data base [B] and SQGs then generated from this data base [A]. The SEDQUAL data base is integral to the SQG development process. Once SQGs are available, chemistry data are screened against them. If a SQG is available for a given contaminant of interest (COI), and it is not exceeded, then no further assessment of that COI at this site is required. However, if the SQG is exceed, then it is the responsible party's choice to either accept a remedial action objective (RAO) equal to the SQG and proceed to remedy selection or conduct acute and chronic bioassays. The SQG is a minimum, consistent level of performance for all sites. If acute and chronic bioassays are conducted and results are acceptable (per Table G-4) then no further assessment is required; however, if results are not acceptable, then a remedy selection process is required. Results of any bioassay tests conducted at a site are made available to the SEDQUAL data base. As the SEDQUAL data base grows, the need to perform confirmatory acute and chronic bioassay testing at sites will diminish.

To maintain continuity with data obtained from previous studies and to expedite SGQ development in the short-term, decisions (per Table G-4) may be based on the results of 10-day *H. azteca* survival, 10-day *C. tentans* survival and growth, and Microtox tests (c.f., Section

5.2.1.1). In the long-term, the Microtox test will be replaced by the new chronic test.

Long-term options include: (1) Replace the 10-day *H. azteca* survival test with a 28-day *H. azteca* survival and growth test (Section 5.2.1.2) and the Microtox test with either a 28-day *Tubifex* reproductive test or a *Lumbriculus* test (Section 5.2.1.2) or (2) Use only the 10-day *C. tentans* growth test, the 28-day *H. azteca* survival and growth test, the 28-day *Tubifex* test and/or the *Lumbriculus* test. At present, Option 2 is preferred for long-term SQG development.

Benthic community analyses are included as an option, as part of a sediment quality triad approach, with the chemistry and toxicity tests the primary tools; data would be made available to the SEDQUAL data base. In these cases, decisions will be based on the results of all tests conducted (per Table G-5).

At present, responsible parties may address benthic issues in three ways: (a) comparison with SQGs, (b) performance of a suite of bioassay tests, or (c) by means of a sediment quality triad (with collection of chemistry, bioassay, and community data). Results of one or more of these approaches would be considered definitive with respect to evaluating acceptability under OAR 340-122-115(5,6). If such investigations indicated acceptable levels of toxicity, then no further assessment would be appropriate with respect to toxic effects in the benthic community. The finding of unacceptable levels of toxicity would be considered to definitively indicate unacceptable risks and would indicate the need for the remedy selection process.

Table G - 5. Interpretation of Sediment Quality Triad Results

Toxicity	Benthic Community	Sediment Chemistry	[Outcome] Possible Interpretation
–	–	–	[A] Contaminants not present in sediment, no toxicity to test species, and no alteration of benthic community. No further assessment needed.
+	–	–	[B] Toxicity to test species due to test factors unrelated to contamination. No further assessment needed.
+	-	-	[C] Toxicity attributable to chemical contaminants for which there are no SQGs available. Further assessment may be warranted.
–	+	–	[D] Alteration of benthic community by unrecognized contaminants or confounding factors (habitat features, disturbance) unrelated to contaminants. Potential for adverse effects to benthic communities. Additional evaluation may be needed to address uncertainty; management decision required.
–	–	+	[E] Contaminants in sediment not toxic to test species and no evident alterations in benthic community. No further assessment.
+	+	–	[F] Toxicity to test species and alteration of benthic community by contaminants without SQGs or unmeasured contaminants or a mixture effect or non-chemical factors. Potential for adverse effects to benthic communities. Additional evaluation may be needed to address uncertainty; management decision required.
+	–	+	[G] Contaminants in sediment are toxic to test species, but adverse effects to benthic community are not discernable. Test conditions may not represent field conditions. Additional evaluation needed to address uncertainty; management decision required.

Table G - 5. Interpretation of Sediment Quality Triad Results

Toxicity	Benthic Community	Sediment Chemistry	[Outcome] Possible Interpretation
–	+	+	[H] Contaminants in sediment not toxic to test species but alterations in benthic community are evident. Test species may not be sensitive or non-chemical factors may be affecting benthos. Additional evaluation needed to address uncertainty; management decision required.
+	+	+	[I] Contaminants in sediment are toxic to test species and alterations in benthic community are evident. Management decision required.

- For toxicity and sediment chemistry, "+" defined as in Table G-4.
- For benthic community analysis, "+" means significant differences in selected ecological metrics between site and reference samples.

3.2.2. Harbor & Reference Areas

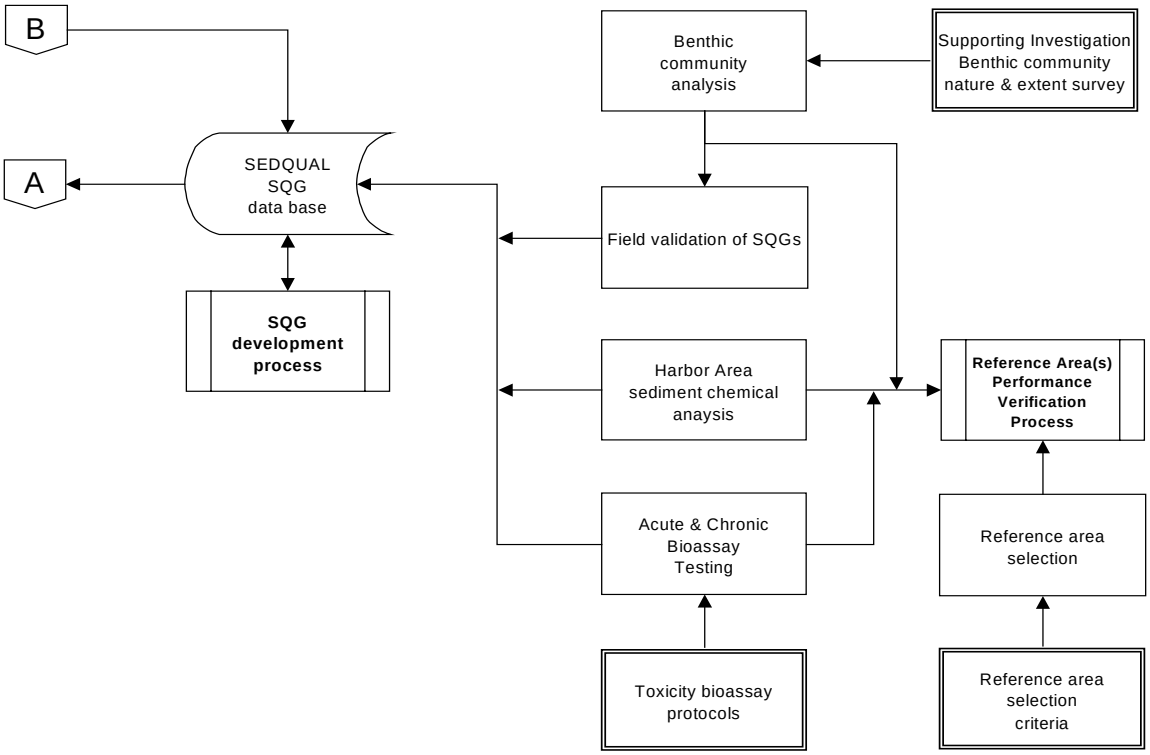
3.2.2.1 Conceptual Model

Sediment chemistry analyses, bioassay tests, and benthic community analyses are conducted in Harbor and reference areas for the purpose of developing the SQG data base and for verifying reference area performance (i.e., is it really a reference area?). Benthic community analyses are currently used primarily to field validate the SQGs (i.e., does SQG exceedance correctly predict adverse changes in the benthic community?). The SQGs may also be tested against an independent data set to determine their predictive capability. The conceptual model for an area-wide benthic community evaluation is the same as that for a site (c.f., Table G-3).

3.2.2.2 Decision Guidelines

As shown schematically in Figure G-4, sediment chemistry and toxicity bioassay data are used to support the SQG development process. Site-specific chemistry and bioassay data are made available to the SEDQUAL data base [B] and SQGs are generated [A] from this data base for use at sites.

Figure G-4. Decision Guidelines for Objective (1) - Harbor-Wide



3.3 Objective (2) - Human Use

Recreational and subsistence fishing, beach use, swimming, and recreational boating activities all occur within and near the Harbor. A person's participation in these activities could facilitate exposure to contaminated sediment or to food items contaminated by exposure to Harbor sediment. Dockyard workers and maintenance personnel, work boat and marine equipment operators, and divers may also have some potential for contact with Harbor sediment. Contaminated Harbor sediment could thus adversely impact a number of human-related beneficial uses, including restricting fish and wildlife consumption (e.g., through fish consumption advisories), tainting of fish and wildlife flavor, degrading of fish and wildlife populations, restrictions on drinking water consumption, taste and odor problems, beach closures, or degradation of aesthetics.

3.3.1 Sites

3.3.1.1 Conceptual Model

Dermal Contact, Incidental Ingestion: Elements of the conceptual model for assessing risks to human health from incidental ingestion of sediment and dermal contact with sediment are

summarized in Table G-6. This conceptual model assumes exposure occurs during: (a) beach use, (b) in-water recreation, and (c) occupational activities. Methods and default exposure factor values for conducting human health assessments for incidental ingestion and dermal contact exposures are described in detail in EPA guidance documents (EPA, 1989, 1991b, 1992ab, 1993c, 1994c, 1997a, 1998cef).

Table G-6: Objective (2) Conceptual Model Elements - Human Dermal Contact and Incidental Ingestion

Assessment Endpoints	Testable Problem Statements	Measures of
Carcinogenic risks from dermal contact and incidental ingestion exposures	Dose received through dermal contact, incidental, and other routes from sediment is less than a dose equivalent to a 1×10^{-6} risk level for individual carcinogens and 1×10^{-5} for al carcinogens.	**Exposure:** Contaminant concentrations in sediment; Dose estimate **Effect:** Cancer slope factor (CSF)
Noncarcinogenic risks from dermal contact and incidental ingestion exposures	Dose of all noncarcinogens received through dermal contact, incidental ingestion, and other exposure routes from sediment is < a dose equivalent to a hazard index (HI) of 1.	**Exposure:** Contaminant concentrations in sediment; Dose estimate **Effect:** Reference dose (RfD)
Aesthetic impacts (sheens, sludges)	Not present	**Exposure:** Visual observation **Effect:** Presence

Fish Tissue Consumption: Elements of the conceptual model for assessing risks to human health from fish consumption at specific sites are the same as those summarized in Table G-7.

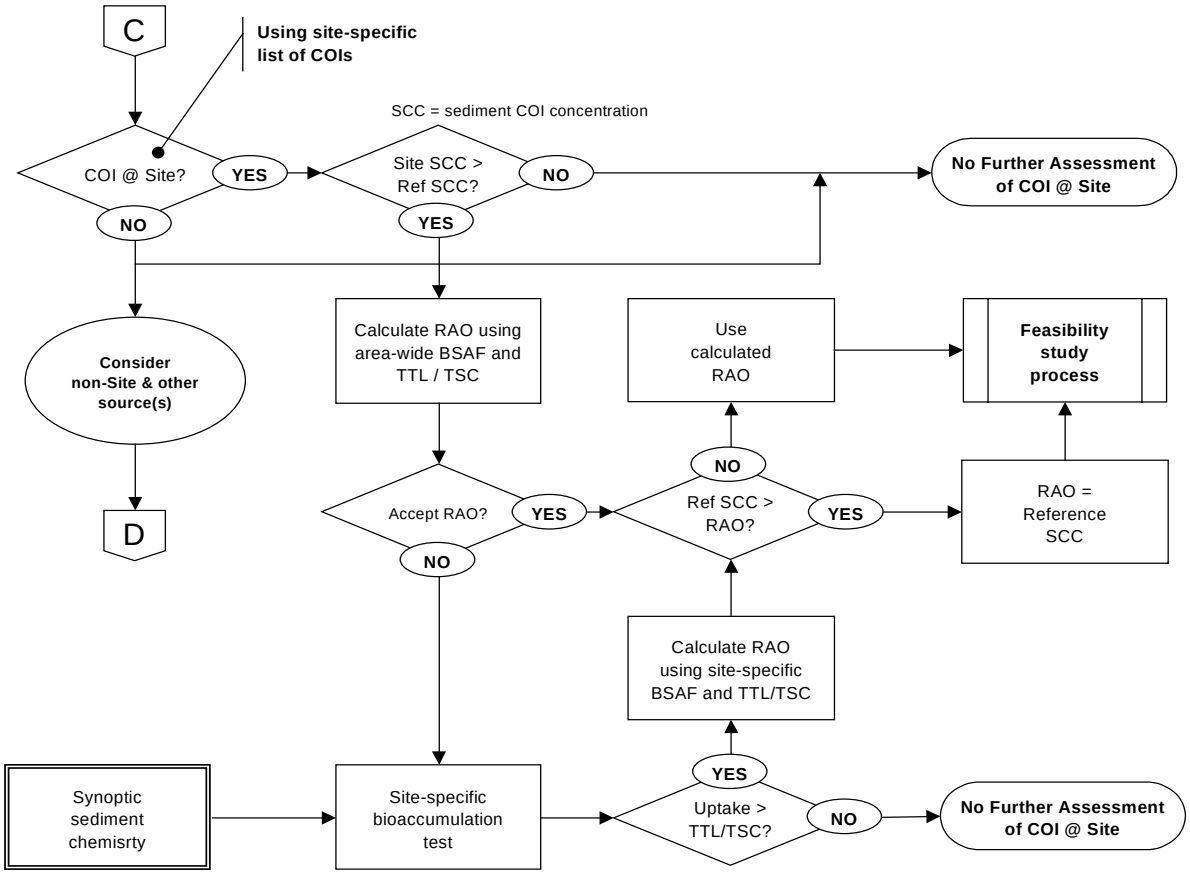
3.3.1.2 Decision Guidelines

Dermal Contact, Incidental Ingestion: As shown schematically in Figure G-3 estimated doses received through dermal contact and/or incidental ingestion of sediment are compared to established regulatory criteria (OAR 340-122-115(2,3,4)). If individual and cumulative risks are found to be acceptable, no further assessments is required; otherwise, the remedy selection process is begun. The same hold true for the observance of sheens or sludges.

Fish Tissue Consumption: As shown schematically in Figure G-5, the evaluation of fish consumption risks will not take place at specific sites until a Harbor and reference area evaluation of tissue levels (Figure G-6) is completed. If Harbor area exceedances are noted for a given COI [C], an attempt is made to find this same COI at specific sites. If it cannot be found at a known site, then [D] a potential non-Harbor, non-sediment (e.g., ubiquitous water-related), or unidentified site source is suspected. If a match is made with a known site, but sediment concentrations of the COI at the site are less than those in reference areas, then no further assessment of that COI at the site is required. This avoids attempting to cleanup sites to below reference concentrations. However, if site concentrations are greater than those in the reference

area, the responsible party calculates a RAO using a human TTL and an area-wide BSAF.

Figure G-5: Decision Guidelines for Objectives (2, food), (3), (4), (5) - Site-Specific



The responsible party may then either accept this RAO, in which case it is compared to the reference area sediment concentration. If the RAO is greater than the reference area concentration, then the RAO is set equal to the reference area sediment concentration and remedy selection begins. Again, this avoids attempting to cleanup sites to below reference concentrations. If not, then the calculated RAO is used in the remedy selection process. If the responsible party chooses not to accept the RAO calculated using an area-wide TTL and BSAF, possibly because they believe there are site-specific factors that may affect bioavailability and uptake, they have the option to perform testing necessary to support a site-specific RAO. If site-specific bioaccumulation testing is performed and, if uptake is less than the TTL, no further assessment is required. Otherwise, the bioaccumulation test results are used to calculate a site-specific BSAF and then a site-specific RAO for that COI. Following comparison to reference area sediment concentrations, This site-specific RAO is carried into the remedy selection process. At sites, TTLs are converted into their remedial action objective (RAO) equivalents using either an area-wide biota-sediment bioaccumulation function (BSAF) calculated from area-wide sediment and tissue data or a site-specific BSAF calculated with data from site-specific bioaccumulation tests and sediment chemistry data (See Section 6.2.2.5). This ensures that the

TTL remains a minimum level of site performance.

3.3.2 Harbor & Reference Areas

3.3.2.1 Conceptual Model

Elements of the conceptual model for assessing risks to human health from fish consumption are summarized in Table G-7. The model assumes exposure scenarios for recreational, subsistence, and Tribal fishing, with the principal exposure route assumed to be consumption of contaminated fish and shellfish.

Table G-7: Objective (2) Conceptual Model Elements - Human Fish Consumption

Assessment Endpoints	Testable Problem Statements	Measures of
Carcinogenic risks for consumption of fish and shellfish	Contaminant levels in food item tissues are ≤ a contaminant-specific TTL for humans.	**Exposure:** Contaminant concentrations in food items **Effect:** TTLs
Noncarcinogenic risks for consumption of fish and shellfish	Contaminant levels in tissues of food items are ≤ a contaminant-specific TTL for humans.	**Exposure:** Contaminant concentrations in food items **Effect:** TTLs
Curtailment of recreational fishery (fishing restrictions)	Contaminant levels in tissues of food items are ≤ a FDA action level.	**Exposure:** Contaminant concentrations in food items **Effect:** FDA action level

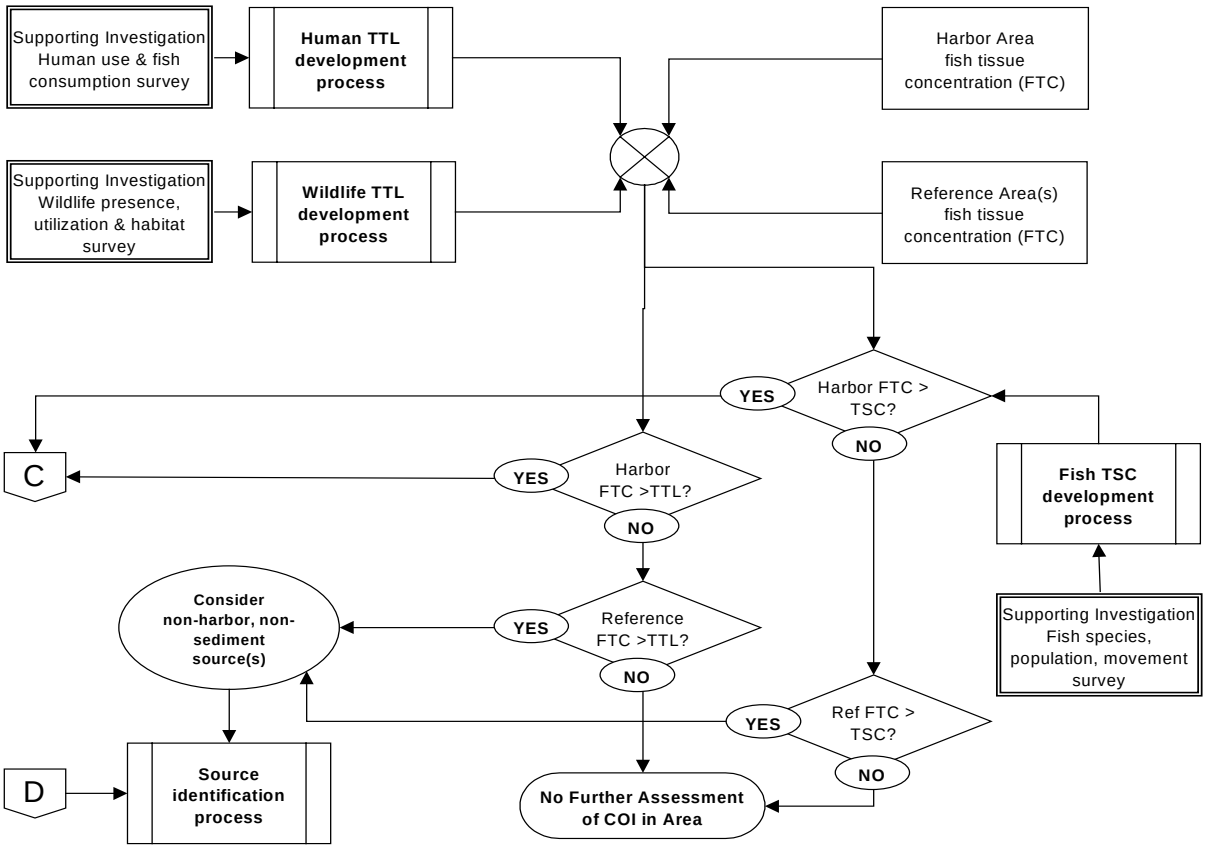
3.3.2.2 Decision Guidelines

As shown schematically in Figure G-6, TTLs would be used to evaluate risks associated with fish consumption exposures. A TTL is the concentration of a given contaminant in a given tissue type that cannot be exceeded without potentially inducing unacceptable risk in a receptor which consumes this tissue with a specified frequency and duration. A contaminant-specific human TTL can be calculated given some reasonably conservative assumptions about fish tissue intake, a contaminant-specific reference dose or cancer slope factor, and an acceptable risk level (e.g., 1×10^{-6}). Contaminant tissue concentrations in food items, determined only by measurement, can then be compared to the TTL to estimate the potential for adverse effects. A detailed discussion of human TTL development is provided in Section 6.2.2.4.

A key consideration in the development of human TTLs is selection of exposure scenarios, including consumption rates, site use factors, and other variables, as these strongly affect the outcome of the risk assessment. In the Pacific Northwest, Native American subsistence fishermen usually have the highest consumption rates, greatest site fidelity, and longest time of residence in one area compared to other groups. However, in some metropolitan areas, southeast Asian populations subsist heavily on locally caught fish, and may have similarly high consumption rates, though very different target species, compared to Native Americans. Non-Native subsistence and recreational fishermen also have higher than average consumption rates.

A second key consideration is the approach used to obtain data on contaminant concentrations in fish tissue - collection of fish and shellfish tissues to compare against calculated target tissue levels for food, or collection of sediment data, which must then be modeled upward into food and compared to the target tissue levels. Because modeling is not yet reliable enough for regulatory purposes, and can be incorrect by several orders of magnitude (usually on the conservative side), particularly for high K_{ow} compounds such as dioxins and PCBs, only measured tissue concentrations will be used in this evaluation framework Tissue collection is also necessary to ensure that the potential for human health effects are not grossly overestimated and that impractical and sometimes nonsensical outcomes are avoided.

Figure G-6. Decision Guidelines for Objectives (2, food), (3), (4), (5) - Site-Specific



To assess risk posed to humans by consumption of fish, fish tissue samples will be collected throughout the Harbor and reference areas (Figure G-6). Harbor area fish tissue concentrations (90^{th} percentile) for a given COI are first compared to the human TTL (10^{th} percentile) for that COI. If there is no exceedance, then reference area fish tissue concentrations (90^{th} percentile) are compared to the TTL (10^{th} percentile). Then, if there is no exceedance, no further assessment of that COI is required. However, if Harbor area tissue concentrations exceed the TTL, then the evaluation moves [C] to a site-specific level. If reference area fish tissue concentrations exceed the TTL, then a potential non-Harbor, non-sediment (e.g., ubiquitous water-related), currently unidentified source is suspected in the reference area - this information would be shared with the site discovery process. The potential for the Harbor area and some reference areas to have similar concentrations of certain COI is suggested by what is known regarding sediment and contaminant transport in and out of the Harbor area (Sections 2.4.1 and 2.4.2).

3.4 Objectives (3), (4), (5) - Fish & Wildlife

Fish: The lower Willamette River upstream to Willamette Falls provides a significant migratory

corridor, nursery habitat, and adult forage area for various salmonids (See Section 2.3.2 for additional information on fish). Although these and other migratory fish species may only spend a limited amount of time transiting the Harbor area, we need to be assured that the presence of contaminants in sediment or food items does not pose an unacceptable risk while in the Harbor area. Recent studies have also identified 39 species of non-migratory fish in the Willamette River. Contaminated sediment could impair beneficial uses for these species by degrading phytoplankton and zooplankton populations, habitat, or the benthos; facilitating eutrophication and the presence of undesirable algae; resulting in adverse effects such as mortality, impaired reproduction, or abnormal development, or initiating fish tumors or other deformities.

Wildlife: Numerous piscivorous birds, migratory waterfowl, and raptors utilize the lower Willamette River during various times of the year. Great Blue Heron, Cormorant, Osprey, Merganser, Kingfisher, and Bald Eagle routinely forage within the Harbor area. Both Great Blue Heron and Osprey nest sites are located in the vicinity of the Harbor area; an active Great Blue Heron rookery exists upstream of the Harbor on Ross Island at RM 15. River otter, nutria, raccoons, and other small mammals may also utilize the Harbor area. As with human receptors, wildlife could be exposed to contaminated sediment or to food items contaminated by exposure to Harbor sediment. Contaminated sediment could adversely impact a number of beneficial uses for wildlife, including restrictions on food consumption, degrading of wildlife populations, by degrading habitat, or initiating wildlife deformities or reproductive problems.

3.4.1 Sites

3.4.1.1 Conceptual Model

Fish: Elements of the conceptual model for assessing risks to fish from contaminant concentrations in tissues at specific sites summarized in Table G-8.

Wildlife: Elements of the conceptual model for assessing risks to higher trophic level wildlife from fish consumption at specific sites summarized in Table G-9.

3.4.1.2 Decision Guidelines

Fish: As shown schematically in Figure G-5, the evaluation of risk to fish from contaminant levels in their tissues will not take place at specific sites until a Harbor and reference area evaluation of tissue levels (Figure G-6, Section 3.3.2) is completed. For sites, however, TSCs are converted into their RAO equivalents using either an area-wide BSAF calculated from area-wide sediment and tissue data or a site-specific BSAF calculated with data from site-specific bioaccumulation tests and sediment chemistry data.

Wildlife: As shown schematically in Figure G-5, the evaluation of risk to wildlife from contaminant levels in fish tissues will not take place at specific sites until a Harbor and reference area evaluation of tissue levels (Figure G-6, Section 3.3.2) is completed. At sites, however, wildlife TTLs are converted into their RAO equivalents using either an area-wide BSAF

calculated from area-wide sediment and tissue data or a site-specific BSAF calculated with data from site-specific bioaccumulation tests and sediment chemistry data.

3.4.2 Harbor & Reference Areas

3.4.2.1 Conceptual Model

Fish: Elements of the conceptual model for fish are summarized in Table G-8. Fish are assumed to be exposed to contaminants in water, through dietary exposures, and through direct contact with the sediment (especially true for flatfish and suckers that spend a good deal of time in and on the bottom sediments). For migratory species, three specific factors ["measures of ecosystem and receptor characteristics"] could influence exposure and will need to be factored into the analysis: (1) water temperature, water velocity, and physical obstructions, (2) abundance and distribution of suitable food sources, and (3) time spent transiting or loitering in the Harbor.

Wildlife: Elements of the conceptual model for wildlife are summarized in Table G-9. The dominant route of exposure for piscivorous wildlife is assumed to be through consumption of food items contaminated by exposure to contaminated sediment. These "food web" exposures place an emphasis on contaminants capable of being irreversibly (or slowly reversibly) bioconcentrated or bioaccumulated in food items. For some species (e.g., dabbling ducks), incidental ingestion of sediment while foraging for food is also be worthy of evaluation.

Table G-8: Objectives (3) and (4) Conceptual Model Elements - Fish

Assessment Endpoints	Testable Problem Statements	Measures of
Survival, growth, and reproduction of populations of endemic fish species	Contaminant levels in tissues of fish exposed to Harbor sediment samples do not exceed TSCs.	**Exposure:** Contaminant tissue levels **Effect:** TSCs
Survival and reproductive success of individual fish (special status species)	Same as above	Same as above

Table G-9: Objective (5) Conceptual Model Elements - Wildlife

Assessment Endpoints	Testable Problem Statements	Measures of
Maintenance of benthic invertebrate community species as an unadulterated food source for higher trophic-level species	Contaminant levels in benthic invertebrates are ≤ a contaminant-specific TTL for wildlife.	**Exposure:** Contaminant concentrations in benthic invertebrate tissues **Effect:** TTLs for wildlife based on LOAEL

Table G-9: Objective (5) Conceptual Model Elements - Wildlife

Assessment Endpoints	Testable Problem Statements	Measures of
Survival and reproduction of waterfowl	Contaminant levels in food item tissues are ≤ a contaminant-specific TTL for wildlife.	**Exposure:** Contaminant concentrations in food items **Effect:** TTLs for wildlife based on LOAEL
Survival and reproduction of piscivorous birds	Same as above	**Exposure:** Contaminant concentrations in food items **Effect:** TTLs for wildlife based on LOAEL
Survival and reproduction of piscivorous mammals	Same as above	**Exposure:** Contaminant concentrations in food items **Effect:** TTLs for wildlife based on LOAEL
Survival and reproductive success of individual birds (special status species)	Same as above	Same as above, but TTL based on NOAEL
Survival and reproductive success of individual mammals (special status species)	Same as above	Same as above

3.4.2.2 Decision Guidelines

Fish: As shown schematically in Figure G-6, threats to fish from contaminant build-up in their tissues will be assessed with TSCs. TSCs are the tissue concentration in fish tissue below which adverse effects (disease, reproductive organ pathologies, DNA damage, locomotion dysfunction, etc.) are not expected in a majority of fish species. This method is becoming more widely used as tissue residue effects data become more widely available. Using tissue residues to predict risk is generally preferable to estimating dose with models, because model uncertainty is avoided and the dose is measured within the organism, closer to the site of toxic action. A major impediment is that toxicity information is not standardized or available for exposures to many chemicals in terms of body burdens; however, this approach may be applicable for some contaminants. This method should *not* be used for chemicals that exert toxic action during metabolism by converting contaminants into toxic intermediates or byproducts (e.g., PAHs in fish), because these contaminants of concern may not bioaccumulate in tissues. A detailed discussion of fish TSC development is provided in Section 6.2.2.2.

To assess risk posed to fish, fish tissue samples will be collected throughout the Harbor and reference areas. Harbor area fish tissue concentrations for a given COI are first compared to the TSC for that COI. If there is no exceedance, then reference area fish tissue concentrations are compared to the TSC. Then, if there is no exceedance, no further assessment of that COI is required. However, if Harbor area tissue concentrations exceed the TSC, then the evaluation moves [C] to a site-specific level. If reference area fish tissue concentrations exceed the TSC, then a potential non-Harbor, non-sediment (e.g., ubiquitous water-related), currently unidentified source is suspected in the reference area - this information would be shared with the site discovery process. Although not shown in Figure G-6, significant differences in gross

morphological or histopathological changes in fish soft or hard tissues between Harbor and reference areas could also be used to assess adverse effects.

The USFWS notes that threats to salmonids from exposure to chemicals associated with sediments from Portland Harbor, especially to PAHs, are not necessarily fully addressed by means of TSCs. Many stocks of salmonids will be listed as threatened or endangered in the near future, and it will be imperative that the ecological risk assessment for the Portland Harbor sediments evaluate the potential impacts to juvenile salmonids.

Studies conducted in urban estuaries in Puget Sound, Washington have documented significant accumulation of PAHs and organochlorine compounds in out-migrating juvenile chinook salmon, and a linkage has been suggested between this accumulation in the salmon and altered immune responses (suppression of B-cell mediated immunity and immunological memory) and elevated levels of hepatic DNA adducts (McCain et al., 1990; Arkoosh et al., 1991, 1994; Stein et al., 1995). PAHs and organochlorine concentrations in sediment collected from the Puget Sound urban estuaries were similar to concentrations observed in the Portland Harbor area of the lower Willamette River (Malins et al., 1982). In addition, some resident fish in the area exhibited induction of hepatic cytochrome P450-1A1 monooxygenases, a biochemical response to contaminant stressors (Curtis et al., 1993).

As PAHs are metabolized in fish and do not readily accumulate in tissues, it is difficult to evaluate the degree or extent of injury from exposure to these chemicals. Injury and risk assessment is further complicated by unclear information regarding the residence time of subyearling chinook within the lower Willamette River. At the suggestion of the USFWS, DEQ will convene a technical workgroup involving USFWS, NMFS, and other pertinent parties to determine the most reliable way to evaluate juvenile salmonid exposure to PAHs and other chemicals, and to assess the potential injury resulting from exposure.

Wildlife: A TTL approach similar to that used for human exposures (as shown in Figure G-6) can also be applied to wildlife exposures. To assess risk posed to wildlife by consumption of fish, fish tissue samples will be collected throughout the Harbor and reference areas. Fish tissue concentrations for a given COI will be compared to wildlife TTLs. At this point, the decision guidelines are the same as those given in Section 3.3.2.2 for human exposures. A contaminant-specific TTL can be calculated given some reasonably conservative assumptions about tissue (fish, invertebrate) intake (using species-specific intake model that considers the quantities of tissues consumed per day), a contaminant-specific toxicity reference value (TRV), and an acceptable "risk" level (e.g., TQ = 1). The proposed TRV is a dose reported in the scientific literature as a lowest-observed-adverse-effect-level (LOAEL), preferably related to a reproductive endpoint. For special status species, the proposal is to base the TRV on a no-observed-adverse-effect-level (NOAEL), also preferably related to a reproductive endpoint. A detailed discussion of wildlife TTL development is provided in Section 6.2.2.3.

4.0 SAMPLING

4.1 Purpose

Sampling of Portland Harbor sediment and sediment-associated biota will be conducted as part of the PHSMP to address two principle questions:

- What is the nature and extent of sediment-associated contamination? (exposure assessment);
- What are the potential effects (ecological and human health) relating to sediment-associated contamination? (effects assessment)

The answers to these questions will help regulatory and resource agencies identify areas within the Portland Harbor for possible remediation, prioritize these areas for maximum efficiency in the allocation of limited resources, and, following site specific assessments, provide a basis for deciding among potential remedial alternatives. In addition, the identification of contaminated sediments under this plan will have significant and direct implications for the dredging and disposal of sediments necessary to maintain navigation. Many of the methods described within this plan have been selected in order to be consistent with/complementary to the existing dredged material management guidance (e.g., Dredged Material Evaluation Framework, Lower Columbia River [DMEF, 1998]).

This section is intended to provide an overview of methods and issues related to sampling of Portland Harbor sediments. While we have attempted to make general recommendations where appropriate, this section is not intended to be a detailed work plan with specific guidance on such things as number and locations of field sampling sites. The methods and approaches described herein represent generally agreed upon methodologies suitable for evaluation of Portland Harbor sediments and reflect the best available science at this point in time.

4.2 Sampling Design

4.2.1 Sample Types

A variety of sample types may be collected as part of this plan. Selection of appropriate sample types will be driven in large measure by the conceptual model, the contaminants of concern, the receptors of concern, and other related site-specific information developed during the problem formulation stage of the assessment. Briefly the types of samples that may be collected and their potential use are summarized in Table G-10.

Table G - 10. Potential Sample Types

Sample Matrix	Method of Collection	Analysis	Purpose
Whole sediment	Short hand or diver core, grab sample	Chemical and/or Bioassay (toxicity & bioaccumulation)	To assess potential chemical contamination in surficial (i.e., generally top 5-10cm) of sediments.
Whole sediment	Core sample (push core, vibracore, impact corer, etc.)	Chemical and/or Bioassay (toxicity & bioaccumulation)	To assess contamination over depth intervals. Note: also can be used to facilitate collection of intact sediment samples with minimal disruption.
Sediment Pore Water	Either grab or core	Centrifugation followed by subsequent chemical analysis and in special cases bioassay	To identify potential confounding factors in sediment toxicity tests. To assess levels of freely dissolved contaminants as an indication of the bioavailable fraction. May also be used in a Toxicity Identification Evaluation (TIE) to isolate classes of contaminants potentially causing toxicity.
Tissue (Infauna)	Grab sampler	Chemical analysis	To assess contaminant bioavailability via measured tissue residues of resident infauna.
Tissue (Epifauna/Nektonic)	Trawl net or trap	Chemical analysis	To assess contaminant bioavailability via measured tissue residues of captured epifaunal/nektonic species. [a]
Benthic Infauna Surveys	Grab sampler	Classification and enumeration	To identify use of the site by receptors of concern and/or assess community level effects on indigenous field populations.
Epifauna/Nektonic Species Surveys	Trawl net or trap	Classification and enumeration	To identify use of the site by receptors of concern and/or assess community level effects on indigenous field populations. [a]

[a] Linking elevated tissue residues and/or effects in migratory species or species with a home range exceeding the site boundary to site-related contamination is problematic.
Source: Adapted from Ecology (1995).

It is unlikely that all of the aforementioned sample types would be collected during an assessment of a specific site location. Each sample type provides unique information to address specific questions as part of a more holistic assessment.

Whole sediment samples. Nearly every assessment will include some analysis of whole sediment samples collected from the site. The types of analysis and method of collection will be determined by the questions that need to be addressed at a specific site. For example, if previous sampling of an area has shown the majority of the contaminants to be confined to the upper 5 to 10 cm of the sediment surface then surficial grab or shallow hand core samples may be adequate. If however, we have little to no previous information for a site then deeper samples may need to be collected via push corer or some other coring device suitable for the collection of intact samples to depth . As a general rule, the justification for collection of samples via surficial grab or shallow hand core will require a higher level of information than what may be required for sampling with a coring device to depth. Regardless of the method of collection, the depth to which one samples must always be accompanied by a detailed rationale (see Section 4.2.4).

Sediment Pore Water. In a smaller number of assessments, sediment pore water samples may need to be collected. Sediment pore water extracts are most useful and most often used for assessing the potential influence of naturally occurring constituents (e.g., ammonia) on sediment toxicity test results. They may also be useful in evaluating the potential bioavailability of certain sediment-associated contaminants (e.g., TBT) prior to bioaccumulation testing. However it should be noted that the manipulation required to extract sediment pore water may alter the apparent bioavailability of these contaminants. Finally if sediment toxicity is observed in more routine laboratory toxicity tests a toxicity identification evaluation (TIE) can be employed to isolate the likely class of contaminants responsible for the toxicity.

Tissue Residue Samples. Tissue samples of resident fauna (benthic infauna, epifauna, and nektonic species) provide perhaps the best measure of contaminant bioavailability. Field collected organisms provide spatial and temporal integration of all the factors contributing to uptake of sediment-associated contaminants. However, the more removed the organism is from the sediment (e.g., salmonid vs. sucker) and the larger the home range of the species (e.g., salmonid vs. mussel), the greater the uncertainty in relating elevated tissue residues to site-associated contamination. Consequently it is recommended for purposes of the management plan that assessments focus more on resident infauna and epifaunal species with limited home ranges. Tissue residues in these organisms can then be linked to higher trophic organisms through food-chain transfer models. Tissue levels of resident infauna can also be used in conjunction with sediment chemistry values to establish site-specific Biota to Sediment Accumulation Factors (BSAF). As these BSAFs are developed they can be used to screen for potential bioaccumulation in future assessments and in establishing meaningful Remedial Action Objectives relating to bioaccumulation. Tissue samples of nektonic and demersal fish species may be collected as part of a larger harbor wide assessment and may be used in conjunction with predicted estimates derived from benthic infauna tissue data in a weight-of-evidence approach to link sediment associated impacts to higher trophic levels. The species and type of tissue that is sampled will be driven by the potential receptor being evaluated. For example, in assessing potential human health risk associated with consumption of finfish it is common that only filet tissue is considered while for potential effects to wildlife, whole body residues are evaluated. Though it should be noted cultural practices may affect which tissues are analyzed for human health evaluations in order to protect those segments of a population that may consume other portions of the fish (e.g., head , roe, etc.).

Benthic Infaunal Surveys. Assessment of benthic communities at the site provides information on potential contaminant-related effects to the benthic community. As numerous other non-contaminant factors (e.g., grain size, light, hydrology, etc.) affect the traditional indices (i.e., diversity and abundance) of benthic community health the selection of an appropriate reference is critical to the evaluation. Information on benthic community health should always be used in conjunction with sediment chemistry and toxicity and never as a stand-alone measure of potential effects.

Surveys of epifaunal and nektonic species. Collection of nektonic and epifaunal organisms from

the site via fish trap and trawls can be useful in determining potential receptors of concern during the problem formulation stage of an assessment. If done over time (e.g., seasonally) such surveys can also provide some information on temporal use of the site (a key element of exposure assessment) by receptors of concern.

4.2.2 Sampling Station Locations

Selection of sampling station locations is potentially the most critical and yet the most subjective element of any sampling and analysis plan. Selection of sampling site locations must be coordinated with relevant resource/regulatory agencies and other stakeholders as a first step towards ensuring acceptability of the assessment. This section provides guidance for selecting sampling locations, determining sampling depth, and information on other factors to consider in the design of a sampling program.

Selecting appropriate station locations depends almost entirely on what is known about the site. Information on past site history (e.g., land use activities, location of outfalls, past spills, etc.) hydrologic information (e.g., bathymetry, currents, etc.) physical characteristics of the sediments (e.g., grain size, total organic carbon content, etc.) should all be considered in developing a sampling location plan. In the unlikely event that nothing is known about the site and there are no obvious sources of contamination, station locations may be placed randomly throughout the site (e.g., stratified random sampling design). In the absence of any previous chemistry data some minimal sampling and chemical analysis will need to be performed to delineate the site boundaries. For the majority of cases, however, at least some information will be available and the following guidance may be used to identify appropriate sampling locations:

- If land areas adjacent to the site are known or suspected to be contaminated then some sampling locations should be placed adjacent to the shoreline. These stations may be evenly spaced or targeted to areas of known contamination. If it is desirable to identify a gradient of contamination then at least two separate transects should be established either parallel to the shoreline or the area of known contamination.
- If there are existing or historic point source discharges then sampling should be conducted in areas adjacent to the outfall. Samples should be located such that they are down current. In areas of high flow, sampling locations should placed in the nearest low flow, depositional areas likely to be affected by the outfall. If a gradient is to be established then it will be necessary to place the sampling transect in line with the current and have at least one sampling location up-current of the discharge.
- If there are loading docks for bulk materials or liquids then sampling locations should be placed along the length of the pier face where loading/ off-loading occurs.
- If there are facilities along the shoreline where ship/boat maintenance (sandblasting) occurs or refueling facilities then sampling locations should be located adjacent to those areas.
- If there is potential groundwater intrusion of contaminants (leaking storage tanks, unlined land fills/waste holding ponds etc.) then sampling stations should be placed adjacent to the shore line in areas where groundwater may be discharged into the river.
- If there is evidence that contaminants may be entering the site from up-current locations

then sampling locations should be placed along the up-current site boundaries with a few sites beyond the up-current boundary.

- If there are records of spills or other accidental releases of materials then sampling locations should be placed in the vicinity of those releases.
- Sampling locations should be located in depositional areas where sediments are known or suspected to have accreted over time. A review of previous physical sampling (grain size, TOC), site bathymetry and/or historical dredging activities will be helpful in identifying these areas. In addition, Sediment Profile Imaging (SPI) camera surveys can be useful in identifying sediment types, overburden, redox layers, and presence of benthic infauna.

Sampling objectives must be clearly understood by all relevant resource and regulatory agencies and other stakeholders. To that end each station should be identified, pre-plotted (latitude and longitude) and the purpose of each station location clearly described (with consideration of the guidance given above) in the work plan.

If sediment toxicity or benthic infaunal surveys are to be performed then one or more reference locations will be required for comparative purposes. The selection of the reference operationally defines the environmentally acceptable endpoint. If there is no difference between the study site and the reference then the study area is judged to be acceptable. Thus the identification of acceptable references for specific types of comparisons is critical to the decision process. In an ideal world, the reference would represent an area that is identical to the study site in every way but unaffected by contaminant inputs. In an urbanized riverine environment such as the Willamette it is virtually impossible to identify a location that has not been affected to some degree by contaminant inputs. Consequently, the selection of suitable reference locations will be guided primarily by science but will also be influenced by input from the relevant resource/regulatory agencies and other stakeholders. Criteria for selection of the reference should include:

- "As free as possible" of contaminants;
- Removed from potential known or suspected contaminant sources;
- Geophysical characteristics (grain size, total organic carbon) representative of potential study areas within Portland Harbor;
- Hydrologic characteristics (current speed, water depth) representative of potential study areas within Portland Harbor;
- Acceptable bioassay performance and presence of a healthy benthic community

4.2.3 Selection of Reference Areas

Selection of suitable reference locations will likely require an initial evaluation of a larger number of sites to evaluate endpoint response (for both toxicity and macro-invertebrate community indices) in terms of suitability for the specific test endpoint being evaluated. For example, if a reference site consistently produces 30% survival in the amphipod *H. azteca* and the cause of the poor survival is undetermined (i.e., not due to grain size or some other geophysical parameter) then this site might not be appropriate for the *H. azteca* tests. Conversely it should be pointed out that certain sediment characteristics might preclude certain types of evaluations. For example, in marine systems the amphipod *Ampelisca abdita* shows reduced survival in coarse-grained material and consequently should not be used to evaluate toxicity of coarse-grained sediments. The current state of the science suggests that the standard freshwater test organisms *H. azteca* and *C. tentans* are relatively tolerant of a wide range of sediment grain size and total organic carbon. However the influence of such factors on other test species (e.g., *H. limbata* and *T. tubifex*) are not as well defined and the effect of these factors may require further evaluation prior to selection of suitable reference sites.

4.2.4 Sediment Sampling Depth

Contamination below the "biologically active zone" is not of significant concern unless there are potential mechanisms for release of those contaminants and a complete exposure pathway. Generally the biologically active zone includes the top 5 to 10 centimeters. If for example, a site is located in a depositional area, and the site is unlikely to be dredged then we may not need to sample to depths beyond the biologically active zone. If however sediments at depth are likely to be uncovered via dredging (e.g., port expansion or channel deepening); subject to periodic scouring (e.g., prop wash or currents); and/or surficial material will likely be removed as part of a remediation effort then it will be necessary to sample to depths beyond the biologically active zone. In determining the depth of sediment collection one should consider:

- The depth of sediments potentially affected by contaminant inputs. If depositional rates are known for a given area these can be used to estimate the depth to which sediments may have been affected by contaminants.
- In navigation channels the depth of proposed dredging plus any over-dredge allowance.
- In areas adjacent to navigation channels the potential for materials sloughing into the channel.
- The sources of contaminant input (e.g., spill, long-term discharge, or contaminated ground water seeps).
- The depth of sediment potentially affected by historical activities (e.g., old disposal sites).

4.2.5 Water Depth

Water depth at potential site locations should also be considered. Stations positioned along a transect relative to an outfall should be located at similar water depths since currents carrying potentially contaminated sediments tend to move along depth contours. Water depth is also an important consideration for selection of a reference site for the evaluation of benthic infaunal data as benthic assemblages are strongly correlated with depth. However, it may not always be possible nor desirable to establish sampling locations along a depth contour. If for example, we are interested in evaluating a gradient into an adjacent channel, or from an onshore point source, sampling locations will by necessity be located at different depths.

4.2.6 Other Considerations

Logistical considerations such as the presence of construction debris or other obstructions, vessel traffic, or strong currents may affect/preclude sampling in a given area. In some circumstances advanced planning may permit access to these sites (e.g., during periods of low flow or reduced vessel traffic).

4.2.7 Number of Samples and Spatial Coverage

The number and spatial coverage of sampling locations is highly site specific and will depend in large measure on the existence of historical data, the nature of the conceptual model for the site, the size of the site to be evaluated, and the desired power of the statistical tests selected for data analysis and interpretation. For areas that have been fairly well characterized in previous studies fewer samples will be required and should be spaced to captured areas not previously sampled. In areas where there is little to no historical information more samples will need to be collected and the spatial distribution should represent a balance between grouping of sampling locations in order to delineate areas of known or suspected contamination and broader spatial coverage within the site boundaries. Obviously larger sites will require more samples while smaller sites will require fewer. The minimum number for even the smallest site should be three samples for the evaluation of spatial heterogeneity. At larger sites it may be desirable to consider field replication to address spatial heterogeneity. If resources are limiting and it not possible to design the assessment with both laboratory and field replication then it may be desirable to forego laboratory replication (i.e., a relatively smaller source of variability in the overall assessment) and utilize field replication to address a larger source of variability (i.e., spatial heterogeneity).

4.2.8 Timing of Sampling

Timing of sampling activities is a critical factor in many sediment assessments. However potential issues to be considered in scheduling field sampling activities might include:

- Availability of the test species may preclude testing during certain times of the year. Most of the test animals recommended under this management plan can be cultured in the laboratory (with the exception of *H. limbata* which is field collected and then reared in

the laboratory) and are generally available year round. However, should additional tests be developed with species for which there are only field-collected populations (i.e., no cultured populations) then it may be necessary to schedule testing when these animals are available.

- In assessing benthic assemblages, it may be desirable to schedule sampling for a time when such assemblages are the most stable (i.e. low variability). Benthic infauna is variable due to seasonal cycles that tend towards smaller populations in the winter and larger populations in the summer. Additionally, river flow regimes also affect population stability with populations tending toward greater stability when flow rates are more constant.
- The Willamette River is subject to seasonal variations in flow. It may be desirable to sample during periods of decreasing or low flow when sedimentation is occurring. Low flow periods may also be the ideal time to capture contaminants migrating into an area via groundwater seeps.
- Endangered species or critical life history stages for other important receptors of concern may only be present during certain times of the year. Consequently to obtain an accurate measure of exposure it may be desirable to schedule sampling when these species are present.

4.2.9 Tiered or Phased Sampling Schemes

In those instances where there is limited historical information for a site and/or a major event (flood, dredging, disposal) has impacted the site since the last sampling event it may be desirable to collect some limited sampling for sediment chemistry to help delineate the site boundaries and potential sources of contamination. This sampling would be conducted as part of the problem formulation stage of the assessment. Once this data was evaluated it would then be used to develop the site-specific conceptual site model and structure a subsequent more detailed sampling design. Similarly once an assessment has been completed under this plan the utility of such information in future assessments must be evaluated in the context of what has occurred at the site in the intervening time frame. For example, if an assessment has been performed recently at a site (e.g., within a year) and the site is largely unchanged (no spills, floods, etc. and bathymetry is unchanged) then additional data would only be necessary to better delineate the site spatially.

4.2.10 Sampling and Analysis Plan Documentation

An important organizing element of all sediment assessments carried out under the PHSMP is the development of a site specific Sampling and Analysis Plan (SAP). While SAPs will differ from site to site as a function of site-specific needs all plans will contain some common elements. Briefly these elements are:

- Background and History – site history including descriptions of any contaminant sources potentially impacting the site and results of previous investigations of the site.
- Project Objectives - should also include a discussion of the regulatory context (e.g.,

CERCLA, CWA, etc.) under which the project will be evaluated.

- Project Management and Team Responsibilities – a listing of points of contact and a description of how personnel and subcontractors will be organized to conduct the assessment.
- Sampling Program - description of where samples will be located (should include a table with latitude, longitude and sample depth and a map), rationale for sampling design, detailed description of how samples will be collected and the equipment that will be used, decontamination procedures, and all sample documentation, handling and storage procedures. (Note: the rationale for the sampling design should provide the basis for approval of the sampling and analysis plan by the relevant resource /regulatory agencies.)
- Analysis Program – description of the methods that will be used to assess the sediments (physical and chemical analysis, biological testing, infaunal assessments) including a description of applicable quality assurance/quality control procedures and standards (i.e., detection limits, biological test performance criteria etc.).
- Data Analysis, Management, and reporting – how results will be evaluated, interpreted and reported.
- Schedule – time frame for completion of the various elements including: field mobilization, initiation of sampling, completion of sampling, initiation and completion of laboratory analysis, completion of draft report, and completion of the final report.

4.3 Sampling Implementation Plan

4.3.1 Sediment Sampling Methods

4.3.1.1 Sampling Equipment

One of the goals of sampling conducted under this management plan will be to collect samples that are reflective of in-place sediments to the maximum extent that is practical. Selection of appropriate sampling equipment will be determined by a number of factors including but not limited to:

- Study objectives (e.g., the depth to which the sediment will be sampled, the level of acceptable sample disturbance)
- Nature of the area to be sampled (e.g., depth, sediment grain size, hydrology, etc.)
- Types of analysis to be performed (e.g., sediment chemistry requires less volume than sediment bioassays)
- Kinds of support equipment required (e.g., vessel size, A-frame, winch, etc.).

There are essentially two types of sediment sampling devices, grab samplers and sediment corers. Grab samplers like the van Veen or the Ponar typically rely on a hinged bucket design and are generally used for collecting surficial sediments. Sediment coring devices include hand corers, gravity corers and box corers which can be used to sample to shallow sediment depths (typically <1m) and larger devices such as the vibracorer and hammer corer which are capable of sampling much deeper sediments (e.g., up to several meters in depth). In general, grab samplers are useful

in obtaining larger quantities of surficial sediments for testing purposes, however, many of these samplers create a bow wake that results in the loss of fines and organisms. In addition grab samplers may not be effective in certain types of substrates (i.e., coarse grain material or consolidated sediments may prevent complete jaw closure). Box corers are more effective than grab samplers in obtaining relatively undisturbed surficial sediment and offer the additional advantage that they can be sub-cored or sectioned at different depth intervals, although they tend to be heavier and more cumbersome to operate. However improved box corers have been developed that overcome some of the deficiencies of traditional box corers (i.e. lighter and less cumbersome) (Diener et al., 1997). Vibratory, hammer, and piston corers offer a greater depth of penetration and tend to be effective over a broader range of substrate types, however they require greater level effort to operate (i.e., 2-3 people) and have larger surface support vessel requirements (i.e., vessel size, winch and A-frame). Additionally the use of corers can result in compaction disrupting the vertical integrity of the sample. Burton (1992) provides a very thorough review of sampling devices and their respective advantages/limitations.

General recommendations for sediment sampling devices follow those outlined in Sampling and Analysis Plan Guidance developed by Ecology (1995). Briefly, in shallow waters that are inaccessible by larger vessels small hand corers or grab samplers may be used depending on the depth of penetration required and the volume of material required for testing. If surficial sediments are to be sampled in deeper water then a box corer or modified van Veen may be used. If sediments are to be sampled to greater depths then a vibratory corer or hammer corer is recommended.

Whatever sampling equipment is used there should careful documentation of the type of material retrieved (grain size, color, odor, sheen and other indications of contamination, presence of organisms), the depth of penetration, and the approximate volume of material retrieved. For grab samplers the presence of overlying water should be noted as this indicates minimal sampling leakage.

4.3.1.2 Sample Station Positioning

Sample positioning should be accurate to within ±3 meters. Achieving this level of accuracy will generally require a differential global positioning system (DGPS). Areas where signal loss occurs (under bridges, piers etc.) can be referenced against known surveyed points or fixed structures with identified GPS coordinates using either a tape measure or range and bearing techniques. Station locations should be reported in latitude and longitude to the nearest hundredth of a second using the 1983 North American Datum (NAD83). If possible the accuracy of the DGPS should be periodically verified via comparison to known survey points.

4.3.1.3 Decontamination Procedures

Procedures for decontaminating field equipment between sampling locations should include scrubbing with a non-phosphate laboratory grade cleanser followed by a site water rinse. For smaller sampling gear and sample handling equipment (spoons, bowls, etc.) solvent rinses (e.g., methanol) may be used to reduce the potential for sample contamination by organics. Acid rinses are not recommended for sampling and sample handling equipment fabricated of stainless steel or aluminum as this may result in leaching of metal contaminants from the equipment. Any chemical used to decontaminate sampling gear in the field must be collected and disposed of in an appropriate manner. Solvent rinses of larger sampling equipment (i.e., vibracores, hammercores) is not practical in the field. However, other precautions should be taken with larger sampling devices to reduce the potential for sample contamination. These procedures may include pre-cleaning barrels (steam cleaning) prior to their use in the field, changing core barrels and/or liners between stations and collecting sediment from the center of the core and avoiding edges that have come in contact with the surfaces of the sampling device. If the distribution of contamination is known, then the potential for cross-contamination may be reduced by sampling less contaminated areas first and working progressively toward more contaminated sites. Only non-contaminating material should come in contact with the samples (e.g., stainless steel, aluminum, Teflon, etc.). If phthalates are of concern then materials containing phthalates should be avoided (e.g., butyrate core liners, lexan, HDPE, etc.).

4.3.1.4 Field Documentation Procedures

Accurate record keeping is essential to the success of all field-sampling activities. Field logs can often provide additional information to explain unanticipated results from subsequent analysis. The field log book serves as a permanent record of where, when and how samples were collected for future studies and any potential litigation that may ensue. At a minimum field records should include:

- A Cruise or Field log that provides general information such as the personnel involved in the sampling, names of the vessels being used, arrival and departure times, weather, river stage, and any other miscellaneous information relevant to the sampling. Essentially the cruise log serves as a diary of each day's events. This type of information is helpful if follow up information is required from specific individuals involved in the sampling program some time after the sampling event.
- The station or sample log provides key information relating to the collection of each sample. Information should be recorded for each sampling attempt, successful or otherwise (e.g., repeated attempts due to refusal of the sampling device provides important information on substrate type for future sampling events). Information to be recorded should include project name, station ID, date, time, attempt number, depth, actual DGPS (latitude and longitude) of each sample location, and depth of penetration). If the attempt is successful (i.e., sediment is retrieved) then information on the sediment type (sand, silt, clay), obvious stratigraphy, sediment color, odor, presence of organisms, and any signs of contamination (strong petroleum odors, sheen, debris, paint chips, etc.) should be noted. If sediment cores are collected observations should be made with depth

(e.g., noting depth at which sediment changes from silt to clay). If waste or other debris is present in the sample the approximate quantity should be recorded. If there are deviations in the sampling plan that were necessitated by field conditions (e.g., ships berthed in an area to be sampled) these should also be noted in the station log.

- Chain-of-Custody forms should be maintained from the point of collection through any subsequent analysis and archival of each sample collected.
- Calibration logs for any water quality instrumentation used. In addition a log should be maintained for verification of the DGPS that is performed.

The project manager is ultimately responsible for determining which appropriate field records will be maintained and ensuring the accuracy and completion of those forms.

4.3.2 Biota Sampling Methods

4.3.2.1 Benthic Infauna

Infauna communities are generally assessed using grab or core samples. Larger samples (i.e., surface area sampled) are preferred over smaller samples and the sampler should penetrate into the sediments at least 10 cm. Most infauna organisms are found within a few centimeters of the surface, exceptions being deep burrowing bivalves and arthropods. Recommended samplers include hand cores, modified chain-rigged van Veen and box core samplers. Hand core samples (10-15 cm in diameter) can be used but multiple samples should be collected to insure sufficient surface area is sampled. Box core samplers are preferred over grab samplers and surface area sampled should be at least 0.1 m^2.

Sediments should be processed immediately upon collection to minimize deterioration. Depending upon sediment type and target organisms, sediments should be sieved using an appropriate sized sieve. Selection of sieve size is critical for assessing conditions and should be consistent with previous studies or existing information and target organisms. Smaller size sieves (e.g., 0.3 and 0.5 mm) retain smaller organisms and juveniles of larger infauna that may be more sensitive indicators of environmental stress. However, the cost of processing the smaller sieve sizes is significantly greater than larger sieve sizes because of the greater number of organisms collected and the increased difficulty of identifying and counting smaller organisms. Larger sieve sizes (e.g., 1.0 and 1.5 mm) are often used to reduce analysis costs while still providing a good assessment of the infauna. However, the larger the sieve size the greater the potential to inadequately assess smaller mature organisms. Consequently, sieve sizes greater than 1.0 mm are not recommended. Often a tiered approach is appropriate where the infauna sample is processed through to different sieve sizes (e.g., 1.0 and 0.5 mm). The two sample fractions are processed separately and the initial analysis and assessment is based upon the larger and less expensive sieve size while the smaller sieve fraction is archived. The analysis of a subset of the smaller sieve size samples can provide quantitative information about the smaller organisms. If significant impacts are found or other factors warrant a closer look at the infauna community the smaller sample sieve fraction that has been archived can then be analyzed as needed. A reconnaissance survey is useful to determine the appropriate sieve size to best

characterize the infaunal community.

Each collected sample should be graded as to surface condition, leakage, and depth of penetration. Samples with disrupted surfaces, excess leakage, or insufficient penetrations should be discarded and replaced with good samples. Field sieving of the infauna samples to remove the sediments and debris should be done gently and carefully using a wash table and the appropriate sieves. Organisms should not be subjected to direct hose pressure upon the sieves. Organisms should be sieved using filtered water representative of the collection site. Following sieving, the surface of the sieve should be examined for stuck organisms which should be removed with forceps and added to other retained organisms for that sample. It is recommended that the retained organisms be relaxed for 30 minutes in a MgCl or $MgSO_4$ solution and then fixed in 7-10% buffered formalin solution for 3-10 days. After fixation the organisms and retained sediments should be transferred to 70% buffered ethanol for storage and/or processing. Laboratory processing involves sorting the organisms from the retained sediments and debris into taxonomic groups for enumeration and identification. Typically, samples are sorted using dissecting microscopes into major phyla groupings, e.g., annelids, mollusk, arthropods-crustacea, arthropods-insects, minor phyla. Upon completion of the sorting process the samples are given to taxonomic experts for identification and counting of the organisms. Voucher collections should be made for future reference and to insure consistency for the study.

The spatial scale of sampling to characterize an area is dependent upon the ecological complexity of the study area and the number and significance of contaminant sources. For example, an area with numerous point source contaminants as well as non-point source inputs will require more samples to characterize contaminant gradients. Generally, sampling should attempt to capture environmental gradients relative to contaminant sources as well as to characterize the natural gradient within the study area, e.g., depth, currents, and sediment types. Where gradients and sources are unknown then a stratified random sampling approach may be appropriate. Furthermore, the study design must consider whether it is more appropriate to sample a few times with replication or sample many times with little replication. If sampling is restricted to a few times at fixed locations then replication is needed at each site to estimate the small-scale spatial variance and to provide an error term for statistical hypothesis testing usually a one-way ANOVA. While this approach is often used, it must be remembered that the sensitivity or power of the test is directly related to the degrees of freedom and in this context this is the number of replicates. Thus, small differences in mean values between reference and impact site can become significant differences by increasing the number of replicates taken. If temporal variability is more significant than small-scale spatial variability, which is usually true for biological sampling, then a proper study design to assess biological impacts should sample often enough to characterize temporal changes. Replication in this context is the number of surveys and not the number of samples collected at one location on a particular day (pseudoreplicates). In a repeated measure sampling design these pseudoreplicates are still useful as they provide a better estimate of the mean, i.e., reduced variance. For most environmental studies the major cause of variation is due to temporal changes, thus, to detect significant environmental effects from temporal changes requires temporal replication. When temporal sampling occurs (i.e. frequent surveys) a Repeated Measure ANOVA analysis is appropriate for hypothesis testing of impacts.

To characterize an area with little previous sampling the best approach is to conduct a reconnaissance survey. A Sediment Profile Imaging (SPI) survey conducted prior to the reconnaissance survey can be useful to help delineate sediment type, overburden, anoxic layers, and general habitat types. Reconnaissance sampling should attempt to sample all areas and habitats using either a stratified random or a grid sampling approach. The results of the reconnaissance survey will identify difficulties in sampling within the study area as well as providing quantitative information for determining the study design, the number of stations, replication, sieve size, and methods most appropriate for the assessment. If designed properly a reconnaissance survey can be used to establish baseline conditions and serve as the initial survey for a repeated measure study. The reconnaissance survey should also delineate the contaminant gradients where specific study objectives can be focused (e.g., gradients relative to contaminant sources and sediment triad approach) as well as locating appropriate reference or control areas.

4.3.2.2 Demersal Fish and Epibenthic Macro-invertebrates

The demersal community, both fish and macro-epibenthic invertebrates, generally represents the larger organisms that live on or near the bottom. The environmental assessment of the larger organisms can utilize community parameters as described above for infauna relative to impact gradients and/or comparison to reference or control areas. Other parameters for larger organisms that can be useful for assessing contaminant impacts include average size or biomass of target species, tissue contaminant concentrations, biomarkers (e.g., histopathology), and disease (e.g., fin rot, lip tumors). Trawling, seining, longlines, gillnets, fishing, and trapping are six commonly used methods for assessing the demersal community.

Trawling involves pulling a net over the bottom that is designed to collect both fish and macroinvertebrates living on or near the bottom. Typically, 16 or 25 ft (7.6m) semi-balloon otter trawl nets are used for this type of sampling. These nets utilize two doors to hold the net open and are equipped with chain/lead foot ropes that drag upon the bottom while the top of the net is supported by floatation. The nets are towed from an appropriate vessel at a speed of 2 to 2.5 knots for a standard time or distance. Thus, the area swept by the net can be calculated and the catch can be standardized for comparison to other areas. Typically, tow times would be 5 or 10 minutes or standardized distances of 200 or 450 m. GPS navigation is useful for trawl management of speed and distances sampled. Trawl duration begins when the nets reaches the bottom and ends with the start of the retrieval of the net. Once the net has been recovered on board the vessel the catch is sorted to species or type. Other types of trawls include beam trawls which generally sample a smaller area because of the fixed sized opening (e.g., 2 m). Beach seines would be appropriate for sampling smaller shoreline fishes and invertebrates in shallow shoreline areas free from obstacles. Trapping can be an effective sampling tool but traps need to be designed and managed for the target species. Traps effective for crabs will not work well for shrimp or small fish and vice versa. Hook and line fishing can also be used to collect and census some fish species.

Generally, fish are identified, weighed, measured, and any disease symptom recorded. Invertebrates are processed in a similar fashion. Specimens too small for field identification or of special interest specimens are preserved in the field and returned to the laboratory for

identification. Specimens for tissue analysis and or histopathology require special handling and processing.

4.3.2.3 Nektonic Species

Fish species that live up in the water column or are migratory can be sampled by using different types of nets (e.g., lampara, purse, gill, barrier, or seines) long line, hook and line, creel census, electrofishing, and/or acoustical methods. Traps may be useful for some smaller species. Migratory and nektonic species by their nature are variable in space and time and thus are difficult to sample quantitatively. Choice of sampling methods is dependent upon target species, mortality of the method, current flows, vessel traffic, and costs. The charter of experienced commercial vessels and equipment can often be a useful and cost effective approach for sampling fish populations. In habitats where flow rates are minimal small purse seines or lampara barrier nets can be useful. These types of nets are set from support boats in a circle of known area and tend to collect most of the fish within the net enclosure. Mixed sized mesh monofilament gill nets can be set in moderate flow rates and are effective sampling devices. However, gill nets require constant management and tend to be lethal to the target species. Electrofishing is a widely used method for assessing fish. However, electrofishing mortality rates are controversial and are largely unknown for most species and are dependent upon the type of equipment, target species, current type and voltage, time required to process captured specimens, and the length of time needed to survey an area. Electrofishing is also dependent upon operator experience and the type of equipment.

4.3.3 Sample Handling Procedures

4.3.3.1 Obtaining Adequate Sample Volumes

As a practical matter, it will often be necessary to combine several smaller samples collected from a single sampling location so that larger volumes of sediment are available to be sub-sampled for subsequent sediment chemistry and bioassay. While this approach assures disruption of sample integrity it permits a more direct comparison of sediment chemical/physical analysis to biological testing under controlled laboratory conditions. This more direct comparison facilitates the identification of potential causal contaminants and helps to focus subsequent risk-based remedial actions (an important feature for a clean-up program). Furthermore, separate collection/analysis of benthic infauna data from the same sampling location as sediment chemistry and bioassay provides an additional weight-of-evidence to "ground truth" results from laboratory testing.

If small volumes (<20 L) of sample are being collected for subsequent analysis (chemistry, bioassay, etc.) it may be reasonable to combine smaller samples in the field. If however, a larger volume of sediment (>30 L) is being combined for subsequent testing and analysis, it may be desirable to combine the samples in a more controlled setting than aboard the sampling vessel. Furthermore the equipment requirements for combining such a large volume material may render shipboard compositing impractical. Prior to combining samples it is often prudent to sub-sample

a small amount (250-500 ml) from each homogenized, discrete sample for chemistry archival. Should anomalous results be obtained (e.g., high variance in toxicity lab replicates and little to no chemical contamination in the combined sample) one may subsequently analyze the archived discrete samples to look for such things as paint chips or other particulate contaminants that might possibly explain the results. Careful thought must be given to any combining scheme. If for example sediment cores are collected to depth and there are obvious signs of sample stratification (e.g., physical differences in grain size, layers of debris or other obvious signs of stratified contamination) the project manager must decide whether those samples should be split (e.g. top and bottom) for combining and subsequent analysis. In some cases these decisions can be made *a priori* based on previous sampling and analysis in other cases the decision must be made in the field.

Combined samples should be thoroughly homogenized to a uniform color and consistency, large pieces of debris may need to be removed (twigs, rubble, pieces of cable, rope, plastic etc.) prior to homogenization. Samples should reflect the relative proportion that each sample represents relative to the total volume of material being evaluated in the field. For example, if a larger volume of material is required for bioassay testing than would be possible via single cores/grabs at each sampling station in a given area then two cores/grabs must be collected from all sampling stations within that area and combined so as to not bias the sample. Once a sample has been combined, appropriate sub-samples can be collected for all relevant analysis (e.g., grain size, TOC, chemistry, toxicity testing, and bioaccumulation studies). If benthic macro-invertebrate sampling is to be performed then these samples will need to be collected separately from those samples collected for bioassay and chemistry. Additional information on the collection and manipulation of sediments for various analyses can be found in a variety of sources (ASTM, 1998a; EPA, 1992c; Mudroch and MacKnight, 1991).

4.3.3.2 Sample Containers and Labels

Container types and labeling procedures for the various types of analyses being performed are critical to the success of any sampling program. The appropriate type of container is entirely dependent on the analysis to be performed (See Table G-11 for a listing of approved container types for various analysis). If a single laboratory is to perform all the analysis and container type, storage conditions, and preservation methods are compatible for each of the analyses then the separate sub-samples from a single station may be combined. However, the laboratory performing the analysis should always be consulted prior to combining samples into a single container.

Waterproof, self-adhesive labels should be attached to the outside of the sample container. Minimum label information to be recorded in waterproof ink should include: project ID, station ID, date and time of sample collection, initials of person performing the collection, type of sample being collected (sediment), type of analysis to be performed (e.g. organic chemistry, grain size, etc.), whether the sample is to be archived, and method of preservation (if applicable). It is often prudent to place containers within a labeled secondary container such as a plastic bag in the event that the label comes loose or the sample leaks as a result of a crack or breakage of the sample container.

For biotic samples, labels may be added directly to the jars with the animals. Larger samples (>5 L) to be subsequently combined for biological testing may be held temporarily (until compositing) in large polyethylene bags. Such bags are useful in that air can easily be removed and the samples held essentially under anoxic condition until compositing. If bags are used the exterior of the bag should be labeled with a waterproof indelible marker. Bags must be placed within a labeled secondary bag to preclude loss of sample due to punctures or tears. Once the samples for biological testing have been combined they may be held in labeled glass or high density polyethylene storage containers until testing is performed (note: the date of compositing should be included on the sample label).

Table G-11: Minimum Sample Size/Container Type for Various Analyses and Tests.

Sample Type	Analysis	Minimum Sample Size[a]	Container Type[b,c]
Physical Analysis (sediment only)	Grain Size	100-150 g	P,G
	Total Solids	50 g	P,G
Chemical Analysis (Sediment only)	TBT	?	B
	Total Organic Carbon	25 g	P,G
	Total Volatile Solids	50 g	P,G
	Ammonia	25 g	P,G
	Oil and Grease	100 g	G
	Acid Volatile Sulfides; Simultaneously Extracted Metals (AVS/SEM)	50 g	P,G
Chemical Analysis (Sediment and Tissue)	Metals other than Mercury (Tissue only)	50 g	P,G
	Mercury	1 g	P,G
	Volatile Organics	50 g	G,T
	Semi-volatile Organics	50 – 100 g	G
	Pesticides and PCBs	50 – 100 g	G,T
Toxicity Testing	Amphipod (*Hyalella azteca*)	1 L	P,G
	Midge (*Chironomus tentans* or *Chironomus riparius*)	1 L	P,G
	Mayfly (*Hexagenia limbata*)	1 L	P,G
Bioaccumulation Testing	Oligochaete *(Lumbriculus variegatus*)	2-3 L	P,G
	Bivalve (*Corbicula fluminea*)	2-3 L	P,G
Biotic Analysis	Identification and enumeration of species. Biomass by major phyla	Dependent on number and size of animals collected.	P,G

[a] Minimum required sample size for one laboratory analysis. Should additional sample be required for possible re-testing sample size should be increased accordingly. For chemical analysis smaller sample sizes may be used if equivalent accuracy and precision can be demonstrated.
[b] P-polyethylene or polycarbonate, G-glass, T-polytetrafluorethylene (Teflon) - lined cap, B-borosilicate glass.
[c] For most chemical and biological testing head space should be either eliminated or significantly reduced, care should be taken in freezing such samples as breakage may occur due to expansion of the sample.
Source: Adapted from Ecology (1995).

4.3.3.3 Sample Storage Requirements

Sample storage requirements are predicated on the type of samples collected and the analysis to be performed. In general, all sediment samples for subsequent chemical and biological testing should be held in the dark, minimal head space, on ice or at 4°C while in field until such time they can be transported to the laboratory for analysis. Samples for macrobenthic invertebrate analysis should be sieved and fixed with formalin in the field. Once samples are received at the laboratory, storage conditions and holdings times are dependent on the analysis to be performed. Suggested holding times and procedures for a variety of analysis are summarized in Table G-12.

Table G-12: Suggested holding times and storage conditions of samples collected for physical/chemical analysis, biological testing, and macro-invertebrate analysis.

Sample Type	Analysis	Handling/Storage Conditions [a]	Maximum Holding Time
Physical Analysis (Sediment only)	Grain Size	4°C (cool)	6 months
	Total Solids	4°C (cool)	14 days
		-18°C (freeze)	6 months
Chemical Analysis (Sediment only)	Total Organic Carbon	4°C (cool)	14 days
		-18°C (freeze)	6 months
	Total Volatile Solids	4°C (cool)	14 days
		-18°C (freeze)	6 months
	Ammonia	4°C (cool)	7 days
	Oil and Grease	4°C (cool) preserved w/HCl	28 days
		-18°C (freeze) preserved w/HCl	6 months
	Acid Volatile Sulfides/Simultaneously extracted Metals (AVS/SEM)	4°C (cool)	14 days
Chemical Analysis (Sediment and Tissue)	Metals other than Mercury (tissue only)	-18°C (freeze)	6 months
	Mercury	-18°C (freeze)	28 days
	Volatile Organics	4°C (cool); -18°C (freeze)	14 days
	Semi-volatile Organics	4°C (cool)	10 days
		-18°C (freeze)	6 months
	Pesticides and PCBs	4°C (cool)	10 days
		-18°C (freeze)	6 months
Toxicity/Bioaccumulation Testing	NA	4°C (cool)	8 weeks
Biotic Analysis	NA	Samples sieved and fixed in field w/ 10% formalin[b] should be transferred to buffered 70% ethanol w/in 10 days.	Indefinitely

Table G-12: Suggested holding times and storage conditions of samples collected for physical/chemical analysis, biological testing, and macro-invertebrate analysis.

Sample Type	Analysis	Handling/Storage Conditions [a]	Maximum Holding Time
[a] All tissue samples should be frozen -18°C and stored frozen until analysis. Sediment samples should be stored in the dark without headspace or under a nitrogen atmosphere until analysis can be performed. [b] Vital stains such as rose bengal and relaxants such as magnesium chloride may be added at the time of fixation to facilitate subsequent sorting and identification. *Source: Adapted from Ecology (1995).*			

4.3.3.4 Chain-of-Custody Procedures

All sampling performed under the PHSMP should follow strict chain-of-custody procedures. The chain-of-custody should track each sample from the point of collection through all handling steps, delivery to the lab and subsequent analysis. Often separate sub-samples are collected for different analysis (i.e., grain size, chemistry, toxicity testing). A separate chain-of-custody form should be created for each discrete sample that is generated. Forms should be filled out in duplicate. It is the project officer's responsibility to ensure that each chain-of-custody form is properly completed and signed at the time of sample transfer. All samples maintained under chain-of-custody should be kept in containers with secure custody seals and/or maintained in a secure location when not under the direct control of the project officer or his/her designated representatives. The project officer should keep a copy of the form at the time of sample transfer. The original form should follow the sample through all subsequent transfers. Minimum information to be included on the chain-of-custody form should include: project ID, sample IDs, sample types, analyses to be performed, date and time of sample collection, project officer and associated contact information. If samples are to be shipped/delivered to the laboratory in coolers the original copy of the form should be placed in a waterproof bag and the bag affixed to the inside of the cooler lid and the cooler sealed.

5.0 ANALYSIS

5.1 Physical and Chemical Analysis

5.1.1 Analytes

Management of sediment in Portland Harbor will include measurement of chemical concentrations in the sediment to determine the nature and extent of sediment-associated contamination. In addition to the measurement of sediment contamination, the concentrations of dissolved chemicals present in sediment pore water may be measured, as well as, the accumulation of contaminants in biological tissues (i.e., bioaccumulation testing and tissue residue analysis of resident species). Analytical evaluations of sediment and tissue samples collected under the Sediment Management Plan will focus on a select group of analytes. In addition to the standard physical analyses (TOC, total solids, grain size etc.) a specific group of target analytes known as COIs was developed based on previous sampling of Portland Harbor (see Section 2.2) . This section provides analytical methods for a much larger group of analytes than the COI identified for Portland Harbor and includes analytes that may be of concern at a particular site due to localized contamination but are not of concern on a harbor wide basis.

Analytes to be evaluated in sediment may include:

- Conventional Analyses - Total Organic Carbon, Grain Size, Total Solids, Total Volatile Solids, Total Sulfides, Ammonia
- Metals - Priority Pollutant Metals (Antimony, Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Silver, and Zinc) and the Ancillary Metals (Aluminum, Barium, Calcium, Cobalt, Iron, Magnesium, Manganese, Potassium, Titanium, Sodium, and Vanadium).
- Organic Chemicals - Semi-volatile Organics (phenols, both high and low molecular weight polynuclear aromatic hydrocarbons (PAHs), chlorinated aromatic compounds, chlorinated alkanes/alkenes, phthalates, organonitrogen compounds, and ethers), Chlorinated pesticides, Chlorinated herbicides, PCB Congeners, Tributyltin, and Dioxins and Furans.

Sediment pore water from Portland Harbor may be tested for:

- Conventional Analyses - Total Sulfides and Ammonia
- Metals - Priority Pollutant Metals (Antimony, Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Silver, and Zinc) and the Ancillary Metals (Aluminum, Barium, Calcium, Cobalt, Iron, Magnesium, Manganese, Potassium, Sodium, and Vanadium).
- Tributyltin

Tissue samples following bioaccumulation test exposure with Portland Harbor sediments may be tested for:

- Lipid Content

- Metals - Priority Pollutant Metals (Antimony, Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Silver, and Zinc).
- Organic Chemicals - Semi-volatile Organics (phenols, both high and low molecular weight PAHs, chlorinated aromatic compounds, chlorinated alkanes/alkenes, phthalates, organonitrogen compounds, and ethers), Chlorinated pesticides, Chlorinated herbicides, PCB Congeners, Tributyltin, and Dioxins and Furans.

5.1.2 Analytical Methods

The selection of appropriate analytical methods is based upon the sample matrix (i.e., sediment vs. water), the anticipated concentration range of the analyte of interest, the required detection limit for the project, and the data quality objectives. The selected analytical methods must produce data that represent the correct form of a chemical to allow for appropriate use of the data in the risk assessment process. Physical and chemical analysis shall be performed using methods that have been validated and are standard test techniques used in the environmental laboratory industry. The use of validated standard methods such as EPA methods (SW-846) is recommended to provide comparable, reproducible, and reliable data for this project.

Additionally, specific guidelines should be provided to each laboratory working on the given project to ensure data comparability. For example, the sediment sample provided for analysis should be the whole sample including any overlying water (i.e., overlying water should not be decanted prior to analysis, but instead should be fully homogenized with the sediment portion before sub-sampling for chemical analysis). Project specific guidance should be determined and followed throughout the project.

Sediment and tissue samples often provide a challenge for laboratories to achieve the required low detection limits and data quality objectives for a sediment investigation program. Because of the inherent difficulty associated with sediment and tissue samples, often laboratories that specialize in sediment and tissue chemistry have developed techniques to address specific interference problems inherent with sediment samples. Such methods include gas chromatography mass spectral analysis using selective ion monitoring (GC MS SIM), organotin analysis methods using gas chromatography with a flame photometric detector (GCFPD), and interfering element reduction by chelation for marine metals analysis. Whatever the technique, the laboratory should have experience in performing the method on sediment and tissue samples and maintain documentation of having conducted method performance verification procedures. Alternative methods should incorporate quality assurance objectives for accuracy and precision of the same type and frequency as those referenced in EPA Methods (SW-846), including the analysis of quality control samples; matrix spiked samples, and standard reference materials. Laboratories to perform analysis on Portland Harbor samples should be selected with care based upon expertise and qualifications. See also: Table G-18 - Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Sediment; Table G-19 - Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Tissues; Table G-20 - Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Pore water).

5.1.2.1 Physical Analysis of Sediments

The physical analysis of sediments shall include the measurement of total solids in order to convert chemical concentrations to a dry-weight basis. Additionally, grain size of sediment should be measured using the method of Plumb (Plumb, R.H., Jr., 1981). Total volatile solids and total organic carbon should also be measured.

5.1.2.2 Inorganics (Sediments and Tissue)

The following priority pollutant metals shall be tested for in sediments and tissues: Antimony, Arsenic, Beryllium, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, Silver, Thallium, Zinc. The following ancillary metals shall be tested in sediments: Aluminum, Barium, Calcium, Cobalt, Iron, Magnesium, Manganese, Potassium, Sodium, Vanadium, and Titanium.

For the determination of metals in sediment the use of the acid digestion procedure EPA 3050 is recommended (except for the mercury digestion procedure, which is included in EPA Method 7471). Although the PSEP program has recommended the use of either total dissolution using hydrofluoric or other strong acids or strong acid digestion using nitric acid, hydrochloric acid and hydrogen peroxide, neither of these methods are recommended. In addition to the health and safety risks to the laboratory associated with conducting these digestion procedures, there is an ecological rationale for recommending EPA Method 3050.

A total dissolution of sediment, including the silicate minerals, provides a biased indication of available metals. Additionally, consistent and reproducible results have been difficult to achieve using the total dissolution method because of the high dissolved solids in the digestate, which cause spectral and physical interference for all the analytical procedures. The ITM describes the total dissolution digestion procedure for metal as neither necessary nor desirable for dredged material investigations. In order to provide reproducible, consistently reliable data that provide an indication of ecological effects for risk assessment, the metal digestion procedure for sediments should follow the strong acid digestion in EPA Method 3050. Additionally, the acid volatile sulfide/simultaneously extracted metals (AVS/SEM, EPA, 1991a) method shall be employed with sediments to measure sulfide, cadmium, mercury, copper, nickel and zinc to facilitate an evaluation of metal bioavailability as these metals can form insoluble sulfides.

Tissues must be completely homogenized prior to sample digestion steps. Tissues should be thawed to allow for complete homogenization and then fully homogenized samples (paste-like consistency) should be stored frozen until digestion or extraction procedures are initiated. A tissue homogenizer or hand-held blender with stainless steel or titanium blades should be used to grind tissues. Any liquid present in the container with the frozen whole tissue sample should be included during homogenization. Care should be taken to retain as much tissue as possible to avoid loss of sample during homogenization. This becomes increasingly important when the amount of tissue available is extremely limited.

Digestion of tissues is recommended to follow EPA Method 200.3. For mercury, EPA method 245.6 includes both sample digestion and analysis procedures. For both sediments and tissues,

the resultant metal extracts may be analyzed by ICP-OES (EPA 6010), ICP-MS (EPA 6020), or GFAA (EPA 7000 series). CVAA may be used for mercury analysis (sediments by EPA 7471A, tissues by EPA 245.6).

5.1.2.3 Organics (Sediments and Tissue)

Total organic carbon (TOC) shall be measured in sediments to provide a measure of the oxidizable organic material and does not include mineralized carbon present as carbonate or bicarbonate. Because concentrations of organic contaminants and sediment toxicity have been found to correlate with the organic carbon content of sediments, it may be appropriate to organic carbon normalize analytical chemical concentration data for non-polar organic contaminants. Organic carbon normalization is performed on a sample-by-sample basis by dividing the dry weight concentration of the chemical by the percent TOC (expressed as a decimal). When data is organic carbon normalized, data should be reported both as dry weight and organic carbon normalized.

There are instances when organic carbon normalization may not be appropriate. For example, if TOC concentrations have been increased by organic contamination such as sewage, petroleum, or wood chips, the organic carbon normalized chemical concentrations may be biased low. Or if TOC values are very low the organic carbon normalized contaminant levels may be biased high. For specific guidance and additional references relating to organic carbon normalization, refer to "Recommended Guidelines for Measuring Organic Compounds in Puget Sound Marine Water, Sediment, and Tissue Samples" (PSEP, 1997b).

PCB Analysis. For this program, it is advisable that the PCB analysis be performed using methods to yield congener-specific results. To control costs, the PCB Arochlor method can be utilized as a screening method and where Arochlors are detected the congener specific analysis should be performed on samples from that site area. The sum of the specific congeners can be applied to indicate total biologically relevant PCBs. This list may be appended over time as additional congeners are determined to have ecological effects (example recent publications have indicated that low-chlorinated congeners elicit neurological effects). Additional research is currently being conducted to further evaluate the biological significance of individual congeners (*personal communication*, Vic McFarland USACE Waterways Experiment Station, Vicksburg, MS).

Tissues shall also be tested for lipid content to allow for lipid normalization of non-polar organic compounds detected in bioaccumulation tissues. Lipid testing may follow the Bligh and Dyer (1959) methodology.

PCB congener specific analysis is more appropriate for evaluation of risk than the Arochlor method. Since Arochlors represent mixtures based on relative amount of chlorine substitution they are more difficult to relate to biological effects as subtle differences in specific congeners present in the mixture may result in vastly different toxicity. The PCB Arochlor mixture method can result in errors in quantification because the method: a) assumes that the distribution of congeners in environmental samples are identical to industrial available mixtures, and; b)

quantifies mixtures of compounds using fingerprinting rather than the individual congeners. For this reason, congener specific analysis is recommended.

Tributyltin. There are several references for organotin methodologies, including Muller (1987) and Krone et al. (1989). The method commonly applied for samples involves extraction with a mixture of tropolone and methylene chloride. After extraction, the solvent extract is concentrated and exchanged into a Grignard reaction solvent and hydride derivitization. Extract clean-up procedures using column silica gel or Florisil are used prior to GC FPD or GC MS SIM analysis.

Chlorinated Herbicides. Chlorinated herbicides are determined by EPA Method 8151 using gas chromatography. The EPA Method 8151 includes all sample extraction, esterification, and instrumental conditions for analysis. Samples are extracted with diethyl ether and esterified with either diazomethane or pentafluorobenzyl bromide. The derivatives are determined by GC.

Dioxins and Furans. Dioxins and furan analysis shall be performed using GCMS EPA Method 1613. Extraction procedures for semivolatile organics and chlorinated pesticides shall follow either soxhlet (EPA 3540) or sonication (EPA 3550) procedures. Method modifications such as smaller final volumes (from 2µl to 1µl) may be necessary to achieve low detection limit requirements.

Semivolatile Organic Chemicals. Following extractions, sample cleanup for sediment and tissues using gel permeation chromatography (GPC) (EPA 3640) is recommended. Semivolatile Organic Chemical determination shall be conducted using the GCMS methodology described in EPA 8270. Additionally, some laboratories may use GCMS with the selective ion monitoring technique to meet detection limits.

Chlorinated Pesticides. Samples shall be subjected to clean-up techniques, as required, including GPC (EPA 3640). For sediment samples additional cleanup techniques including alumina (EPA 3610), florisil (EPA 3620), and sulfur removal (EPA 3660) may be required. Pore water extracts may require no cleanup. Chlorinated pesticides are determined by GC/ECD analysis. Second column confirmation is required pursuant to EPA SW-846 Method 8080.

5.1.2.4 Other Analysis (Pore-Water Organotins & Metals)

The following priority pollutant metals shall be tested for in sediment pore water: Antimony, Arsenic, Beryllium, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, Silver, Thallium, and Zinc. The following ancillary metals shall be tested in sediment pore water: Aluminum, Barium, Calcium, Cobalt, Iron, Magnesium, Manganese, Potassium, Sodium, Vanadium, and Titanium.

Metals analysis on pore water is performed by centrifuging the whole sediment sample and decanting the resultant water. Samples are subject to filtration through a 0.45 micron filter following centrifugation and prior to analysis to provide a “dissolved metals” concentration of the pore water.

Certain ICP-MS (EPA Method 6020 and EPA Method 200.8) instrument models may not require sample pre-treatment, depending upon the complexity of the sample and the sensitivity of the instrument. Pore water may be analyzed by ICP-OES (EPA 6010), ICP-MS (EPA 6020), or GFAA (EPA 7000 series). CVAA may be used for mercury analysis (EPA 7470A).

The same method references for organotin in sediments apply to pore water analysis, Muller (1997) and Krone et al. (1989).

5.1.3 Quality Assurance/Quality Control for Chemical Analysis

It is important that data be comparable from one data set to the next for a particular project. Data comparability allows data generated for a project to be used to support longer-term environmental studies. For this reason, the analytical chemistry procedures utilized must produce relatively uniform and comparable data. The greatest degree of data comparability can be assured by:

- The use of established and validated analytical methods such as EPA SW-846 methods.
- The consistent use of the same methods from one data set to the next for a particular chemical parameter. If methods must change from one data set to the next, the comparability between methods should be verified prior to method changes.
- The analytical method used should be capable of detecting the chemical or analyte of interest at a level at or below the regulatory limit. If data is to be organic carbon normalized, then every effort should be made to achieve the detection limit requirement following normalization. In addition, data should be expressed in the same units and format. For example, sediment parameters should be represented on a dry-weight basis.
- The adherence to data quality objectives in terms of bias and precision.
- The collection and analysis of appropriate quality assurance/quality control samples.

5.1.3.1 Data Quality Objectives

Data Quality Objectives generally are established for a project to demonstrate the degree to which the data is accurate, precise, complete, representative of a population, and comparable to other data sets. Within the analytical laboratory specific quality control steps are taken to ensure that data collected for the various test methods meets specific data quality objectives with regards to the above criteria. In addition to a formal quality control program to regulate data quality, analytical laboratories must ensure and measure data quality using specific quality control checks. If quality control checks are not within specified method performance guidelines, corrective action must be taken including and up to repeating the instrument calibration, sample preparation, digestion/extraction, and analysis steps.

5.1.3.2 Method Performance

For all methods used, method performance characteristics must be established by the laboratory

and documentation must be maintained to demonstrate method performance in terms of bias, accuracy, instrument and method detection limit verification. Laboratories must maintain written standard operating procedures for each method employed. Standard reference materials (SRM) can also be analyzed to verify method performance characteristics (a list of possible SRMs suppliers is provided below; inclusion of this list does not constitute an endorsement of these suppliers by DEQ). Additionally, Quality Control samples must be routinely analyzed with environmental samples to verify and document bias and precision.

National Institute of Standards and Technology (NIST)
Standard Reference Materials Program
Room 204, Building 202
Gaithersburg, MD 20899
Phone: 301-975-6776
This vendor can provide tissues, sediments, and water samples.

National Research Council of Canada (NRCC)
Institute for Marine Biosciences
Halifax, Nova Scotia, Canada B3H 3Z1
Phone: 902-426-9413
This vendor provides mostly marine materials, with some limited freshwater sediments and tissues.

Resource Technology Corporation
PO Box 1346
2931 Soldier Springs Road
Laramie, WY 82070
Phone: 307-742-5452

The Method Blank, Matrix Spike and Matrix Spike Duplicate, Laboratory Duplicate, Laboratory Control Sample, and SRM/CRM are all used to demonstrate analytical procedure control. Corrective action must be taken if results for these samples are outside of control limits. Corrective actions include re-digestion/re-extraction and reanalysis of batch, recalibration, etc. If adequate sample volumes are not provided to allow for re-extraction, all results must be provided with summary of the corrective actions taken to allow for data validation and qualification of the analytical results. To support possible litigation efforts and evaluate potential matrix interferences, full matrix spikes (matrix spike addition of all target compounds) are recommended for MS/MSD quality control samples.

The following quality control guidelines are used for quality control samples:

Analysis Type	**Recommended Minimum Frequency of Analysis**	**Control Limits**
Method Blank (MB)	Minimum of one per batch of 20 or fewer samples	< detection limit (If > DL, the lowest analyte concentration must be at least 10X the MB value.)

Laboratory Duplicate (LD)	One set of duplicates for each batch of 20 or fewer samples	≤ 20% RPD (If outside control limits and ratio of unspiked sample to spike amount is >4, no corrective action.)
Matrix Spike (MS)	One MS for each batch of 20 or fewer samples	75% - 125% for Metals ratory derived control limits for nics/but within SW-846 limits
Matrix Spike Duplicate (MSD)	One MSD for each batch	Same as LD and MS above
Lab Control Sample (LCS)	One for each batch of 20 or fewer samples	80%-120%
Reference Material (SRM/CRM)	One for each batch	85% - 125% or depends upon SRM/CRM
Surrogate Spikes	Each sample for organic analysis	Within EPA SW-846 guidelines or more stringent based upon lab control charts

5.1.3.3 Laboratory Qualifications

It is imperative that the laboratory and its analysts performing chemical testing be experience with sediment, tissue and water matrices. The laboratory should have a quality assurance program in place and the demonstrated ability to meet the requisite data quality objectives and method detection limits for the project. The laboratory should have environmental laboratory accreditation and have undergone external audits to demonstrate the documentation of its quality systems. The Washington State Department of Ecology and the California State Department of Environmental Health both have such laboratory accreditation programs.

5.1.3.4 Detection Limit Capabilities

The ability of the laboratory to achieve the required low detection limits is critical to the success of the ability to conduct a risk assessment. Detection limit objectives are set in Table G-21 - Chemical Parameters and Detection Limits. These detection limits guidelines were based on information from Washington State Sediment Programs including PSEP (1997ab) and Ecology (1995) as well as the OTM.

The laboratory performing the analysis must be able to document their ability to achieve the detection limits. Specific guidance on determining method detection limits is found in 40 CFR Part 136. Additional discussion of matrix specific detection limits can be found in "Recommended Quality Assurance and Quality Control Guidelines for the Collection of Environmental Data in Puget Sound" PSEP (1997d). The ability to meet detection limits can be demonstrated by periodically analyzing a low-level standard containing all target analytes at the detection limit concentrations. It is important to note that when samples are organic carbon normalized or converted to a dry weight basis, the detection limits must be converted as well.

5.1.4 Assessment of Costs

General estimated cost ranges for chemical parameters are provided below on an analyte group

basis.

- Conventionals
  - Total Solids $5-$15
  - Total Volatile Solids $15 - $30
  - Total Organic Carbon $70 - $80
  - Grain Size $70 - $80
  - Total Sulfide $40 - $70
  - Ammonia $10 - $30
- Metals
  - Priority Pollutant Metals $150 - $250
  - AVS SEM $150 - $250
  - Ancillary Metals $150 - $250
- Semivolatile Organics $350 - $700
- Chlorinated Pesticides $100 - $250
- PCB Arochlors $100 - $300
- PCB Congeners $350 - $1500
- Organotin (TBT) $150 - $350
- Dioxin & Furans $850 - $1500
- Herbicides $150 - $250
- Porewater extraction processing $100 - $300

5.2 Toxicity and Bioaccumulation Testing

5.2.1 Laboratory Test Methods

The PHSMP will use standardized toxicity and bioaccumulation tests in a weight of evidence approach to assess potential toxicity to benthic infauna and the potential for contaminant transfer to higher trophic levels. Standardized toxicity tests to be used in the evaluation of Portland Harbor sediments include 10 and 28-day tests with the amphipod *H. azteca* and a 10-day test with the midge *C. tentans*. In addition, descriptions are provided for alternative test species such as *Hexagenia limbata* and *Tubifex tubifex*. While protocols for these alternative test species are not as well developed at this time to be used routinely they may be useful for special applications or to provide additional information.

Comparisons for all tests (toxicity and bioaccumulation) will be made to appropriate reference sediments. In addition to the reference sediment, a control sediment will also tested. The control is a sediment in which animals are cultured, or sediment from where animals were collected, or some other "clean" sediment known to produce consistently acceptable survival, growth and/or reproduction in the test species. The control is generally used to assess test validity by providing a benchmark for test animal performance (e.g., *H. azteca* exposed to control sediment must have >80% survival in order for the test to be considered valid). The standard test organisms described below are considered relatively tolerant of a broad range of sediment physicochemical characteristics (e.g., grain size, TOC, etc.). However, the presence of indigenous organism in test

samples (especially oligochaetes) has been shown to affect sublethal endpoints with many of these test species (Reynoldson et al., 1994). In addition the presence of predatory species has obvious implications (Ingersoll and Nelson, 1990). If indigenous oligochaetes or predatory species are present in the test sample one should consider removing them by pre-sieving the material. If test sediments are pre-sieved then control and reference material must also be pre-sieved to control for any potential effects relating to sieving.

5.2.1.1 Standard Laboratory Toxicity Tests

10-day Survival, amphipod H. azteca. The freshwater amphipod *H. azteca* is widely distributed throughout all of North America and is a standard test species used in the assessment of contaminated sediments. *H. azteca* is easily cultured in a laboratory setting and there are numerous commercial sources. Test protocols for evaluating 10-day survival in *H. azteca* are thoroughly discussed in both ASTM E-1706 (1998d) and EPA (1994b). Briefly, test sediments are homogenized just prior to being added to test chambers (300 ml tall form glass beakers or similar chamber providing equivalent surface area). Approximately 100ml of homogenized test sediment is added to each of the eight laboratory replicates per treatment. After sediment has been added, 175 ml of clean water is added. Suitable water sources for testing include reconstituted water, well water that has been thoroughly characterized and found suitable for testing with *H. azteca*, aged, filtered municipal water that has been thoroughly characterized, or site water. If site water is used, it should be freshly collected and/or maintained under aeration at test temperature until used in testing. If site water is used, one should also be aware that test results could be potentially confounded by water quality from events (e.g., up current storm water discharges, undocumented spills) unrelated to sediments at the site under investigation.

Overlying water is renewed two times in the 24 hours prior to adding test animals and initiating the test. Renewal of overlying water can be done manually, or via water renewal systems described by Benoit et al. (1993) or Zumwalt et al. (1994). If water renewal is done by hand care should be taken so as not to disturb the test sediments. Water renewals are done twice daily for the duration of the test. The test is initiated by adding ten 7-14 day old amphipods to each test chamber. Animals are fed 1.5 ml of a specially prepared mixture of yeast, Cerophyl and trout chow known as YCT each day. Instructions for obtaining known age amphipods and for preparing YCT are found in both ASTM (1998d) and EPA (1994b). The test is run at a temperature of 23°C, a photoperiod of 16 hours light and 8 hours dark, and without aeration unless dissolved oxygen levels fall below 40% saturation. [NOTE- Dissolved oxygen should be measured prior to addition of test organisms at test initiation; if dissolved oxygen is less than 40% saturation then test beakers should be aerated in addition to the prescribed twice daily renewal of overlying water.]

Water quality measurements of conductivity, hardness, pH, alkalinity, and ammonia should be measured at test initiation (day 0) and test termination (day 10) [NOTE - If there is reason to believe that test sediment may contain elevated pore water ammonia levels a sample of sediment pore water may be collected from a dummy replicate (i.e., an additional test replicate without animals) just prior to test initiation. Sediment pore water is collected by decanting the overlying water and centrifuging the sediment at 3,000 - 4,000 rpm for 30 minutes. Pore water samples

should be analyzed for pH and total ammonia. With the advent of new electrode technologies these samples can be rapidly analyzed and the potential for ammonia toxicity evaluated prior to test initiation. It should be noted that for purposes of the Portland Harbor Sediment Management Plan ammonia may be a contaminant of concern if related to anthropogenic inputs.] Temperature should be measured daily in at least one replicate test chamber per treatment. Daily observations should include the appearance of any dead animals, absence of burrows, and any signs of avoidance (e.g. # of animals in the water column or trapped in the surface tension). After 10-days of exposure animals are recovered by gently sieving the beaker contents through a 500µm sieve. The test endpoint is survival.

Microtox® 100 percent Sediment Porewater Toxicity Assessment. Microtox represents a commercially available assay for which substantial information exists on Columbia and Willamette river sediments. However, the ecological relevance of this assay is at best limited in its applicability to freshwater sediments (i.e., *Photobacterium phosphoreum* is a planktonic, marine bacterium). Consequently it is envisioned that this test will be utilized on an interim basis, until more experienced is obtained in conducting the alternative chronic tests described below).

Microtox® is a rapid method of assessing toxicity in aqueous media by utilizing the bioluminescent properties of the marine bacteria *Photobacterium phosphoreum*. The test method assumes that light emitted by the bacteria can be used as an accurate assessment of the overall biological condition of the bacteria exposed to chemical compounds and mixtures. Light emitted by the bacteria exposed to potentially toxic samples is compared to light emitted to unexposed bacterial controls. Differences in luminescence is therefore deemed an indication of relative toxicity.

Microtox® has been recommended by EPA for TIE/TRE applications (EPA/600/2-88/070) as well as storm water investigations. Successful applications also include NPDES compliance and sediment evaluations in freshwater, estuarine and marine applications. Washington State PSEP (Puget Sound Estuarine Protocols) uses both an organic and an aqueous extraction protocol to assess sediment toxicity. Recognizing that the goal of most sediment toxicity studies is to determine if ecologically/toxicologically significant differences exist between reference and investigative site sediments, three significant differences exist between the PSEP protocol and this freshwater protocol: 1) Extraction procedures are 100% pore water extraction rather than complex organic and aqueous extractions; 2) no serial dilutions are performed because LC_{50} calculations are not required to assess sediment toxicity between reference and site sediments and 3) statistical procedures utilize standard t-test procedures.

The general Microtox® procedure involves centrifugation of 500 ml of both reference and test sediments at 9000G resulting in approximately 50 ml of pore water. Pore water is pipetted into a flask where salinity is adjusted to 20+ 2ppt using commercially available dry bulk marine aquarium reef salts (e.g. Forty Fathoms Reef®). The pH of the salinity-adjusted reference and test sediment pore water should not differ by more than 0.4 pH units. If sufficient volume of pore water extract is available, pH should be adjusted to 7.9-8.2 (if necessary) using a dilute

NaOH or HCl solution. Dissolved oxygen of the extracts should be adjusted by gentle aeration to between 50-100% saturation.

A vial of freeze-dried bacteria is rehydrated with 1.0 ml of Microtox® Reconstitution Solution and allowed to equilibrate for 30 minutes in the 4-degree Microtox Analyzer well. One (1.0) ml of control solution is transferred into each of 5 test cuvettes previously placed within the 15-degree incubation chambers. This procedure is followed for the reference sediment pore water samples and up to 4 test sediment pore water samples/batch. In each of the test, reference, and control sample cuvettes, 10 uL of rehydrated bacteria suspension is added at 15 second intervals and allowed to incubate for 5 minutes.

At the initial (I_0) 5-minute mark the first control vial is placed into the read chamber to "set" the instrument. At 30 second intervals each cuvette (inclusive of A1) is placed into the read chamber for the initial reading (I_0). After 5 additional minutes a second reading (I_5) is obtained following the above procedure. A 15-minute (I_{15}) reading is obtained in an additional 10 minutes. Statistical analysis consists of performing t-tests (at 5 and 15 minute intervals) between reference results (negative controls) and test site results. Controls are used for inter-test comparison to determine test performance, bacterial batch consistency and technician variability. It should be noted that no ($I_0 - I_5$) or ($I_0 - I_{15}$) percent decrease in luminescence or Gamma is calculated to determine relative toxicity between reference and test site pore water extracts.

10-day Survival and Growth, midge *C. tentans*. The midge *C. tentans* is another widely used standardized freshwater test species. Like *H. azteca, C. tentans* can be cultured in the lab and there are numerous commercial suppliers. Culturing of this test species is somewhat more involved than for *H. azteca* but detailed procedures are described in both ASTM (1998d) and EPA (1994b). Test procedures for measuring survival and growth in 10-day sediment toxicity tests with *C. tentans* have also been described (ASTM 1998d, EPA 1994b). In general test procedures for *C. tentans* are nearly identical to those used in 10-day test with *H. azteca* (e.g., temperature [23±1°C], photoperiod [16:8], test chamber [300ml], renewal rate [twice daily], number of replicates [8], number animals per replicate [10]). Tests with *C. tentans* are initiated with 3rd instar larvae or younger animals. Procedures for obtaining 3rd instar larvae are described in both EPA (1994b) and ASTM E 1706 (1998d). Recognizing that synchronous development is not possible even in laboratory cultures of this test species, protocols specify that a minimum of 50% of the larvae used in the test must be 3rd instar (8.5 to 12.5 days after hatching). To confirm that test organisms are 3rd instar or younger head capsule width must be measured on a subset of the animals used to initiate the test (head capsule widths should be between 0.33 and 0.45 mm). Head capsule width may be measured under a dissecting scope equipped with an ocular micrometer. Animals in each test chamber are fed 1.5 ml of Tetrafin® goldfish food prepared as a suspension (i.e., 4g dry solids / L suspension) each day. Should excess food begin collecting at the sediment surface feeding may need to be suspended for a day or two (note if feeding is to be suspended it must be suspended in all treatments including control and reference). Monitoring of the test is identical to that described for the 10-day *H. azteca* test, however evaluating burrowing behavior may not be possible, as *C. tentans* are often not visible during the test. At test termination, any immobile or dead organisms are removed from the sediment surface (note: immobile organisms are scored as dead for the survival endpoint). Test chamber contents are

then gently rinsed through a 500 μm mesh sieve (in coarser sediment it may be necessary to sieve a portion of the sediment and rinse retained material into a dissecting pan to collect surviving organisms). Test endpoints included survival and growth. The measurement of growth is identical to that used for *H. azteca* in the 28-day test (i.e., measured as average individual dry weight and recorded to the nearest 0.01mg). However, any pupae or adult organisms must not be included in the weight measurement.

5.2.1.2 Alternative Toxicity Tests

28-day Survival and Growth, amphipod *H. azteca*. A 28-day test can also be conducted with *H. azteca*. A 28-day/42-day test method is currently under review as part of the new EPA guidance for freshwater toxicity testing (EPA in review). The 28-day test measures survival and growth following 28-days of exposure to contaminated sediments. The 42-day test requires animals to be removed from test sediments and placed in beakers with a Nitex® mesh substrate (no sediment) and then monitored for reproductive output. Due to the length of the 42-day test and the lack of sediment exposure for nearly half of the test duration only the 28-day test is being recommended for use in the evaluation of Portland Harbor sediments. The 28-day test is conducted in a manner similar to the 10-day test with the exception that water quality monitoring is performed weekly on randomly selected replicates. At test termination growth is measured in addition to survival. While growth in *H. azteca* may be measured either as dry weight or as length, accurate measures of length require specialized equipment (image analysis and/or digitizing software) not commonly available at most testing labs. Therefore all testing performed under this management plan will measure growth as dry weight. Growth measured as dry weight is determined by pooling all surviving organisms onto a single pre-weighed aluminum drying pan and drying the sample to a constant weight (i.e. 60°C for 24 hours). Average individual dry weight in a replicate is then calculated by dividing the total dry weight (measured to the nearest 0.01 mg) by the number of surviving organism weighed.

21-day Survival and Growth, mayfly *H. limbata*. *Hexagenia limbata* is used less frequently (relative to *H. azteca* and *C. tentans*) in the evaluation of freshwater sediments and test methods are not as well developed (i.e., ASTM has guidance for conducting tests but there is no standard method at this point in time). Unlike *H. azteca* and *C. tentans* the life history of *H. limbata* is such (i.e., in terms of length and complexity) that laboratory cultures are impractical. However, nymphs can be obtained directly from the field or eggs may be collected and reared in the laboratory. Eggs have been stored up to a year and used successfully in testing (ASTM 1998d). Detailed procedures for collecting, rearing, and testing mayfly larvae are provided in ASTM E 1706 (1998d). Tests are initiated with 3-4 month old nymphs (approximately 5mg wet weight); 10 organisms per test chamber. Test chambers are 2 L glass jars (≈12 cm in diameter). Sediment volume is 325 ml with an overlying water volume of 1300 ml. The test is conducted under static conditions without renewal or aeration (unless oxygen saturation falls below 40%), at a temperature of 20-22°C, under a photoperiod of 16 hours light and 8 hours dark. Temperature and dissolved oxygen are monitored daily for the duration of the test. Other water quality parameters (e.g., hardness, alkalinity, conductivity, pH, and ammonia) are measured at test initiation and termination (since there is no renewal). After 21 days the test is terminated by gently rinsing the contents of the test chambers through a 0.5mm mesh sieve. Material retained

upon the screen may be washed into pans and organisms removed with a Pasteur pipette. The number of surviving organisms is recorded for each test chamber. Pooled survivors from each test chamber are then placed onto pre-weighed aluminum pans dried at 60°C for 24 hours. Average individual dry weight in a replicate is then calculated by dividing the total dry weight (measured to the nearest 0.01 mg) by the number of surviving organisms weighed.

28-day Survival and Reproduction, oligochaete *Tubifex tubifex*. Tubificid oligochaetes are relatively easy to culture in the laboratory. In addition, their short life-history makes it possible to obtain information on potential reproductive effects in a reasonable time frame (28-days) for routine testing purposes. General culturing and testing procedures are described in ASTM E-1706 (1998d). Like *H. limbata* there is no standard test method developed for *T. tubifex* at this point in time. Tests with *T. tubifex* are conducted in 250 ml test chambers containing 100 ml of sediment and 100 ml of overlying water. Approximately 24 hours prior to adding the test organisms 5 ml of a trout chow suspension (1mg dry material per 1 ml of distilled water) is added to each test chamber as a food source, no additional food is required for the duration of the test. Tests are initiated with four sexually mature (i.e., presence of testes and ovaries) *T. tubifex* per test chamber with five replicates per treatment. Recommended test conditions are similar to those described for *H. limbata*. The test is conducted under static conditions without renewal or aeration (unless oxygen saturation falls below 40%), at a temperature of 20±1°C, under a photoperiod of 16 hours light and 8 hours dark. Temperature and dissolved oxygen are monitored daily for the duration of the test. Other water quality parameters (e.g., hardness, alkalinity, conductivity, pH, and ammonia) are measured at test initiation and termination (since there is no renewal). At test termination contents of each beaker are sieved through a series of nested sieves (e.g., 250 μm and 500 μm mesh sizes, respectively). Animals retained on the 500 μm sieve are adults and large juveniles. Empty and full cocoons are also retained on the larger sieve. Animals retained on the 250 μm are small young. Endpoints include number of surviving adults, total young produced, number of young per surviving adult. Collection of cocoons permits an estimate of percent hatch (empty cocoons/total cocoons).

Toxicity testing with fish. Methodologies for sediment testing with fish are not well developed. Since benthic infaunal invertebrates are presumed to have maximal exposure to sediments they have generally been used as surrogates for the protection of higher organisms such as fish. However, there are standardized effluent testing procedures developed for the National Pollutant Discharge Elimination System (NPDES) program that could be adapted to address the potential for toxicity of sediment to fish. For example the larval survival and growth test with the fathead minnow *P. promelas* used in the evaluation of effluents could be adapted to evaluate potential toxicity from bedded sediment (Weber et al., 1989). Test methods also exist for measuring acute toxicity (survival) in the rainbow trout *Oncorhyncus mykiss* (Ecology, 1997). However, it should be noted that since these tests were not developed for testing of sediment, potential interferences are not well defined and existing interpretative guidance may not be appropriate. As a consequence results from such test should never be used to make decisions in the absence of other information (e.g., results from more standardized test procedures). Such tests may be useful, however, in a weight-of-evidence approach to elucidate the potential for direct toxicity of contaminated sediment to fish.

5.2.1.3 Standard Laboratory Bioaccumulation Tests

Laboratory bioaccumulation tests provide an estimate of contaminant uptake by benthic infauna. In addition information collected from such tests provide important information on the potential for trophic transfer of contaminants to higher organisms. In general all laboratory bioaccumulation tests involve exposing test organisms to sediment for a 28-day period without feeding (i.e., presence of food may alter bioavailability of the compound and/or alter uptake kinetics). The test duration of 28 days was selected to represent the period of time generally required for most contaminants to approach steady-state (though for certain contaminants, such as PCBs, much longer periods of exposure are required for contaminant uptake to approach steady state). Test animals are generally exposed to a control and reference sediment in addition to the test sediments. The purpose of the control in bioaccumulation testing is to establish that contaminants were not introduced during the course of testing via laboratory water, glassware, or some other source unrelated to the sediment being tested. As in toxicity testing the reference serves as the point of comparison. If tissue residues in test sediment exposed organisms are found to exceed that of reference exposed organisms then the significance of those elevated tissue residues must be evaluated in terms of potential risk to higher organisms, (i.e., test sediment exposed organisms are less than the reference) otherwise risk is considered *de minimus*. General guidance for conducting bioaccumulation tests is provided in EPA (1993a).

28-day bioaccumulation, oligochaete *L. variegatus*. The oligochaete worm *L. variegatus* is perhaps the most commonly used test species for evaluating bioaccumulation in freshwater sediments and is indeed the only freshwater bioaccumulation test species for which the EPA has a published test method (EPA, 1994b). In general, most bioaccumulation test species are selected because they are relatively insensitive to contaminants thereby ensuring that a sufficient number of animals will survive to the end of the exposure for subsequent tissue analysis. *L. variegatus* is actually quite sensitive and has been used as a toxicity test species. Consequently, a 96h toxicity screening test should be performed to ensure that the sample is not overtly toxic prior to expending the resources to set-up the bioaccumulation study. This screening test can be conducted in 300 ml test chambers containing 100ml of sediment and 175 ml of overlying water similar to that described for *H. azteca*. The screening test is initiated with ten adult oligochaetes/ replicate with 3-4 replicates per treatment. Test is conducted at 23° C, 16:8 photoperiod, with twice daily renewal of overlying water. Animals are not fed during the test. If there is significant mortality or animals are exhibiting avoidance behavior then bioaccumulation testing with *L. variegatus* may not be possible or appropriate. Should results of this preliminary screen indicate that test sediments are not toxic and animals are not avoiding the sediment then one can proceed with the bioaccumulation test. Test methods for bioaccumulation testing with *L. variegatus* are described in detail in EPA (1994b) and ASTM E1688-97a (1998b). Briefly, bioaccumulation tests with *L. variegatus* are conducted in 4 to 6 L aquaria containing a minimum of 1L of test sediment (sediment volume should be consistent across all treatments) with approximately 1L of overlying water. Sediments are added to the test chambers and overlying water exchanged twice approximately 24 hours in advance of test initiation. The test is initiated with adults. A sub-sample of animals (approximately 100 animals) are weighed in-advance and the test is then stocked at densities ranging from 1 to 5 grams wet biomass per replicate test chamber. There are five replicates per treatment. The test is conducted under a 16L: 8D photoperiod, without

aeration (unless dissolved oxygen falls below 40%), at a temperature of 23 ± 1°C. Animals are not fed for the duration of the experiment. Water quality monitoring should include measurements of hardness, alkalinity, conductivity, pH and total ammonia at test initiation and termination and daily measurements of temperature and dissolved oxygen. Test chambers should be monitored daily to evaluate survival, burrowing activity, and/or avoidance behavior. If an automated water delivery system is used it should also be monitored daily. At test termination animals are removed from the sediment via gently sieving test chamber contents through a 500 µ m mesh sieve. Material retained on the sieve should be transferred to a shallow pan to a shallow dissecting pan for sorting. Animals that are unresponsive to gentle prodding should be considered dead and excluded from subsequent tissue analysis. All surviving organisms from an individual replicate should be transferred to a 1L beaker containing clean water for 24 hours to purge their gut contents. After this 24 hour period, wet biomass for individual replicates are determined by placing surviving animals on a pre-weighed aluminum weigh boat, removing excess water by blotting and weighing the pooled sample. Animals are then placed in clean containers and frozen for subsequent tissue residue analysis.

5.2.1.4 Alternative Laboratory Bioaccumulation Tests

28-day bioaccumulation, bivalve *C. fluminea*. The Asiatic clam *Corbicula fluminea* was introduced sometime prior to 1938; it has since become widely distributed throughout streams, rivers and lakes in North America. It is a filter feeder that generally buries itself in surficial sediments. Though there are no standard methods currently available for testing with *C. fluminea* it has been used in other studies. In addition, mollusks represent a potentially important vector for the transfer of contaminants to higher organisms. Test methods described herein represent a compilation of generic guidance (EPA 1993a, 1998?) and published studies where *C. fluminea* has been used (Baudrimont et al., 1997; Mac et al., 1990). Test animals may be obtained through commercial suppliers. Supplier should document source of the organisms and provide control sediment from area where animals were collected.

Animals should be acclimated to test conditions for 1 to 2 days prior to testing. Organisms should have soft tissue weights of approximately 1 gram wet weight and generally 20 to 30 animals are used per replicate test chamber (5 replicates per sediment treatment). Test may be conducted in 39L glass aquaria or similar container with a 5cm layer of sediment (approximately 2-3L). Twenty-four hours prior to adding test animals sediment is placed in aquaria and overlying water added. Aquaria are then placed in flow-through system with a flow rate of 0.1 L/min. After 24 hours test animals are added. The test is conducted under a 12L: 12D photoperiod, without aeration (unless dissolved oxygen falls below 40%), at a temperature of 20 ± 1°C. Animals are not fed for the duration of the experiment. Water quality monitoring should include measurements of hardness, alkalinity, conductivity, pH and total ammonia at test initiation and termination and daily measurements of temperature and dissolved oxygen. Test chambers should be monitored daily to evaluate survival (any dead animals should be removed). Flow rates should be monitored daily. At test termination animals are removed from the sediment via gently sieving test chamber contents through a 1mm mesh sieve. Any gaping animals that are unresponsive to gentle prodding should be considered dead and excluded from subsequent tissue analysis. All surviving organisms from an individual replicate should be

transferred to an aquarium containing clean water for 24 hours to purge their gut contents. After this 24 hour period, animals are placed in clean containers and frozen for subsequent tissue residue analysis.

28-day bioaccumulation, fish *P. promelas*. Traditionally, bioaccumulation tests have been conducted with benthic invertebrates because their intimate contact with the sediment and relatively sessile motility maximize potential exposure to sediment-associated contaminants. Other species such as certain fish, however, may have unique exposure pathways (e.g., resuspension that can increase contaminant bioavailability) that are not readily assessed through tests with traditional benthic invertebrate test species. Consequently, a more comprehensive assessment of contaminant uptake by sediment exposed organisms should include exposure of fish whose life-history habits result in resuspension of sediments. The fathead minnow, *Pimephales promelas* represents one such test species for which test methods are available. Test methods for a 10-day bioaccumulation test with *P. promelas* have been described by Mac et al. (1990). These methods can be easily adapted for a 28-day exposure duration. Test animals may be obtained through commercial suppliers or from stock maintenance in laboratory culture. Animals should be acclimated to test conditions for 1 to 2 days prior to testing. Tests are initiated with adult *P. promelas* weighing between 2 to 4 grams wet weight. Generally 10 to 20 animals are used per replicate test chamber (5 replicates per sediment treatment). The test may be conducted in 39L glass aquaria or similar container with a 5cm layer of sediment (approximately 2-3L in 39L aquaria). Twenty-four hours prior to adding test animals sediment is placed in aquaria and overlying water added. Aquaria are then placed in flow-through system with a flow rate of 0.1 L/min. Note a baffle, trough, or stand pipe should be used for exiting water to reduce loss of fines (resulting from sediment resuspension) over the duration of the exposure. After 24 hours test animals are added.

The test is conducted under a 12L:12D photoperiod, with gentle aeration (higher aeration may be required if dissolved oxygen falls below 40%), at a temperature of 20 ± 1°C. Animals are not fed for the duration of the experiment. Water quality monitoring should include measurements of hardness, alkalinity, conductivity, pH and total ammonia at test initiation and termination and daily measurements of temperature and dissolved oxygen. Because *P. promelas* resuspend sediment, daily observation of survival may prove difficult, however, dead organisms floating on the surface should be removed. Flow rates should be monitored daily. At test termination animals are removed from the exposure chamber by siphoning off the overlying water and netting the surviving organisms. Dead should be excluded from subsequent tissue analysis. All surviving organisms from an individual replicate should be transferred to an aquarium containing clean water for 24 hours to purge their gut contents. After this 24 hour period, animals are blotted dry, placed in clean containers and frozen for subsequent tissue residue analysis.

5.2.2 Use of Indigenous Test Species

While the use of standardized test procedures and test species offers consistency and permits comparison across sites over time the use of indigenous test organisms can provide useful information about potential effects to resident species. Both ASTM E1850 97 (ASTM 1998c) and EPA (1991) provide guidance for the selection of resident species as test organisms.

Candidate species for testing of Willamette River sediments include: demersal fish such as the white sturgeon *Acipenser transmontanus*, the catfish (*Ictalurus* sp.) and suckers (*Catostomus* sp.); nektonic species such as the small mouth bass (*Microptorus dolomieu*), salmonids such as Chinook (*Oncorhynchus tshawytscha*), Coho (*Oncorhynchus kisutch*), and Steelhead (*Oncorhynchus mykiss*). Many of these species could be obtained through local hatcheries. Demersal species are better suited for the evaluation of bioaccumulation potential compared to nektonic species. Demersal fish tend to have higher lipid content, more intimate contact with sediment and tend to be less sensitive to sediment-associated contaminants than nektonic species.

There are numerous studies evaluating contaminant effects on *Ictalurus sp.* but there is little to no published information on testing with sturgeon or suckers. Many of the studies with *Ictalurus sp*. have examined subcellular responses (e.g., immunosupression, p450 production, etc.) in addition to bioaccumulation (Winston et al., 1989; Rice and Schlenk, 1995; Plakas et al., 1996; Gale et al., 1997). While such measures can provide a good indication of exposure, the linkage to whole organism effects (e.g., reduced growth, survival, or fecundity) is generally not clear. As a result, interpretation of these subcellular endpoints at the individual or population level is difficult.

As mentioned previously, test methods for evaluating the toxicity (acute survival) of effluents (under the NPDES program) have been developed for the rainbow trout (steelhead) *Oncorhyncus mykiss* (Ecology, 1997) and could be applied/adapted for the evaluation of sediments with salmonids. Small mouth bass have been used to assess toxicity of aqueous phase contaminants but not sediment-associated contaminants and there are no published methods. Indigenous invertebrate species other than the test species described above (sections 5.2.1.1 through 5.2.1.4) could also be evaluated, however, appropriate test methods would need to be developed.

5.2.3 In Situ Testing

Site assessment may include *in situ* testing (i.e., bioaccumulation and/or toxicity). Such tests are useful in that they can provide more realistic measures of exposure accounting for the influence of site specific conditions on contaminant uptake. However, like laboratory bioassays, *in situ* tests can be confounded by factors unrelated to sediment exposure (e.g., short-term changes in turbidity, current flow, etc.). Unlike laboratory bioassays, which are conducted in a controlled setting, there is a greater potential for such factors to go undetected. *In situ* tests have been conducted successfully and there are many examples in the published literature where such tests have helped to elucidate environmental effects (Rice and White, 1987; Gale et al., 1997). Methods for conducting *in situ* exposures are determined largely by the site characteristics and species being evaluated. *In situ* toxicity test methods have been described for invertebrates such as the amphipod *H. azteca*, the midge *C. tentans* (Chappie and Burton, 1997), and the oligochaete *L. variegatus* (Monson et al., 1995) as well as for fish species such as the fathead minnow *P. promelas*, (Wilde and Parrott, 1984; Jones and Sloan, 1989), and rainbow trout *Oncorynchus mykiss* (Camusso et al., 1995). These test methods can be adapted for the evaluation of other species and/or to address site-specific issues.

5.2.4 Statistical Analysis of Sediment Toxicity and Bioaccumulation Data

Statistical Analysis of Sediment Toxicity Data. Data from sediment toxicity tests are assessed for differences in response (e.g., survival, growth, reproduction) by comparing mean response values for samples from potentially contaminated sites to a mean response value for samples from a reference site with Analysis of Variance (ANOVA) and Fisher's Least Significant Difference (LSD) comparison of means. ANOVA relies on the assumption that the data are normally distributed and that the variances of each set of samples are equal. Data are evaluated for adherence to test assumptions prior to parametric statistical tests. For those cases when data fail to meet the test assumptions, non-parametric tests are used. To perform the non-parametric tests, the data are ranked, the ranks are evaluated as to whether they meet the test assumptions, and ANOVA and LSD are applied to the ranks. Detailed guidance related to statistical analysis of sediment toxicity data is provided in the Inland Testing Manual (ITM) (EPA/COE, 1998).

The assumptions of a normal distribution and equal variances must be evaluated to determine which statistical test is most appropriate for the data set to be tested. The test assumptions apply to both the actual or transformed data and to the ranks.

An appropriate transformation applied to the data will typically provide normalization; for survival data, an arcsine transformation is considered appropriate. To determine whether the data are normally distributed, the Shapiro-Wilk's Test is then applied to the residual values for each site (i.e., the difference between each value and the mean for the site). Residual values are used because they remove any differences between sites as the mean for each site is zero.

Equality of variances can be tested by several methods; Levene's Test is most commonly used. This test compares the absolute values of the residuals between sites using an ANOVA. If the variances are equal, ANOVA and LSD comparisons can be used. If variances are significantly unequal, a t-test should be used to compare each site to the reference using an adjustment for unequal variances.

When data meet the assumptions of normality and equality of variance, ANOVA and LSD are performed on the actual data (with appropriate transformation) or on the ranks (non-parametric test). The ANOVA is performed to provide the mean square error, a pooled variance across all sites, which is used in the LSD comparison. The LSD then compares the means of each site to determine which are significantly different. Means that are significantly different and lower than the reference site mean indicate that the sediment is more toxic than the reference sediment.

When the variances of the data are not equal, the data are tested using a t-test for unequal variances to compare each site to the reference site. This test uses an approximation of the *t* statistic from the variances of each set of data. If the test site mean is significantly lower than the reference site mean, the sediments at the site are more toxic than the reference sediment.

Statistical Analysis of Tissue Residue Concentrations from Sediment Bioaccumulation Tests. Testing of chemical concentrations in tissues from organisms exposed to contaminated material is performed similarly to that described for solid phase testing. The data tested are the

contaminant concentrations rather than the response data. Data must meet the assumptions of normality and equality of variance prior to ANOVA and LSD comparison. With these data, the actual values often meet these assumptions; when they do not, a log transformation is typically used as contaminant concentrations often are lognormally distributed. If the assumptions are not met with the transformed data, data are converted to ranks and the assumptions are tested again.

With contaminant concentration data, the likelihood of encountering non-detectable (censored) data must always be addressed. To statistically compare data using ANOVA or t-tests, it is necessary to have a variance estimate for each set of data. When the proportion of censored values is low in a data set, variances can be computed with substitution of a constant value such as one-half of the detection limit for the censored data. To provide a variance estimate for a data set when censored data are proportionately high, values can be substituted that uniformly surround the mean for the set. If only one value is censored, one-half the detection limit is substituted. In situations where more than one value is reported below the detection limit, estimated data values based on a symmetrical breakdown of the data range are applied in such a way that the mean of the estimates is centered around a value one-half of the detection limit. This statistical manipulation of the data generates statistically valid means and variances so that the required statistical evaluation of the data can be performed.

After appropriate substitutions and transformations have been applied, and the statistical assumptions tested, ANOVA and LSD comparison or t-tests can be performed. These tests are as described for the solid phase testing and are one-tailed tests to determine if the data from test sites are significantly higher than the reference site data. Detailed guidance on statistical analysis of tissue residue data from sediment bioaccumulation is provided in the Inland Testing Manual (ITM) (EPA/COE, 1998).

5.2.5 Quality Assurance/Quality Control Procedures

A good quality assurance/quality control program is paramount to ensuring that data is of sufficient quality to be used in remedial action decision making. A good quality assurance program should have a clear structure of responsibility, formal data quality objectives, defined test procedures, and mechanisms for identifying and correcting potential problems early in the evaluation process. In contrast, programs with substandard QA/QC often have no way of assessing data quality. As a consequence conflicts associated with suspect data may not be resolved, and the decision-making process is either slowed or stopped completely. A comprehensive QA/QC program is fundamental to the success of a project.

Quality Assurance Project Plans vary in content depending on program needs, but should address the following elements:

- Project organization and responsibilities.
- Definition of data quality objectives.
- Sampling procedures.
- Instrument calibration procedures.
- Procedures for recording, reducing, validating, and reporting data.

- Procedures for performing quality assurance verification and internal quality control checks.
- Preventative maintenance schedules.
- Specific routine procedures to evaluate precision, accuracy and completeness.
- Definitions of deviations and appropriate actions.
- Information on appropriate training and indoctrination.

Additional guidance on quality assurance/quality control procedures relating to biological testing may be found in Moore et al. (1994), EPA (1994), USEPA (1993) and USEPA (1989).

5.2.5.1 Performance Standards

Performance based standards for evaluating the validity of standardized laboratory toxicity tests and bioaccumulation test results are provided in the associated guidance documents (ASTM 1998 [1706-95b; 1688-97a], USEPA 1994, USEPA 1993). Table G-22 - Summary of Published Test Acceptability Standards provides a summary of test acceptability standards for the test procedures described in these documents. Table G-23 - Summary of Test Deviations and Suggested Responses provides a summary of potential test deviations and suggested responses. For more generic QA/QC guidance relating to biological testing the reader is referred to Moore et al. (1994).

5.2.5.2 Reference Toxicant Testing

Reference toxicant tests should be conducted in parallel with all sediment toxicity tests. Reference toxicant tests are used to evaluate consistency of test organism sensitivity to a specific contaminant (e.g., cadmium). Results are generally evaluated by developing a control chart in which a laboratory mean LC50 value has been plotted (based on approximately 20 or more observations) along with lines representing ± two standard deviations of the laboratory mean. Generally test animal response is considered "out-of-control" when the calculated LC50 for a given a reference toxicant test falls outside of the two standard deviation (2 S.D.) lines. Such out-of-control responses are generally only of concern if no toxicity is observed in the sediment test and the reference toxicant response is greater than + 2 S.D. line (i.e., animals were less sensitive than normal) or if many sediments are shown to toxic and the reference toxicant response is less than the –2 S.D. line (i.e. animals were more sensitive than normal). In such cases it may be necessary to rerun the sediment toxicity test with a new batch of test organisms. Reference toxicant tests are not generally run on bioaccumulation test species. However, it may be useful to expose a group of bioaccumulation test organisms to a given bioaccumulative contaminant in an aqueous exposure or spiked sediment assay in order to evaluate consistency in uptake by that species across multiple tests. Aqueous phase exposures are preferred to spiked sediment exposures because of the potential for introduced variability associated with sediment spiking.

5.2.5.3 Reference Performance Criteria

Setting performance criteria (e.g. minimal survival standards) for toxicity reference locations should not be attempted until sufficient experience is gained. If performance criteria are to be set, they should be set using a control chart format for each reference location and endpoint. A running mean is tabulated and after about 20 tests are performed over the course of a year the variance about the mean is plotted as ± 2 standard deviations. Test responses outside the two standard deviations are judged to be out-of-control and therefore the reference response is invalid.

5.2.5.4 Time Zero Samples in Bioaccumulation Testing

A sub-sample of animals used in bioaccumulation tests should be purged for 24 hours in a container of clean water (no sediment). After this 24 hour period, animals are blotted dry, placed in clean containers and frozen for subsequent tissue residue analysis. Results from the analysis of these time zero samples can be used to confirm that test organisms were relatively free of contaminants at test initiation. Results of the time zero analysis can also be compared to results control animals exposed for 28-days to ascertain whether contaminants were inadvertently introduced to the test system over the course of the exposure.

5.2.6 Assessment of Costs

Cost of toxicity and bioaccumulation testing will vary by method and the laboratory conducting the analysis. However one can generally expect to pay somewhere between $200 to $1,000 per sample for standard acute laboratory toxicity tests, $500-1,500 per sample for longer term chronic toxicity tests. Bioaccumulation tests are equivalent to chronic test with the added cost of chemical analysis of the tissue residues which can range from approximately $1000/sample to as high as $10,000/sample or higher (see Section 5.1.4) depending on the number or types of analytes and number of replicates to be analyzed. Cost of *in situ* testing and testing with non-standard indigenous species are entirely site/project specific. [Note: cost estimates provided in this section are provided for informational purposes and should be considered only approximate.]

5.3 Biota Analysis

There are several communities in different habitats that will need to be evaluated for impact assessment. Similar types of analyses can be applied to all the biotic data regardless of the collection method. Infaunal and fish communities respond to impacts (environmental stress) in predictable patterns (successional gradients). When impacts are catastrophic (e.g., obliteration of habitat through burial or excavation or toxicity) assessment depends upon measuring the recovery of the community through time and/or comparing impacted sites to similar but non-impacted sites. When impacts are less than catastrophic, communities are affected by the amount of environmental stress encountered (e.g., wastewater outfalls, sediment contaminants, or impacts related to modest amounts of dredging or burial) and respond by changes in species composition, abundance, size, and/or behavior. Assessing the significance of impacts along gradients usually involves measuring the change in community measures relative to non-impacted or reference site areas (spatial comparisons) and/or the amount of time required for impacted areas to return to conditions similar

to reference areas (temporal changes). Regardless of the degrees of impacts, the analytical approach is similar, assessments are made using ANOVA statistics, multivariate techniques (e.g., cluster or ordination), and/or by gradient analysis (temporal and spatial).

Biotic assessments utilize community measures (e.g., number of species, abundance, biomass, diversity indices, and trophic or community response indices) to evaluate environmental impacts. It is important to remember that these community measures (indicators) are not equally sensitive to community changes and some have no ecological bases (e.g., diversity indices). The number of species and diversity indices while generally useful for indicating community responses to environmental stresses are limited because they are not sensitive to changes in species composition. Thus, while some studies may find no change in the number of species with distance from a suspected impact, one may find that there are significant changes in the species composition. Some community measures are more sensitive to changes in community composition and function than others e.g., Benthic Index of Biotic Integrity, Benthic Response Index (BRI), and Infaunal Trophic Index (ITI). While most of these measures have been developed for marine communities, similar type of analyses can be developed and used for any benthic community. These types of measures are useful because they incorporate species composition and not just the number of species. Thus, impacted and non-impacted communities may have similar number of species and diversity indices, but they will never have the same community composition. Fish community assessments include many of the above measures but also the size of fish, their biomass, and disease symptoms.

5.3.1 Methods

The primary objective of data analysis is to determine whether statistically significant, as well as qualitative, differences in community measures exist between potential impacted areas and appropriate reference stations. Statistical hypothesis testing will be dependent upon the study design, replication (time and space), and types of measures. Appropriate statistical tests may include Chi Square, t-test, and Analysis of Variance (ANOVA). Null hypotheses tests will typical state that there is no statistical difference between test and reference sites. Rejection of the null hypothesis is usually stated as $p<0.05$. Depending upon the duration of the study and the frequency of sampling. The use of Repeated Measure ANOVA is highly recommended. RM-ANOVA can test for differences between areas (impacted versus reference) as well as seasonal effects, temporal trends, whether different areas had different trends, gradients relative to the impacted area, temporal changes in the gradients, and whether regional trends were indicated. Multivariate techniques such as cluster analysis are useful for delineating habitats and communities and provide simplified graphics for understanding community patterns. Other multivariate methods, e.g., discriminant analysis, and principal component analysis, are useful for reducing the number of independent variables and identifying the relative importance of the variables. Multivariate techniques are most important when replication is minimal and large number of parameters have been measured in time and space.

Data transformations generally should only be used to fulfill the assumptions of the statistical test e.g., normalize data or assumptions pertaining to homogeneity of variance. Abundance data is typically not normal and has non-homogeneous variance. Data should be tested and only the

appropriate transformation used, e.g., abundance data for one test might be ok non transformed, in another test log transformed data would be best, and in some cases rank transformations would be most appropriate. Proper use of multivariate methods depends upon fulfilling assumptions about the methods and usually involves appropriate transformation of the rare data. For example, Bray-Curtis dissimilarity matrix are often used in multivariate cluster analyses where data transformations are often done to minimize dominance of abundant organisms and not for fulfilling assumptions pertaining to statistical hypothesis testing. Generally, cluster analysis would transform rare data, e.g., abundance data should be square-root transformed and then normalized by dividing each species abundance by the mean for all stations. These transformed values can then be used to calculate a Bray-Curtis dissimilarity matrix for each species and station. Cluster analysis utilizes the transformed dissimilarity matrix to generate visual representations of among-station and among-species relationships that have similar characteristics. Typically, cluster analysis uses an agglomerative, hierarchical method with flexible sorting (Beta = -0.025) as this most often produces well-defined "clusters" of entities.

5.3.2 Quality Assurance Quality Control Procedures

QA/QC procedures begins with a well-designed study plan, supported by a QAPP documenting all the methods, equipment, protocols, and responsibilities of the personnel. Strict adherence to the QAPP is important for program consistency and for acquiring defensible data. Field sampling QA/QC involves review of procedures and protocols and then audits to determine compliance with these documents. Field identifications can be verified by voucher collection verification and return to the laboratory of specimens requiring further verification. Laboratory protocols are all detailed in SOPs, which should be reviewed and modified specifically for the requirements of the study. Infauna laboratory processing should include QA/QC procedures to insure adequate removal of organisms from the sediments. That is, all sorted samples should be QA/QC for at least 95% removal criteria. Taxonomic QA/QC can be accomplished by reanalysis of 10% of the samples by different taxonomists and/or by voucher collection review. Fish and macro-invertebrate QA/QC includes daily calibration of scales used for fish weights, field audits of procedures and measurements, and verification of voucher specimens.

Data QA/QC objectives are to establish data bases of the survey data free from errors. Acquired data should be directly entered into a computer database or recorded on data sheets. Data sheets for field and laboratory measurements should be designed for the study, easy to use, and provide space for all data entries. Transcription of data should be minimized to reduce data entry errors. Data entry should be double entry and compared for entry errors. If double entry is used at least 10% of all data entries should be reviewed to verify that no errors have be entered. If double entry is not used then more of the data entry should be hand verified. Data base control should be strictly regulated and under the supervision of a data base manager.

5.3.3 Assessment of Costs

Benthic sampling and laboratory analysis often considered expensive, generally, is comparable or

significantly cheaper than costs associated with chemical or toxicity sampling and testing. Benthic biota are the organisms must likely to show effects from contaminants. Infauna data can easily be mapped to provide graphical depiction of the communities so that spatial and temporal patterns can easily be visualized as well as relationships to physical and chemical variables. Depending upon conditions (e.g., weather, sediment type, sieve size, type of sampler, support vessel) 20-40 benthic grab samples or over a 100 small core samples can be collected in a day. Laboratory costs are dependent upon numerous factors (e.g., size of sampler used, sieve size, habitat, sediment type, water depth, and level of taxonomic detail) and can run as low as $50-100 for small hand cores to $250-600 for larger grab or box core samples. The most significant factors are surface area sampled and the sieve size used. Voucher collection adds an additional expense of $5-10 per species voucher. Biomassing of major categories of organisms adds an additional $5-15 per sample. Data entry and establishment of data bases runs from $5-50 per sample and a detailed report with statistical tests, multivariate analyses, tables, and graphical plots can be as low as $1000 and up to $50,000 depending upon the number of surveys and the complexity of the study.

6.0 FRESHWATER SEDIMENT AND TISSUE GUIDELINES

6.1 Introduction

This section describes the derivation of sediment quality guidelines, tissue screening levels, and target tissue levels for use within the overall decision framework for Portland Harbor. These levels are first defined and their use and applicability are discussed. Technical methods for derivation of the guidelines are provided in detail, and the guidelines are calculated to the extent existing data allow. In some cases, not enough data are yet available to derive the guidelines. In the third section, available data are reviewed, data gaps are identified, and sampling and data analysis tasks are described that will be undertaken during implementation of this plan to complete the guidelines. Finally, a sediment quality database is described that will facilitate calculation of the guidelines and will provide a single electronic data repository for all sediment chemistry, bioassay, benthic, and tissue data collected in the Portland Harbor.

6.1.1 Purpose and Regulatory Authority

The purpose of the guidelines derived in this section is to provide numeric screening levels for sediment and tissue data that can be used to determine if further biological testing and/or a feasibility study is needed at a contaminated site. The guidelines may also be used as remedial action objectives for sediments on a voluntary basis. In each case in which the guidelines are exceeded, the regulated party will have the option to use the guidelines as the basis for RAOs, or to conduct further biological testing to develop site-specific RAOs.

The Oregon cleanup statutes provide DEQ with the authority to develop cleanup standards for environmental media impacted by the release of oil and hazardous substances. In addition, the federal and state Clean Water Acts provide DEQ with the authority to develop water quality criteria for waters of the state, which include water, sediments, and pore waters. Although the guidelines derived in this plan could eventually be promulgated under these authorities, they are currently provided as guidance only, for use in Portland Harbor by DEQ, other agencies, and the regulated community.

6.1.2 Definitions

The following terms and abbreviations will be used in this section:

- **Sediment Quality Guidelines (SQGs).** A numeric sediment concentration above which further biological testing and/or a feasibility study is warranted. The sediment quality guidelines derived under the PHSMP address only direct toxicity to benthic organisms, and do not address bioaccumulative endpoints.
- **Tissue Screening Concentrations (TSCs).** A contaminant concentration in tissues designed to be protective of the fish and shellfish in which the tissue concentrations are being measured.
- **Target Tissue Levels (TTLs).** A numeric tissue concentration in food items (e.g., fish or

shellfish) that may result in adverse effects to higher consumers, including birds, mammals, or humans. If this level is exceeded, or predicted to be exceeded, further bioaccumulative testing and/or a feasibility study is warranted.

- **Guidelines.** The general term "guidelines" is used to refer to SQGs, TSCs, and TTLs.
- **Remedial Action Objectives (RAOs).** Remedial action objectives are sediment concentrations selected on a site-specific basis which are expected to be met as a result of the cleanup actions selected for the site. RAOs may be the same as, higher than, or lower than SQGs depending on site-specific factors.
- **Bioconcentration.** The process whereby chemical substances enter aquatic organisms through the gills or epithelial tissue directly from water; the bioconcentration factor (BCF) is the ratio of contaminant concentration in biota to that in water.
- **Bioaccumulation.** A process which involves uptake of chemical residues from dietary sources, as well as through bioconcentration.
- **Biomagnification.** A process by which the tissue concentrations of bioaccumulated chemical residues increase as these materials pass up the food chain through two or more trophic levels.

6.1.3 Applicability

SQGs, TSCs, and TTLs will be applied under the Portland Harbor Sediment Management Plan to assess sediment and tissue quality at individual cleanup sites, and in Harbor-wide studies conducted by the DEQ cleanup and water quality programs. The SQGs will also be used for site discovery and prioritization purposes. The guidelines will be used to make cleanup decisions in accordance with the decision framework and conceptual model outlined in Section 2.0 and the assessment process described in Section 3.0.

The guidelines developed for Portland Harbor are not formally applicable to other areas of the state, but may be considered when evaluating sediment and tissue data for similar freshwater environments. In addition, these guidelines may be used by other local, state, and federal agencies, at their discretion, to carry out related regulatory functions in the Portland Harbor, such as source control, public health advisories, natural resource damage assessment, and endangered species evaluations.

The guidelines developed as a result of this plan will not immediately be applied to evaluations of dredged material for open-water disposal, because the dredged material framework has recently been adopted, and revisions to the DMEF require agency approvals by several state and federal agencies in Oregon and Washington. However, it is expected that the Lower Columbia River Dredged Material Evaluation Framework will be revised once the Portland Harbor freshwater guidelines are completed, to increase compatibility between the cleanup and dredging programs and to replace the current SLs, which are based on marine AETs, with the freshwater SQGs developed here. The DMEF agencies will be involved in development of the guidelines to ensure their eventual acceptability in the Columbia River dredging program.

6.2 Sediment and Tissue Guideline Derivation

In this section, the technical approach for derivation of sediment quality guidelines (SQGs), tissue screening concentrations (TSCs), and target tissue levels (TTLs) is described. One or more workgroups will be established to further develop the details of these methods and provide guidance during calculation of the guidelines.

6.2.1 SQG for Benthic Toxicity

A variety of possible methods were reviewed for calculating sediment quality guidelines for benthic toxicity, including equilibrium partitioning, spiked sediment bioassays, benthic reference ranges, apparent effects thresholds (AETs), effects-range low and median (ER-L/ER-M), and threshold effects levels/probable effects levels (TELs/PELs). The available methods were reviewed to determine their technical strengths and weaknesses, availability of guidelines, data needed to calculate guidelines that are not currently available, and whether missing data could reasonably be collected as part of the Portland Harbor process.

Of the available methods, equilibrium partitioning, spiked sediment bioassays, and benthic reference ranges were eliminated due the unavailability of existing guidelines and the magnitude of the data requirements for calculating such criteria. Guidelines based on equilibrium partitioning and spiked sediment bioassays are being developed by EPA and Environment Canada, respectively, and require substantial additional data and/or method development and validation prior to promulgation. Benthic reference ranges are being proposed for use in the Great Lakes, but the feasibility of this method for developing guidelines in river systems has not been demonstrated, and few benthic data exist in the Portland Harbor area.

All three of the remaining approaches rely on field-collected data sets containing chemistry data paired with bioassay and/or benthic data. The AET approach is considered a regional approach, while ER-Ls/ER-Ms and TELs/PELs have been used at a larger scale. All three methods, however, can be used at any scale, as long as an adequate data set is available. In addition, the three methods have a number of other similarities. Each divides the data set into stations that showed adverse biological effects, and stations that did not show adverse effects. The "effects" and "no-effects" distributions are plotted, and a guideline is developed by selecting a percentile of one or both of the distributions.

An apparent effects threshold is the chemical concentration above which an adverse effect in a specific biological test is always seen in the database used for their calculation (i.e., the 100^{th} percentile of the no-effects distribution). AETs are specific to individual chemicals and test species. Therefore, each chemical may have several AETs, each corresponding to a different type of biological test. AETs are used as the basis for marine sediment quality standards in Washington State, and as screening levels in the Dredged Material Evaluation Framework for the Lower Columbia River Management Area. AETs have been approved by EPA Region 10 as water quality standards, and by DEQ, Ecology, the Corps of Engineers and other state and federal agencies for use in dredged material management programs in Oregon and Washington.

TELs/PELs are calculated as follows:

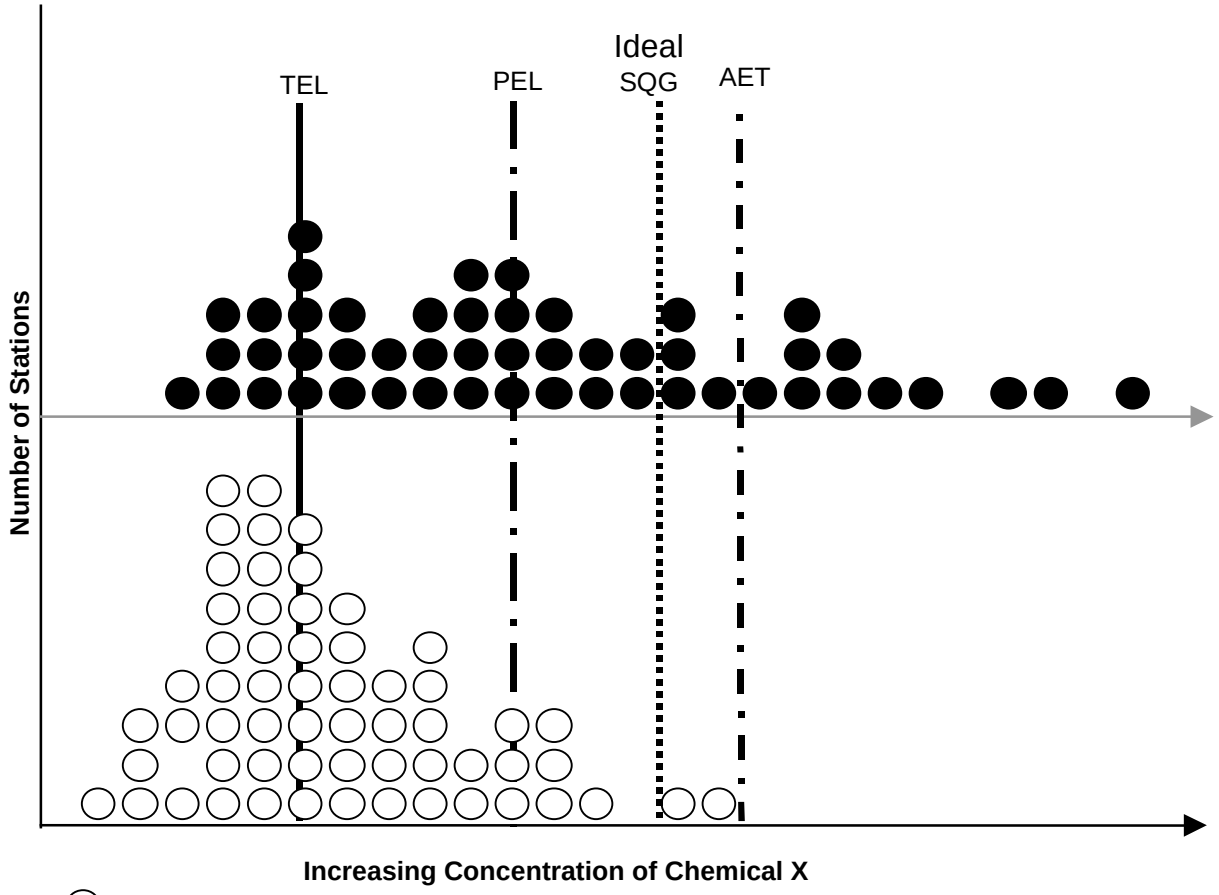
- TELs are the mean of the 15th percentile of the effects and the 50th percentile of the no-effects distributions.
- PELs are the mean of the 50th percentile of the effects and the 85th percentile of the no-effects distributions.

Guidelines have been developed using this method for Environment Canada (national guidelines) and Florida (state guidelines). Unfortunately, the existing guidelines developed using this method have a number of drawbacks. A variety of different types of data were used in calculating guidelines (e.g., field data, spiked laboratory bioassays, equilibrium partitioning values, AETs), which are not all comparable in nature. Effects and no-effects determinations were as defined by the original researchers, which were not all consistent. Various species and habitats were mixed together. TELs and PELs, if used, would need to be recalculated with a regionally appropriate data set, a high level of quality control, consistent effects determinations, and using only field data sets.

Both of the methods discussed above have been approved for use by EPA and various state agencies. Both have reasonably wide acceptance in the scientific community and are the only methods in regulatory use today. Both rely on exactly the same type of data, and differ only in the specific percentile of the distributions that is selected for use as a guideline, as shown in Figure G-7. One drawback to both existing methods is that they rely on pre-specified points in the distribution for calculating guidelines, and only after the guidelines are calculated are error rates determined. In addition, error rates have often been determined incorrectly in guidance and in the literature, resulting in assumptions about the protectiveness of the criteria that may not be accurate. As a practical matter, it is not possible to know which of the effects data are associated with which chemicals, and chemical-specific error rates often seen in the literature have no actual meaning. Error rates can only be calculated based on application of the guidelines as a complete set to the data for a station, to determine if the correct prediction regarding toxicity is made. Because it is not possible to determine in advance which percentile will result in the best prediction of toxicity, percentiles for guideline development have been selected largely based on policy considerations.

A modification of these two approaches is recommended for Portland Harbor which uses the same data set, but selects the numeric guideline as that point along the distribution which provides the lowest overall Type I and Type II error rates, as shown in Figure G-7 as the “Ideal SQG.” The actual point in the distribution where the ideal SQG will fall is unknown in advance, and is determined through an iterative error rate minimization routine. This will ensure that the set of guidelines which are developed best represents actual adverse effects in the region in which the data were collected, and has the greatest likelihood of correctly predicting adverse effects in future samples collected in that area.

Figure G-7. Comparison of Alternative Sediment Quality Guidelines



TEL = Mean of the 15th percentile of the effects distribution and the 50th percentile of the no-effects distribution

PEL = Mean of the 50th percentile of the effects distribution and the 85th percentile of the no-effects distribution

Ideal SQG = The concentration that results in the fewest prediction errors (false positives + false negatives)

AET = Highest no-effect concentration (100th percentile of the no-effects distribution)

The steps required to calculate SQGs using this approach are described in the sections below, including:

1. Identify of contaminants of interest,
2. Select toxicity tests and endpoints,
3. Compile synoptic bioassay/chemistry data,
4. Develop hit/no-hit considerations,
5. Calculate error rates associated with percentile values,

6. Select optimal percentile value, and
7. Conduct sensitivity analysis.

6.2.1.1 Identify Contaminants of Interest

SQGs will initially be calculated for all benthic COIs listed in Section 2.2.1. However, the COIs were determined solely from detections in sediments or elevations above ambient levels, and are not necessarily all present at concentrations associated with adverse effects. In the process of calculating SQGs, it will become apparent which of the COIs are not present above toxicity thresholds, and SQGs will not be calculated for these chemicals. Because chemicals must exceed toxicity thresholds in order for it to be possible for SQGs to be calculated, the final list of SQGs will determine which chemicals are of potential concern in the database. Because of the inclusion of western Washington data, it may be possible to calculate SQGs for some chemicals that do not exceed toxicity thresholds in Portland Harbor. A final list of COPCs for Portland Harbor will be developed by comparing maximum concentrations in Portland Harbor to the calculated SQGs. Only chemicals that exceed SQGs in Portland Harbor will be retained as COPCs.

6.2.1.2 Select Toxicity Tests and Endpoints

Toxicity tests for use in calculating SQGs would ideally have the following characteristics:

- Include a variety of acute and chronic endpoints
- Include a variety of taxonomic types that are exposed to contaminants in sediments
- Be appropriately sensitive to contaminants, but not to confounding factors (e.g., grain size)
- Have standardized, widely-used test protocols with unambiguous endpoints
- Have a large existing database within the region

Only one acute test meets all five criteria – the 10-day survival test for *Hyalella azteca*. *Chironomus tentans* 10-day growth and mortality test meets most criteria, but there are not a lot of existing data for this test in the region. However, it has been included in the dredged material evaluation framework for the Lower Columbia River, so should be more widely used in the future. It is also one of the tests that will be recommended for use by the Department of Ecology's regulatory workgroup for freshwater bioassay tests.

There is currently a lack of chronic tests that meet the above criteria. Benthic community structure is likely to be variable enough that it is not included among the initial tests proposed for SQG development. It could be added if a harbor-wide study shows good correlation between benthic community structure and chemical concentrations (see Section 6.3.2). Three chronic tests are identified in Section 5.2.1.2 – *Hyalella azteca* 28-day survival and growth, *Tubifex tubifex* 28-day survival and reproduction, and *Hexagenia limbata* 21-day survival and growth. Any of these would be an appropriate choice, although using *Hyalella azteca* would limit the species represented by the suite of tests to only two. Unfortunately, there are no data for any of these tests in the Pacific Northwest region (Washington or Oregon).

There are a significant number of stations for which Microtox data are available in Oregon and Washington, including some within Portland Harbor. The Microtox bioassay has worked well in Ecology's sediment cleanup program for freshwater sites, and is likely to be recommended as one of the freshwater tests by Ecology's regulatory workgroup. Although the ecological significance of Microtox is questioned by many, research conducted in the Great Lakes has shown it to be a sensitive test with good correlation to benthic community impairments and to the results of other freshwater bioassays (Burton et al., 1992, 1996; EPA, 1994a).

A recent evaluation of 25 different freshwater tests (including a total of 55 endpoints) for the ARCS program showed that Microtox results had the greatest degree of correlation with other tests and with benthic community measures of any of the tests evaluated (EPA, 1994a). Therefore, it is recommended that the Microtox bioassay be retained for initial calculation of SQGs. Once data are available for one or more of the chronic tests listed above, SQGs for those tests may be calculated and used in place of Microtox SQGs. Alternatively, the workgroup could decide to use data from other regions (e.g. NOAA's BEDS database) to calculate a chronic SQG for the *Hyalella* 28-day test.

Although a benthic community SQG would be desirable and consistent with the sediment quality triad approach, a benthic SQG is not proposed for development initially. There are very few freshwater stations with benthic community data in Oregon or Washington, and there is a lack of consensus on interpretation metrics and whether benthic community studies are implementable in a river environment, which may be more heterogeneous than marine areas. A Harbor-wide benthic study is proposed in the PHSMP, in part to help answer these questions. Synoptic chemistry data will be collected as part of that study; therefore, if benthic community studies are determined to be useful and correlated with sediment chemistry results, a benthic SQG could be calculated at that time.

In summary, the following tests and endpoints will be included for initial calculation of benthic SQGs:

- *Hyalella azteca* 10-day mortality
- *Chironomus tentans* 10-day mortality and/or 10-day growth
- Microtox pore water extract

Once data are available for one or more of the chronic tests listed above, and/or if benthic community analysis proves to be viable on a Harbor-wide basis, these endpoints could be substituted for Microtox to provide a more ideal test suite.

6.2.1.3 Compile Synoptic Chemistry/Bioassay Data

To increase the size of the data set while maintaining a regional focus, some data from outside Portland Harbor will be included. While using entirely data from within Portland Harbor would be optimal for the purposes of this plan, there are currently not enough data from within the Portland Harbor to calculate guidelines. Many of the site investigations would be completed

before enough data were generated to calculate Portland Harbor guidelines, limiting their usefulness during the cleanup process. Addition of regional data from similar watersheds allows more rapid calculation of guidelines and may allow wider application of the resulting guidelines to other freshwater sites in western Oregon (and conceivably, Washington).

Additional data sets will be gathered from the Washington Department of Ecology's SEDQUAL database and available data sets in western Oregon. Only freshwater (< 1 ppt salinity) from urban watersheds west of the Cascade Mountains will be included. Estuarine stations will be excluded, as will stations that are predominantly coarse-grained. For this reason, Columbia River data will generally not be included (there are very few data for the Columbia River), with the possible exception of the Columbia River Backwater Study, which targeted fine-grained areas. Data sets that will be added come from the following areas: Columbia Slough, Puyallup River, Duwamish River, Lake Washington/Lake Union/Salmon Bay watershed, and the Snohomish River.

Once preliminary SQGs are calculated using the available data, it will be possible to specifically identify data gaps that need to be filled to finalize the SQGs (i.e., specific concentration ranges for specific bioassays). It is likely that additional data will still be required for some bioassay endpoints (e.g., *Chironomid* bioassays and chronic bioassays). These data will be collected before the guidelines are finalized, either through Harbor-wide or site-specific investigations in Portland Harbor, or through other ongoing data collection efforts in Oregon and Washington. Details will be included in the implementation sampling plan once preliminary SQGs are calculated. In addition, the guidelines can be refined over the years as more data are collected (See Section 6.4.1.1).

For each biological test, stations will first be classified as "hit" (shows adverse effects) or "no-hit" (shows no adverse effects) stations. An adverse biological effects will be determined for each test as follows:

- ***Hyalella azteca* 10-day mortality.** Statistically significant reduction in survival relative to reference ($p \leq 0.05$).
- ***Chironomus tentans* 10-day mortality.** Statistically significant reduction in survival relative to reference ($p \leq 0.05$) or statistically significant reduction in final biomass relative to reference ($p \leq 0.05$). The growth endpoint is evaluated only if the mortality endpoint does not show effects.
- **Microtox pore water extract.** Statistically significant reduction or increase in photoluminescence relative to reference ($p \leq 0.05$).
- **Additional freshwater chronic test.** Interpretation endpoints to be determined.

These interpretation endpoints may be refined based on bioassay workshops or SQG workgroup efforts. Statistical analysis will be conducted in accordance with Fox et al. (1998) using the SEDQUAL bioassay statistical interpretation module, based on software developed by the Corps of Engineers, Seattle District, for the dredged material management program. Quality assurance reviews will be conducted in accordance with Section 5.2.5, and DMMP/SMS guidance, as follows. Tests that fail performance standards for controls or for which adequate QA/QC

information cannot be located will not be included in the database. Tests that fail performance standards for the reference station but have acceptable controls will be included and will be interpreted in accordance with Fox and Michelsen (1997). Tests with multiple acceptable reference stations will be interpreted in accordance with Michelsen and Shaw (1996). All chemical and bioassay data used for guideline development will undergo a QA2 review, in accordance with PTI (1989a).

For each chemical, data will be divided into effects and no-effects distributions and graphed in order of increasing concentration (see Figure G-7). As an initial screen, the effects and no-effects distribution will be compared using an ANOVA test to determine whether they are statistically different (if the distributions deviate significantly from normality, the non-parametric Kruskal-Wallis test will be used instead). If the effects and no-effects distributions for a chemical are not statistically different, it is likely that that chemical is not contributing to toxicity in that data set. In other words, the effects threshold for that chemical has not been reached. Any such chemicals will not be carried forward as chemicals of concern and guidelines will not be developed for them, as inclusion of these chemicals would not improve, and may worsen, the overall error rates.

Certain chemical classes whose toxicity is largely additive (e.g. PAHs) may be summed during the guideline calculations to determine if this provides a more predictive and/or more practical approach to guideline derivation.

6.2.1.4 Calculate Error Rates

Once hit/no-hit distributions have been calculated for each chemical, error rates will be calculated for the full range of possible percentile values corresponding to these distributions. Because this SQG method relies on field data, in which a mixture of chemicals may affect overall toxicity at a station, error rates should also be calculated using the entire suite of guidelines that are developed to predict the presence or absence of toxicity at a station. Therefore, false positive and false negative errors will be determined as follows:

- **False positive.** A false positive error occurs when one or more sediment quality guidelines are exceeded at a station, yet the biological test results do not indicate toxicity.
- **False negative.** A false negative error occurs when no sediment quality guidelines are exceeded at a station, yet adverse effects were observed in that biological test.
- **Overall reliability.** Overall reliability will be calculated as the percentage of the time that the sediment quality guidelines, when applied as a set, correctly predict the presence or absence of toxicity at a station (100% minus false positives and false negatives).

Optimization of the guidelines can also be done in various ways. Because different chemicals may have different types of distributions, a method that allowed the percentiles selected for different chemicals to vary would be ideal. However, the computing resources necessary to optimize the overall error rate while allowing percentiles for each chemical to vary are considerable. Initially, the same percentile will be applied to the distributions for each chemical. This percentile will be varied throughout the entire possible range (0-100) for both effects and

no-effects distributions, at intervals of five percentile points. Error rates as described above will be calculated for each possible percentile value. Alternative methods are under development that would allow percentages to vary for individual chemicals, to further optimize error rates. These will be discussed in greater detail in the work plan and workgroup discussions.

6.2.1.5 Select Optimal Percentile Value

Error rates for the full range of percentile values will be compiled into a table and/or displayed graphically. Once the optimal range within the effects and no-effects distributions are identified, fine-tuning of the percentile values can be conducted in an attempt to further optimize error rates. This may consist of decreasing the interval between percentile values tested to one percentile point, removing chemicals responsible for the greatest number of errors and recalculating error rates, and/or adjusting percentile values for individual chemicals.

Ideally, the guidelines would be set at that percentile of the distribution that provides the best overall reliability. However, because these guidelines will be used in some contexts as screening guidelines, and because they are intended to be reasonably conservative, adjustments to the optimal rate may be made to better reflect the policy goals of the regulatory agencies and implementing legislation. For example, if a variety of percentile levels provide similar overall reliability (e.g., within 5% of each other), the set of guidelines that provides the fewest false negatives will be selected. In addition, if the optimal percentile level results in more than 20% false negatives, the percentile level may be adjusted to a level which provides the greatest overall reliability while also allowing no more than 20% false negatives.

Given the overall accuracy of any type of sediment quality guidelines, and the context in which they will be used, an upper limit of 20% for false negatives seems reasonable. It is important to consider that this is a station-by-station error rate. In cleanup programs, site decisions are seldom made on the basis of an individual station. An error rate of 20% is not likely to change an overall decision, such as whether or not to proceed to a feasibility study, since that decision should be based on more than one station within the area being evaluated. To ensure that this is the case, the minimum number of stations required to make site management decisions will be adjusted based on the actual error rate of the guidelines set, once developed.

6.2.1.6 Conduct Sensitivity Analysis

The optimal percentile value will be tested in a variety of ways to ensure that it represents the best possible SQG (i.e., has the lowest possible error rates). To ensure that inclusion of out-of-area data was appropriate, error rates will be calculated both with and without the additional regional data to ensure that the regional guidelines set is at least as accurate as the Portland Harbor data alone in predicting adverse effects. Eventually, data from outside the region can be eliminated from the data set if doing so improves the reliability of the guidelines for predicting effects in Portland Harbor.

Individual data sets, as well as data from specific stations, can also be tested in this manner if

there are questions about the appropriateness of including the data. This may occur if the data set or station is believed to be unrepresentative in some way, or an outlier, due to chemicals being present in unusual matrices or from sources unrepresentative of the Harbor. Stations suspected of being outliers that may influence the ideal percentile value (i.e., are in the critical concentration range) will be tested using a statistical outlier test, as recently adopted by Ecology for the marine AETs.

In addition, individual chemicals from the SQG set may be temporarily excluded to determine whether inclusion of that chemical increases or decreases reliability of the overall set of SQGs. Chemicals that contribute significantly to toxicity in the data set should increase the reliability of the SQGs, while inclusion of chemicals that do not contribute materially to toxicity in the Harbor will decrease the overall reliability of the SQGs. Covariance analysis will be conducted to identify chemicals that may be strongly correlated with other chemicals, and whose apparent toxicity may be misleading for this reason. Such chemicals will be further evaluated to determine their appropriateness in the criteria set, by comparison to known toxicity ranges and other available information.

Finally, SQGs will be calculated both in dry weight and in organic-carbon normalized units (for nonpolar organics only), to determine which method best predicts actual toxicity.

6.2.2 Bioaccumulation-Based Guidelines

As contaminants move upward through the food chain, they may affect various receptors at higher trophic levels, including primarily fish and receptors that eat fish and shellfish, including birds, wildlife, and humans. The following sections discuss how bioaccumulation-based guidelines will be developed for each of these types of receptors.

Because of the difficulty of accurately predicting, on a regional or state-wide basis, the partitioning of chemicals between tissue and sediment, sediment quality guidelines based on bioaccumulation are not proposed for development at this time. Instead, measured or predicted tissue concentrations will first be compared to the lowest TTL or TSC that applies (either on a Harbor Area or site-specific basis). If tissue concentrations exceed this value, then remedial action objectives for sediments will be back-calculated using site-specific biota-sediment accumulation factors (BSAFs), as described in Section 6.2.2.5. However, following completion of a Harbor-wide fish study, it may be possible to calculate Harbor-wide BSAFs, which could be used to calculate default sediment RAOs for use at any site in the Harbor. Sites would still have the option of conducting bioaccumulation tests to derive site-specific BSAFs and associated RAOs.

6.2.2.1 Selection of Contaminants of Interest

Contaminants of interest for bioaccumulation are identified in Section 2.2.2, and include:

- Mercury
- Butyltins
- Bis(2-ethylhexyl)phthalate, butylbenzyl phthalate, di-n-butyl phthalate, and di-n-octyl

phthalate
- DDT, DDD, and DDE
- Aroclors 1254 and 1260
- PCDDs/PCDFs

The above contaminants have been confirmed in Portland Harbor tissues and/or are widespread in sediments. If additional bioaccumulative contaminants are confirmed in tissues and sediments through harbor-wide studies, the methods described below can be used on an as-needed basis to calculate additional criteria. The COIs will be further screened once bioaccumulation guidelines have been developed and tissue data in the Harbor are compared to the guidelines. Any COIs exceeding tissue guidelines will be retained as bioaccumulative COPCs or CPECs for the Harbor Area.

6.2.2.2 TSCs for Fish

Tissue screening concentrations (TSCs) for fish will be calculated using tissue residue-effects data available in compiled databases (e.g., ERED) and in the literature for freshwater and marine fish. Freshwater and marine data are proposed to be combined because the effect of the chemical, once in the tissue, on the organism is not expected to be affected by the salinity of the water. In addition, tissue-residue effects data for benthic invertebrates may be added, as TSCs are generally derived using both trophic levels (Shepard, 1998), and benthic invertebrates or shellfish are commonly used in laboratory bioaccumulation tests as a surrogate for bioaccumulation to a variety of benthic and pelagic species.

Many of the types of effects caused by these chemicals are very generalized, and should not be affected by whether the organism is a marine or freshwater fish or invertebrate species. Any differences between freshwater and marine species that could exist are likely to be overshadowed by species differences within the habitat type and other factors, such as age and sex of the fish. Combining these types of data will provide a larger database upon which to base criteria. To ensure that inclusion of marine and invertebrate species is not biasing the data, the data will initially be divided into separate distributions, and the distributions tested with ANOVA on a chemical-by-chemical basis to determine whether they are significantly different (if the distributions deviate significantly from normality, the non-parametric Kruskal-Wallis test will be used instead). If a significant difference is found, data from marine and/or invertebrate species will not be included.

All available effects data will be compiled into a single database. In all cases, the original literature will be obtained and reviewed to ensure data quality. Endpoints used for calculation of criteria will include effects that are reasonably likely to affect a population, including mortality, reduced growth, reproductive effects, abnormal development, and narcosis. For dioxins, maternal transfer of contaminants in lipid tissue to eggs will be considered, as described in EPA (1993b). Biomarkers such as enzymatic effects or markers of exposure such as biliary FACs for which the ecological significance is unknown are not being included at this time. The effects of PAHs on fish are of interest to DEQ, but cannot be assessed using this methodology, because PAHs are metabolized in fish and do not accumulate in fish tissues. A specific method for

assessing risks of PAHs to fish does not appear to be available at the present time. However, as noted previously, a workshop is planned by the trustees to assess the state of the science and methods for assessing these risks, and DEQ will evaluate any tools recommended as a result of this workshop for possible inclusion in the PHSMP.

If more than one data point is available for a particular effect in a given species, the geometric mean or median of the available data will be used to represent that effect in that species. Data (and the derived criteria) will be lipid-normalized for organics, but not for mercury or butyltins. Data will also be normalized to a single endpoint (e.g., a LOAEL) using conversion factors provided in EPA (1997c), in cases where both NOAELs and LOAELs are not provided in the study results.

Once normalized, the data will be sorted in order of increasing concentration, and the 10^{th} percentile of the data set will be selected as the criterion (i.e., that value that would be protective of 90% of the adverse effects compiled in the database). LOAELs will be used for protection of general fish populations, and NOAELs will be used for threatened and endangered species. Therefore, two criteria will be calculated for each chemical, one for protection of threatened and endangered individuals, and one for populations. Although the 10^{th} percentile is proposed as the criterion, special consideration will be given to data for endpoints and species of special concern in the Portland Harbor (e.g., juvenile salmonids). This issue will be addressed by the TSC workgroup.

For some chemicals, there may not be enough data to calculate an effects-based tissue guideline using the method described above. In these cases, two options are available. First, the workgroup may decide to use data from one or more of the available studies to set the criterion value, based on the combined professional judgment of the workgroup and regulatory agencies, with appropriate documentation. Alternatively, for chemicals of lesser concern in the Harbor, the narcosis approach may be used to assess the combined impacts of chemicals for which criteria cannot be developed.

The narcosis approach will be used to derive a single TSC that will be used to assess chemicals that are measured in fish tissue but for which tissue guidelines are not available. A complete analyte list for the fish tissue study is not yet available, and will be determined during development of the harbor-wide sampling and analysis plan. However, any chemicals that are analyzed and detected will be converted to their molar concentration and added together.

The total molar concentration of the detected chemicals will be compared to the narcosis-based critical body residue to determine whether additive effects may be occurring from these chemicals. If an exceedance of the CBR is found, the chemicals with the greatest contribution to exceedance of the CBR will be addressed further as part of the site-specific bioaccumulation assessments, in the same manner as other chemicals that may exceed chemical-specific TSCs or TTLs. In addition, the narcosis approach could be used on a site-specific basis to assess areas that may be heavily contaminated with petroleum, to evaluate the combined impacts of aliphatic and aromatic fractions that may be present in sediments or groundwater discharging to the river.

Narcosis is a form of toxicity resulting from the presence of foreign molecules in hydrophobic or lipid tissues, which depresses and disrupts various cellular functions (Abernathy et al., 1988; Franks and Lieb, 1978). It is a well-studied phenomenon, as it is the basis for anesthesiology in medicine. Because narcosis represents a general disruption of basic cellular functions, which are essentially the same in all living organisms (microorganisms, invertebrates, fish, mammals, humans), the narcosis endpoint is applicable to any freshwater or marine aquatic receptor. Researchers have found that narcotic effects occur at similar tissue concentrations in a wide variety of aquatic receptors (Abernathy et al., 1988; McCarty and Mackay, 1993; McCarty, 1991; EPA, 1988a).

In aquatic receptors, narcosis is manifested in various ways, including immobility, loss of equilibrium in fish, and mortality (McCarty et al., 1992; Rogerson et al., 1983; Bobra et al., 1985; Mackay and Hughes, 1984). These different manifestations are not really different endpoints, but rather can be thought of as a continuum of increasing responses to cellular dysfunction and shutdown. Although narcotic effects associated with relatively water-soluble chemicals may be reversible (as the chemicals partition out of the lipid tissues over time) and therefore primarily acute, narcotic effects associated with highly lipophilic compounds will occur on a chronic basis, as these chemicals will remain in the lipid tissues over long periods of time and their effects will be relatively irreversible. These effects are clearly related to population-level impacts, as they affect the ability of the organism to perform day-to-day functions, such as foraging, predator avoidance, and reproduction, and may finally result in mortality. Moreover, onset of narcosis effects would be expected at similar exposure concentrations for any member of an exposed assemblage of organisms, regardless of its taxonomic or community status.

In addition, the narcotic effect is not dependent on the specific lipophilic chemical or chemicals present (Call et al., 1985). Various studies (Ferguson, 1939; McGowan, 1952; Hermens et al., 1984; Hermens et al., 1985a,b; Deneer et al., 1988) have demonstrated that the narcotic effect is instead related to the total number of foreign molecules present, and therefore effects in tissue can be predicted from the total molar concentration of contaminants in the tissue. This approach can be used for individual organic chemicals, or for mixtures of organic chemicals, such as petroleum hydrocarbons or pulp mill effluents. For individual chemicals or mixtures, the tissue criterion is calculated according to the following formula:

$$TSC = CBR_l \cdot MW$$

where: TSC = TSC (mg/kg lipid)
CBR_l = Lipid-normalized critical body residue (mmol/kg lipid)
MW = Molecular weight of chemical or representative molecular weight of the mixture (g/mol = mg/mmol)

Much of the literature is reported as whole-body critical body residues (CBRs) at which acute mortality is observed. However, lipid content is generally also reported, allowing calculation of lipid-normalized CBRs. The whole body acute CBR is reported to range from approximately 2-8 mmol/kg wet tissue (McCarty and Mackay, 1993; McCarty, 1991; van Hoogan and Opperhuizen, 1998; Carlson and Kosian, 1987; McKim and Schmieder, 1991). Lipid-normalization of these

values (using actual lipid data provided in the references), along with additional lipid-normalized values in the literature (Abernathy et al., 1998; van Wezel et al., 1995), produces a range of lipid-normalized acute CBRs of 30-200 mmol/kg-lipid.

Fewer data are available on chronic CBRs, and none are lipid-normalized. Whole-body chronic CBRs are reported in McCarty and Mackay (1993), Donkin et al. (1989), Carlson and Kosian (1987), Borgmann et al. (1990), Mayer et al. (1977), Mauck et al. (1978) and Opperhuizen and Schrap (1988), producing a range of 0.2 - 0.8 mmol/kg (wet tissue). Dividing by a typical lipid content of 5% (McCarty et al., 1992; Mackay, 1982) yields a chronic lipid-normalized CBR of 4-16 mmol/kg-lipid. An empirically-derived acute-chronic ratio of about 10 for narcosis endpoints has been reported by a number of researchers for a wide variety of organisms (Abernathy et al. 1988; McCarty, 1986; Call et al., 1985).

The acute-chronic ratio can also be applied to the acute lipid-normalized CBR range to obtain chronic lipid-normalized CBRs of 3-20 mmol/kg-lipid, comparable to the measured range reported above. NOELs are somewhat lower than these values; chronic lipid-normalized NOAELs are reported in Van Loon et al. (1997) to range between 0.5 and 5 mmol/kg lipid. Consistent with other endpoints, the 10th percentile of the chronic distribution will be selected as the regulatory endpoint.

6.2.2.3 TTLs for Wildlife

Similar to human health, TTLs for protection of wildlife will be back-calculated on a species-specific basis from an acceptable dose. The relationship between dose and the concentration in food items can be represented as follows:

$$Dose_f = \frac{IR \cdot CF}{BW} \sum f_i \cdot C_{xi}$$

Where:
- $Dose_f$ = total dose of chemical x from food items (mg/[kg·day], dry weight)
- IR = total ingestion rate (kg/day)
- CF = conversion factor (mg dry weight/mg wet weight)
- BW = body weight (kg)
- f_i = fraction of food item i in the diet (unitless)
- C_{xi} = concentration of chemical x in food item i (mg/kg, wet weight)

In risk assessment, it is necessary to identify the contributing food items and the concentrations of a chemical in each to know the total dose. However, when back-calculating from an acceptable dose to a TTL, a single TTL value is calculated which would be protective for that receptor if all its food contained that concentration of chemical. Although TTLs will be calculated on a chemical-specific basis, comparison of fish tissue data to TTLs (and TSCs) will use a hazard index approach to account for the potential combined effects of multiple chemicals. TTLs and TSCs for chemicals with similar modes of action and target organs will then be adjusted downward if necessary on a Harbor-wide basis to ensure that hazard indices are less

than one.

When the chemical concentration in all food items is constant, the equation above simplifies and can be rearranged to solve for the TTL as follows:

$$TTL = \frac{TRV \cdot BW}{IR \cdot CF}$$

Where: TTL = target tissue level (mg/kg, wet weight)
TRV = toxicity reference value (mg/[kg·day], dry weight)
BW, IR, CF = same as above

Applying this equation to derive species-specific TTLs requires three basic steps. First, the assessment endpoints (species of interest) must be selected. Second, information on the ingestion rate and body weight of that species must be obtained. Third, a Toxicity Reference Value (TRV) must be obtained from the literature for each COI. The TRV is the acceptable dose, often called a benchmark value, and is derived from laboratory dose-response studies. To better reflect the available data and portray uncertainties involved in this calculation, a probabilistic approach will be used to calculating the TTL, similar to that described for human health below and in DEQ (1998b). Distributions will be obtained or compiled for body weights, ingestion rates, and TRVs, and a single overall distribution will be calculated for the TTL using Monte Carlo techniques. The 10^{th} percentile of the TTL distribution, or TTL_{10}, will be selected as the regulatory endpoint.

Species proposed as indicator species for Portland Harbor include:

- Great Blue Heron
- Osprey
- Bald Eagle
- Merganser
- Mink
- River otter

Great Blue Heron and Osprey nest and forage in the Portland Harbor area, and feed primarily on fish and shellfish. Bald Eagles are listed species that forage in the Harbor and may nest in the area. Mergansers have been observed in the Portland Harbor and are representative of smaller birds that may ingest small fish. River otter are common in the Columbia and Willamette Rivers, and may be present in the Harbor area. Mink is a widely-used indicator species for other small mammals and is considered a sensitive receptor, particularly for PCBs. Several of these receptors were included in a recent ecological risk assessment for the Columbia Slough, and therefore, available information on ingestion rates and TRVs for these species may be relatively easily obtained.

For species for which information has not been recently summarized, ingestion rate distributions will be obtained from EPA's Wildlife Exposure Factors Handbook (EPA, 1993d), USGS data

bases (e.g., BEST), and other available literature, including other recently completed ecological risk assessments for contaminated sediment sites in the Pacific Northwest. Information on ingestion rates and body weights is available for each of the species proposed above.

TRV distributions will be obtained from literature used to derive the oral dose benchmarks proposed by Oak Ridge National Laboratory (Sample et al., 1996), other state and federal databases and reports including Great Lakes research, and the scientific literature. TRV distributions will be developed for LOAELs (for population endpoints) and NOAELs (for individuals of protected species). As with human health, TRVs and TTLs for dioxins/furans and coplanar PCBs will be in TEC units. To support this approach, PCB analyses in fish tissue will need to be conducted for PCB congeners rather than Aroclors.

TRVs are not available for most wildlife species of interest, and must be extrapolated from laboratory species. For birds, most data are available for ducks, chickens, or quail. Although none of these are fish-eating species, the overall dose-response information is still valid. Similarly, for mammals, data are generally available for mice, rats, rabbits, dogs, and mink. Uncertainty factors recommended by EPA Region 10 (1997c) will be used to account for interspecies differences. Conversion factors recommended by EPA Region 10 (1997c) will be used to extrapolate to chronic doses from acute or subchronic data. Recently completed ecological risk assessments conducted for contaminated sediment sites in the region and approved by DEQ and/or EPA Region 10 will be reviewed to rapidly compile as much information as possible, as there is a limited amount of information available on wildlife benchmarks.

6.2.2.4 TTLs for Human Health

TTLs for protection of human health will be back-calculated from acceptable risk levels using the equations provided below, in accordance with federal, state, and regional human health risk assessment guidance documents (DEQ, 1998ab; WDOH, 1995; EPA, 1997a). The equations provided in these guidance documents are all conceptually similar, though they may use different combinations of terms to represent the consumption rate. Rearrangement of the risk assessment equations to solve for an acceptable tissue concentration yields the following:

Carcinogens:

$$TTL = \frac{ARL \cdot BW \cdot AT}{CPF \cdot IR \cdot ED}$$

Noncarcinogens:

$$TTL = \frac{RfD \cdot BW \cdot HQ}{IR}$$

Where: TTL = Target tissue level (mg/kg)
ARL = Acceptable risk level (unitless)
BW = Body weight (kg)
HQ = Hazard quotient (unitless)
CSF = Cancer slope factor $(mg/kg\text{-}d)^{-1}$

RfD = Reference dose (mg/kg-d)
ED = Exposure duration (yr)
AT = Averaging time (yr)
IR = Ingestion rate (kg/day)

For the purposes of calculating TTLs, there is no need to differentiate between different types of seafood. The equations derive tissue levels that would be safe for the consumer no matter what combination of fish or shellfish they are eating, as long as their overall fish consumption rate remains below the ingestion rate used in the calculations. Although the ingestion rates are expressed on a kg/day basis for use in the equation, they are based on annual consumption rates divided by 365 days/yr. Therefore, a person could consume this much fish each day and still be protected. For carcinogenic risks, which build up over time, the equations assume a 30-year exposure duration within a 70-year lifetime (averaging time) (DEQ, 1998a). Based on these assumptions, if fish and shellfish within the Harbor area are at or below these concentrations, the risks to humans are considered acceptable.

The acceptable risk level (ARL) for individual carcinogenic chemicals is defined in OAR 340-122-115(2)(a) as $1x10^{-6}$, or a one in a million risk of getting cancer over a person's lifetime. A hazard quotient (dose ingested divided by safe dose) of 1 is used in the equation for noncarcinogens. Although TTLs will be calculated on a chemical-specific basis, comparison of fish tissue data to TTLs will use a hazard index approach to account for the potential combined effects of multiple chemicals. TTLs for chemicals with similar modes of action and target organs will be adjusted downward on a Harbor-wide basis to ensure that hazard indices are less than one.

CSFs and RfDs are obtained from EPA's Integrated Risk Information System (IRIS) or, if not available in IRIS, EPA's Health Effects Assessment Summary Tables (HEAST), and are contaminant-specific. Because the CSFs and RfDs may be updated over time, the TTLs listed in this Plan should also be updated as new toxicity values become available. TTLs for dioxins/furans and coplanar PCBs will be derived in TEC units. To support this approach, PCB analyses in fish tissue will need to be conducted for PCB congeners rather than Aroclors.

A probabilistic method will be used to derive the TTL. Under this approach, distributions, rather than point estimates, are used in the equations for some or all of the input parameters, and a single combined distribution is calculated for the TTL using Monte Carlo techniques (DEQ, 1998b). A point on the distribution is then selected as the regulatory endpoint. In this case, the 10^{th} percentile of the TTL distribution will be selected, designated as the TTL_{10}. Parameters to be distributed include body weight and ingestion rate. Body weight distributions for adult males and females can be found in DEQ (1998b).

Some risk assessment guidance documents suggest using age-adjusted equations to account for differences in ingestion rates between children and adults (EPA 1991b, 1998c). However, this is a much more important issue for soil ingestion than for fish consumption, since children may ingest a disproportionately high amount of soil compared to adults. In contrast, adults and children eat similar proportion of fish relative to their body weight. For example, Table B-1 of

DEQ (1998a) provides some default values for reasonable maximum exposure (RME) for fish ingestion by adults and children. Dividing the RME consumption rate (g/day) by the body weight gives a daily fish intake of 1.1 g/kg for children and 0.9 g/kg for adults, roughly equivalent. Therefore, age-adjustment is not considered necessary for calculation of TTLs for seafood, and the simpler equations described above can be used.

The ingestion rate depends on the human subpopulation and exposure scenario selected for protection. For the Harbor area, three exposure scenarios are proposed as representative of human populations that may have relatively high consumption rates of seafood caught in the Harbor. Recreational fishing is a popular activity in the Harbor area, and recreational anglers in the Pacific Northwest have been documented as having higher consumption rates of seafood than the average population. A second exposure scenario is designed to be protective of non-tribal subsistence consumers, including eastern European, southeast Asian and other urban subsistence fishermen. A tribal fish consumption scenario will be added as a third scenario.

Regional data for recreational anglers in the Pacific Northwest were used to estimate ingestion rates for this exposure scenario (Pierce et al., 1981; EPA, 1988; Landolt et al., 1987). A site-specific consumption survey conducted for the Columbia Slough (Adolfson Assts., 1996) was included to estimate consumption rates in the area, along with information available from the above-referenced studies. Only studies of self-caught fish are included in this review, specifically for the purpose of determining ingestion rates of wild-caught fish as opposed to fish purchased in a store or restaurant. Although surveys of the general U.S. population typically show lower consumption rates than these studies (e.g., Javitz, 1980), recreational anglers and subsistence consumers are the subpopulations most likely to be exposed to contaminants in the Harbor and also have higher consumption rates of fish than the general population. These more highly exposed subpopulations are protected by state and federal law, and form an appropriate basis for regulation of contaminants in sediments.

A tribal subsistence scenario is proposed for Portland Harbor. Tribal consumption rates for the region will be estimated from a study of consumption rates among Columbia River tribes (CRITFC, 1994; Harris and Harper, 1997). It is possible that these studies may overestimate tribal fishing within the relatively industrialized Portland Harbor area. Tribal consumption rates in the Pacific Northwest (CRITFC, 1994; Toy et al., 1996) have been described as similar to those of other shoreside anglers included in consumption surveys (e.g., Landolt et al., 1987).

Table G-13 shows ingestion rates compiled from the studies listed above (adapted from Ecology, 1999). Where distributions for ingestion rates were available, the 90^{th} percentile value is reported, in accordance with OAR 340-122-115(2)(b), along with the 50^{th} percentile and the mean. Although both Oregon and Washington recommend using the 90^{th} percentile of the distribution, EPA's Risk Assessment Guidance for Superfund recommends using the 95^{th} percentile. Therefore, the 95^{th} percentile value has also been included on the table. Complete distributions will be used in the Monte Carlo simulation for calculation of the TTL_{10}.

Table G-13: Consumption Rate Distributions for the Pacific Northwest (g/day)

Study	50th %ile	Mean	90th %ile	95th %ile
Pierce et al.(1981) EPA (1995)	10	39	78	146
Landolt et al. (1985) EPA (1988)	31	61	176	277
Adolfson Assts. (1996)	0[a]	14	51	105
CRITFC (1994)	42	63	127	182

[a] A large percentage of fishermen in this study did not catch any fish, or did not consume the fish they caught.

It should be noted that the fish consumption survey for the Columbia Slough was conducted after fish advisory warnings and fact sheets had been provided to the community and there was some level of awareness of contamination. As a result, a much higher percentage of fishermen released their catch (instead of eating it) than did fishermen at Sauvie Island (Adolfson Assts., 1996). This accounts for the 50th percentile of zero consumption reported in this study. Data from Pierce et al. (1981) were reported by EPA as the basis for their Pacific Northwest consumption estimates in the Exposure Factors Handbook (EPA, 1997a). Unlike the other studies, however, this study excluded salmon from catch and consumption estimates. For these reasons, both of these studies likely underestimate total fish consumption by recreational and subsistence populations in the absence of contamination warnings.

Landolt et al. (1987) has long been considered the definitive study of recreational anglers in Washington State, and is based on far more data (over 4,000 data points over a 13-month period) than most of the other studies in the region. More recent studies of freshwater and marine tribal consumption rates have resulted in very similar estimates for the Columbia River and Puget Sound, respectively (CRITFC, 1994; Toy et al., 1996). These three studies have been selected by the Washington Department of Ecology as the basis for their proposed default consumption rate of 177 g/day, based on the 90th percentile values of the various distributions (Ecology, 1999). To put these values into context, a meal has been estimated at about 150 grams by EPA (1997a). EPA (1997a) recommends consumption rates ranging from 30 g/day for recreational fishermen to 170 g/day for subsistence consumers (based on 95th percentiles), and these values fall within that range. However, the two studies with highest reported consumption rates (Landolt et al., 1987; Toy et al., 1996) are both from marine areas where total fish and shellfish consumption may be higher than in freshwater systems.

None of the studies shows a clear distinction between recreational, subsistence, and tribal consumption rates. It is likely that each of the studies included a wide range of fishing frequency and effort among the respondents, including both recreational fishermen and subsistence fishers. In addition, while different ethnic groups are catching and eating different species, the overall consumption rates do not appear to vary dramatically by ethnicity (Ecology, 1999). Therefore, it is likely that the recreational and subsistence (including tribal) exposure scenarios may not really be distinct, but may represent different areas within a continuous distribution of fish consumption rates. To best reflect potential freshwater consumption rates in the absence of contamination, a consumption rate distribution will be compiled using the Pierce et al. (1981) and the CRITFC

(1994) studies. The TTL_{10} will be considered protective of both subsistence and recreational fishermen.

This consumption distribution is proposed for use as an initial screening-level evaluation of potential human health risks in the Harbor, and will be used to derive TTLs for comparison to fish tissue results from the harbor-wide study. Contaminants that exceed TTLs in fish tissue will be considered bioaccumulative COPCs for the Harbor, and will be compared with site-specific COPCs at known sites to identify sites that may need to conduct bioaccumulative risk assessments. The TTLs could be recalculated using harbor-specific consumption rates if such a study is considered warranted to reduce uncertainty in the risk assessment.

6.2.2.5 Derivation of Bioaccumulation-Based RAOs for Sediments

If TTLs or TSCs are exceeded, bioaccumulation-based remedial action objectives (RAOs) for sediments will need to be calculated. The relationship between tissue concentrations and sediment concentrations is known as the biota-sediment accumulation factor, or BSAF. The BSAF is often thought of as a simple ratio between the tissue concentration and the sediment concentration. However, in reality, many factors affect the bioaccumulation of chemicals from sediments that are not well-represented by a ratio derived from point estimates. The bioavailability of chemicals in sediments is affected by site-specific factors, such as grain size, TOC, sulfides, and matrix effects. In addition, uptake of chemicals may vary according to feeding strategy, habitat preferences, avoidance behaviors, and other species-specific factors (PTI, 1995). Bioaccumulation of some chemicals also appears to be affected by age of the fish and initial concentration in sediments (i.e., bioaccumulation may not be a strictly linear process) (O'Niell et al., 1995). For these reasons, it may be more accurate to refer to the relationship between contaminant concentrations in sediment and tissues as a biota-sediment accumulation *function*, which is not a simple ratio and may or may not be linear. This broader definition of the BSAF will be used in this section.

For the reasons discussed above, it is not recommended that point estimates of BSAF values found in the literature be applied, as both field and laboratory-derived values may vary over orders of magnitude for a single chemical (PTI, 1995). Similarly, it is not recommended that models be used to estimate bioaccumulation from sediments, as the models that are currently available (e.g., Thomann et al., 1992; Gobas et al., 1993) may also be incorrect by several orders of magnitude when compared to actual site data, particularly for high K_{ow} compounds (e.g., see Appendix C of Foster Wheeler, 1998). Instead, it is recommended that BSAFs be empirically derived using tissue and sediment chemistry data from the Harbor or the site.

Following the harbor-wide investigation, both fish tissue and sediment data will be available for the Harbor. At this point, DEQ will attempt to calculate a harbor-wide BSAF that can be used to calculate default bioaccumulation-based RAOs for use at sites with bioaccumulative COPCs. However, area-wide calculation of BSAFs may or may not be possible for all chemicals, due to a variety of complicating factors described below. If harbor-wide BSAFs are not available for all COPCs at a particular site, or if the responsible party prefers to calculate site-specific BSAFs, then site-specific tissue and sediment data may be used to calculate the BSAF and associated

sediment RAOs. Methods are described below for development of both site-specific and harbor-wide BSAFs.

Because of the heterogeneity of sediment and tissue data, particularly in field-collected organisms, BSAFs should never be calculated as a simple ratio of point estimates or single-value statistics that represent a distribution. For additional discussion of this issue, in-depth reports are available on BSAFs prepared for the Washington Department of Ecology (PTI, 1995; Exponent, 1998a). A regression should be calculated from pairs of sediment and tissue data from the site. Generally, a linear regression that passes through the origin should be assumed, and the slope of the line is then equal to the BSAF. However, to obtain a linear regression, it may be necessary to perform separate regressions for individual species, for high and low concentration areas, and/or for different age fish. Some experimentation and professional judgment must be applied to determine whether such stratification of the data is necessary. In addition, fish may be experiencing exposure to chemicals through other sources (e.g., water, food), or there may be a time lag between concentrations in fish tissue and changing concentrations in sediments. In these cases, the regression may not pass through the origin, and the relationship between sediment and tissue concentrations will be in the form of $y = ax + b$. Additional methods for calculating linear and non-linear regressions are reviewed in Exponent (1998a).

Tissue-sediment data pairs for regression analysis can be obtained in a variety of ways. The most straight-forward involves the use of tissue data for stationary species, including field-collected benthic organisms or shellfish, which can be paired with sediment chemistry data from the point of collection. Similarly, laboratory bioaccumulation studies using fish or benthic organisms provide tissue data that can be easily paired with chemical concentrations in the sediments used in the study. However, laboratory tests must be of sufficient duration for chemical concentrations in tissues to have reached equilibrium. For some chemicals of concern (e.g., dioxins, PCBs), 45- or 60-day bioaccumulation studies may need to be conducted for this purpose. Finally, *in situ* bioaccumulation tests can be conducted with caged bivalves or other species. These arrays may be left in place for 2-3 months, providing a sufficient exposure time, and can be placed along chemical gradients to provide the best possible data set for regression analysis.

Obtaining tissue-sediment data pairs for field-collected fish is more problematic. To ensure that the sediment concentration used is representative of the entire area the fish has been exposed to, the sediment concentration should ideally be an area-weighted average over the species' entire home range – not a point concentration from the location where the fish were caught. To calculate the area-weighted sediment concentration, the species' home range must first be determined or estimated. Obviously, this approach is easier to use for species with a relatively small home range or restricted habitat preference (such as pile perch) and cannot be used at all for species with excessively large home ranges (e.g., anadromous fish).

Once the home range is established, the area-weighted sediment concentration within that area can be calculated as follows:

$$AWC = \frac{\sum SC_i \cdot A_i}{A}$$

Where: AWC = area-weighted concentration
SC_i = sediment concentration associated with station i
A_i = area associated with station i
A = total area within home range

A_i is defined as the area around a station that is closer to that station than any other station, and can be determined using a GIS or other mapping tool by drawing a Thiessen polygon around the station and determining the area within the polygon (Ecology, 1991). A recent example of the use of this approach to calculate a site-specific BSAF can be found in the Whatcom Waterway Remedial Investigation Report (Hart Crowser, 1998). At this site, species-specific regressions were calculated for mercury in fish and Dungeness crab in Bellingham Bay to derive a sediment cleanup standard protective of human health.

In some cases, multiple regressions may be obtained for different species (as in Bellingham Bay), and/or regressions may not be possible to derive for some species and only point estimates will be available. In these cases, an "envelope" relationship can be derived that encompasses and is protective of all the regressions and point estimates available for that site. All the data for different species are placed on a single graph, and a line drawn that provides a relationship for the BSAF that is at least as protective as each of the individual regressions or point estimates.

When a risk assessment being done at a harbor-wide or watershed scale for bioaccumulative chemicals, an alternative approach is available that does not require explicit calculation of BSAFs. Using this approach, actual tissue concentrations are compared to the TTLs or TSCs for each pathway (human health, fish, and wildlife) and exceedance factors are calculated (defined as the concentration in tissue divided by the tissue guideline). The largest exceedance factor is used to determine the degree to which exposure in the area needs to be reduced in order for the tissue guideline to be met, and is simply the inverse of the exceedance factor. For example, if the largest exceedance factor for a chemical is two, exposure of fish to that chemical within the harbor needs to be reduced by half.

Sediment concentrations within the area are entered into a GIS-compatible database, and an evaluation undertaken that simulates the effect of cleaning up various sized areas by replacing the existing concentration with a concentration that simulates clean dredged material (i.e., a capping alternative) or underlying native sediments (for a dredging alternative). Starting with the highest-concentration areas, sediments can be successively targeted for cleanup until the predicted exposure (as represented by the area-weighted surface sediment concentration) has been reduced by the desired amount. Implicit in this approach is the assumption that the entire Harbor is a single exposure unit and that fish are evenly exposed to surface sediments within the Harbor; however, alternative area-weighting schemes can be developed based on more detailed knowledge of receptor use of habitats within the Harbor. Safety factors can be added if desired to address the uncertainty in actual exposure patterns. This approach allows for the simultaneous assessment of multiple sources of bioaccumulative chemicals and efficiently allocates cleanup dollars to those areas that represent the greatest contribution to area-wide exposures.

6.3 Review of Existing Information

In this section, the existing data for Portland Harbor are reviewed to identify the extent to which existing data is adequate to calculate sediment and tissue guidelines and assess risks associated with contaminated sediments in the Harbor. Included are data for stations from Willamette Falls to the confluence of the Willamette and Columbia Rivers. This section is currently based on a review of data that were available as of June 1999.

6.3.1 Chemistry-Only Data Sets

The following data sets containing only sediment chemistry have been obtained, subjected to quality assurance review, and entered into the SEDQUAL database:

- **Portland Harbor Site Assessment**. This study was conducted by Weston on behalf of EPA and DEQ. This survey includes 195 samples (both surface and subsurface), primarily in nearshore areas in a 5-mile stretch centered on Portland Harbor. Data for split samples analyzed by Elf Atochem and the Port of Portland are also available.
- **Portland Shipyard Drydocks 3 & 4 Post-Dredge Data.** Together these data sets comprise 17 samples taken from under and adjacent to these drydocks following dredging activities. An additional 83 subsurface chemistry samples for 23 stations are also part of this data set.
- **Corps of Engineers Channel Deepening Data.** 43 samples were collected by the Corps of Engineers from the mouth of the Willamette River to the turning basin upstream of Swan Island. An additional 53 surface and subsurface sediment chemistry samples are also part of this data set. The samples are generally located in the shipping channel. The final RI report is not yet available.
- **Local Sponsor Data for Channel Deepening.** The Port of Portland conducted this study of several berths at the request of the Corps of Engineers, as part of preparations for the Channel Deepening project. 26 samples, including grab samples in the river and core samples near berths, were collected from upstream of Portland Harbor to berths in the Columbia River downstream of its confluence with the Willamette River.
- **Portland Stormwater Discharge Study.** This study of five major CSO outfalls in the Portland area was conducted by the Port of Portland, and is comprised of 29 samples, with 3-6 samples in the immediate vicinity of each outfall.
- **Riedel Sediment Investigations.** A two-phase study offshore of the former Riedel property next to McCormick & Baxter includes a total of 7 surface and 27 subsurface samples.
- **Willamette Cove Supplemental Site Assessment.** This study of the cove just downstream of McCormick & Baxter included three composite samples along the shoreline.
- **U.S. Moorings Sediment Data.** This site, owned by the Corps of Engineers, was sampled in 1994 and 1995, including 27 surface samples (some of which were composited) and 39 core samples.

The following chemistry-only data sets exist but are not suitable for entry into the database, as insufficient quality assurance information is available to verify their quality. These are both small, relatively dated data sets, and their exclusion should not significantly affect the overall

data set for Portland Harbor:

- **U.S. Moorings 1989 Sediment Data.** Three stations were sampled off the dock in 1989. These sample locations are essentially duplicated in the 1995 survey.
- **Portland Shipyard Berth 311.** Several composite samples were collected offshore of this berth in preparation for dredging, which was never completed.
- **USGS 1983 Bed Sediment Data.** This report provides metals and organics data for several stations in Portland Harbor, but is relatively old and quality assurance information are not included in the published report.

In addition, a data set for the Willbridge Terminals site should be available in the near future.

6.3.2 Synoptic Chemistry/Bioassay Data

Paired bioassay and chemistry data are needed to calculate benthic SQGs and assess risks to the benthic community. The data are reviewed with respect to species used or collected, number and location of stations, whether synoptic chemistry data are available, and the availability of quality assurance data. Where quality assurance data were provided, the quality of the data is also discussed. Data sets considered of adequate quality for risk assessment and calculation of SQGs are described first, followed by other data sets reviewed but not proposed for use. Finally, data sets from other areas of western Oregon and Washington are described that will be used to supplement the Portland Harbor database for calculation of benthic SQGs.

6.3.2.1 Portland Harbor Data Sets of Acceptable Quality

Data sets proposed for use in calculating regulatory guidelines must meet a very high level of quality assurance. The following data sets were collected using modern sampling and testing protocols, and have adequate quality assurance information available. They are generally acceptable for use in risk assessment and for calculation of benthic SQGs. In a few cases, QA data have not yet been reviewed. These data sets are noted below and will be further reviewed prior to inclusion.

- **McCormick & Baxter Remedial Investigation.** The McCormick & Baxter remedial investigation, conducted in 1990-1992, included sediment chemistry and two rounds of sediment bioassays (PTI, 1992). Complete methods, laboratory data sheets, and quality assurance reviews are available in appendices in DEQ files. *Hyalella azteca* 10-day mortality bioassays were conducted at 58 stations, and Microtox pore water bioassays were conducted at 17 stations. *Hyalella* (Phase I) bioassays had synoptic chemistry, while Microtox (Phase II) bioassays were relocated at or near stations with existing chemistry data. An additional 37 subsurface chemistry samples and 24 tissues chemistry samples are also included with this data set.
- **Portland Shipyard Sediment Investigation.** Bioassay and chemistry data were collected as part of the Port of Portland's1998 PSY sediment investigation (SEA, 1998). This data set includes saline extract Microtox, *Hyalella azteca* 10-day

mortality, and *Chironomus tentans* 10-day growth and mortality bioassays (55 stations), all with synoptic chemistry. Complete methods, laboratory data sheets, and quality assurances reviews are available.

- **Portland Shipyard Environmental Audit.** As part of an environmental audit of the Portland Shipyard by Cascade General (Dames & Moore, 1998), one bioassay, the *Hyalella azteca* 10-day mortality bioassay, was run at five stations, three within the shipyard/lagoon area, and two upstream. Sediment chemistry results are available for all five stations. Chemical and biological testing was conducted in December of 1997. The upstream stations tested showed moderate to severe mortality and are therefore not suitable as reference stations. The control mortality was somewhat higher than usual, at 14%. Therefore, bioassay data for the shipyard and upstream stations will be compared against the control mortality for evaluation of adverse effects. An additional 18 stations near the shipyard and in the Willamette River were analyzed for chemistry only.
- **Terminal 4 Remedial Investigation.** A remedial investigation of sediments was recently completed at the Port of Portland's Terminal 4. Hart Crowser (1998) provides a work plan for the collection and testing of sediment chemistry and bioassay samples that was recently completed. Two rounds of bioassay and chemistry sampling were conducted, totalling 16 stations. Bioassays conducted included *Hyalella azteca* 10-day mortality and *Chironomus tentans* 10-day survival and growth, in accordance with the Columbia River Dredged Material Evaluation Framework. Results of the study have not yet been released to DEQ.
- **Tosco Dredged Material Evaluation.** Tosco has recently completed sediment chemistry and bioassay testing of sediments proposed to be dredged for dock maintenance (Exponent 1998b). Bioassay testing will include *Hyalella azteca* 10-day mortality and *Chironomus tentans* 10-day growth and mortality bioassays at 3 stations, including two stations from the dredging area and a reference station. However, sediment chemistry is not being conducted at the reference station, so only the two dredging stations can be used for criteria development. Data have been recently received but not yet QA'd or entered into SEDQUAL.
- **Terminal 2, Berths 203-206 and Terminal 4, Berth 416.** These studies, conducted to assess the suitability of sediments to be dredged, each have a few stations with synoptic chemistry and bioassay data, as well as reference stations in the Columbia River. These data sets have been recently received, but not yet QA'd or entered into SEDQUAL.

6.3.1.2 Unusable Data Sets

The following data sets are not appropriate for use, for one or more reasons. In some cases, older bioassay protocols were used that are not comparable to current protocols. QA/QC and sampling methods are often not described. These data sets typically have few data points, and in most cases, the sediments were tested for dredge disposal purposes, and the sediments tested have been dredged and are no longer in place. In the case of drydock data, the presence of sandblast grit would make these samples unsuitable for SQG calculation, due to potential anomalies in

bioavailability of metals in these samples.

- **1988 COE Lower Willamette Bioassays.** COE (1997b) summarizes various Corps sampling events in the Willamette and Columbia Rivers, and references a March/April 1988 sampling event where samples were collected from RM 4.4, 5.1, 7.1, and 7.3 and subjected to a D. magna elutriate bioassay and an unspecified (probably *Hyalella azteca*) solid phase bioassay. Chemical analyses were also conducted. No methods, quality assurance information, or results were provided, except that "elutriate from Doane Lake sediments was toxic to *D. magna*, while the less disturbed sediments in the solid phase test were not." The original data set could not be located for review.
- **Portland Shipyard Drydock 4 Bioassays.** A letter report from Northwestern Aquatic Sciences to Danil Hancock of the Port of Portland provides results of *Daphnia magna* 48-hr suspended particulate phase and *Hyalella azteca* 10-day mortality bioassays on unspecified sediment samples (Caldwell, 1991). Based on information provided in Hancock (1995), these results were conducted for pre-dredge testing of Drydock 4 sediments in 1991. All of the sediments tested were dredged and disposed of at Ross Island. Pre-dredge sediment chemistry data for Drydock 4 are provided in Hancock (1995), but it is not clear whether the chemical analyses and bioassay tests were run on the same samples. QA information is limited to listing of water quality ranges during the test and control survival.
- **Terminal 2, Berth 203 Bioassays.** Two reports are available (NAS, 1994) providing results of bioassays (*Hyalella azteca* 10-day mortality and *Daphnia magna* 48-hr mortality) conducted on one sediment sample from Berth 103 at Terminal 2. Companion chemistry data have not been located. These are pre-dredge tests on sediments that have since been removed.
- **Willamette River Toxics Study (1988-1991).** DEQ (1994) presents the results of several bioassays performed over several years in the Willamette River basin. However, the chemicals analyzed and biological tests run at each station varied from year to year, and not all stations were sampled each year. In 1988, two stations in the lower Willamette River (RM 7 and 16) were tested with *D. magna* (solid phase and elutriate 48-hour mortality tests) and *H. azteca* (10-day mortality test). In 1989, two stations in the lower Willamette River (RM 7 and 18) were tested with *D. magna* and *Chironomus riparius* (10-day mortality test). Also in 1989, 4 stations in the lower Willamette River (RM 7, 8, 14, and 18) were tested with the Microtox pore water extract bioassay. Quality assurance information is not presented in the report. Original laboratory data were obtained from DEQ files, and it appears that neither the chemistry or bioassay data have sufficient quality assurance information to be usable.

6.3.1.3 Supplemental Data Sets from Western Oregon and Washington

The following supplemental data sets will be added from western Oregon and Washington to provide a larger data set for SQG calculation. All of these data sets have been reviewed by DEQ and/or Ecology, are of known and acceptable data quality, and have already been entered into SEDQUAL by Ecology. All are from fine-grained freshwater rivers, streams, or lakes in urban

areas with similar industries as Portland Harbor. All references below to *Hyalella* and *Chironomus* bioassays refer to the *Hyalella azteca* 10-day mortality bioassay and the *Chironomus tentans* 10-day growth and mortality bioassay, unless otherwise noted.

- **Columbia Slough**, Portland, OR – 20 stations with *Hyalella* data
- **Lower Columbia River Backwater Study** – 15 fine-grained stations from backwater areas with *Hyalella* data
- **Mill Creek**, Kent, WA – 19 stations near the Western Processing site with *Chironomus* and *Hyalella* data
- **Cedar River**, Renton, WA – 6 stations with *Hyalella* data at the mouth of the Cedar River in Lake Washington
- **Quendall-Baxter**, Renton, WA – 4 stations near a wood treating site in Lake Washington with *Chironomus* and *Hyalella* data
- **Lake Union**, Seattle, WA – Ecology study of Lake Union, 9 stations with *Hyalella* data
- **Lake Union Drydock**, Seattle, WA – 4 stations in Lake Union with *Hyalella* data
- **Gas Works Park**, Seattle, WA – 1 station in Lake Union with *Hyalella* data
- **Seattle Commons**, Seattle, WA – 3 stations in Lake Union with *Hyalella* and Microtox data
- **Tri-Star Marine**, Seattle, WA – 3 stations in Salmon Bay with *Hyalella* and Microtox data
- **Marco Shipyard**, Seattle, WA – 1 station in Salmon Bay with *Hyalella* data
- **Payne Field**, Mukilteo, WA – 5 stations from a stream near Boeing's Payne field with *Hyalella* data
- **Ferndale**, WA Wastewater Treatment Plant – 3 stations with *Hyalella* data

In addition, Ecology has recently obtained additional freshwater bioassay data for Salmon Bay, Lake Washington, and other areas which have not yet been entered into the SEDQUAL database. Ecology's contractor SAIC will be conducting a quality assurance review and entering these data into the database over the next few months, to assist with the development of freshwater guidelines as part of this Plan. These data will add approximately 80 stations with a variety of test types, including *Hyalella*, *Chironomus*, and Microtox bioassays.

The following freshwater bioassay data are available in SEDQUAL but are not proposed for use:

- Two studies of Lake Roosevelt, one study of the Columbia Basin, and one study in the Spokane River were excluded because of their location in eastern Washington – 10 stations with *Hyalella* data, 5 stations with *Chironomus* data, and 3 stations with Microtox data
- Several small studies in the lower Columbia River were excluded due to the coarse-grained nature of the sediments and/or their location near industries not present in Portland Harbor, including Kalama Chemical, Longview Fibre Co., Weyerhaueser Longview, and Reynolds Aluminum – a total of 12 stations with *Hyalella* data.
- Several studies were excluded due to very limited chemical data, including Port of Vancouver (copper only), Lake Steillacoom (metals data only), and Everett Simpson

property (mercury only) – 12 stations with *Hyalella* data and 8 stations with *Chironomus* data.

6.3.1.4 Summary of Chemistry and Bioassay Data

Table G-14 summarizes the available chemistry and bioassay data of acceptable quality for Portland Harbor and supplemental areas. This table will be updated as additional freshwater data are made available by Ecology.

Table G-14: Available bioassay data for calculation of benthic SQGs

	Number of Stations		
Area	***Hyalella azteca***	***Chironomus tentans***	**Microtox**
Portland Harbor	138	75	72
Western Oregon	37	2	0
Western Washington	58	23	6
Total	**233**	**100**	**78**

At this time, the database for *Hyalella azteca* is probably adequate to calculate SQGs. The number of stations for *Chironomus* is misleading, because the majority of these stations did not show effects, and therefore the existing data are probably not sufficient to calculate criteria for most chemicals. A similar situation exists for Microtox, although a greater percentage of the data showed effects. In addition, there are data for only three bioassays. Additional data do exist for other bioassays outside the Portland Harbor, but only for a few stations (less than 20), not enough to calculate criteria.

The addition of the newer Ecology data may improve the situation considerably, as these are somewhat larger studies that often included *Chironomus* and Microtox. However, once these data are entered, there is still likely to be a need for some focused sampling in Portland Harbor to fill data gaps in higher concentration areas. A fourth bioassay may need to be identified and a relatively large study conducted to identify guidelines for that test. Alternatively, benthic data may prove to be usable in calculating a fourth SQG. A final option is to calculate SQGs for a chronic test (e.g., Hyalella azteca 28-day test), using a national data set such as BDES, until enough regional data become available to caluculate regional chronic criteria.

With respect to risk assessment in Portland Harbor, only a few of the known sites have conducted toxicity testing on a site-wide basis – McCormick & Baxter, Portland Shipyard, and Terminal 4. Through these investigations, some bioassay testing has also been done in the shipping channel and in areas upstream and downstream of these sites. At these sites, toxicity in the bioassays was confined to areas within 300 feet of the facilities; stations in the main river did not show toxicity (Port of Portland, 1998). Therefore, it does not appear that ambient levels of chemical contamination are associated with adverse effects in the bioassays. Additional bioassay testing will be needed in areas with chemical concentrations above ambient concentrations to evaluate potential impacts to the benthic community associated with specific sources.

6.3.2 Benthic Data

Benthic data may be used for a variety of purposes in the Portland Harbor investigation:

- To assess baseline conditions in the benthic community, and explore relationships between observed depressions and land use, chemical concentrations, and/or physical conditions in the Harbor
- To assess the usefulness of benthic community studies as a tool for evaluating sediment quality, and to identify appropriate interpretation metrics
- As an optional component of an evaluation of benthic toxicity on a site-specific or Harbor-wide basis
- To field-validate benthic SQGs
- To identify appropriate reference areas for toxicity testing

Only two limited studies of the benthic community in Portland Harbor are currently available:

- **Willamette River Basin Water Quality Study.** This study was conducted by Tetra Tech for Oregon DEQ over a three-year period from 1992-1994, and included water quality modeling and field calibration of the models, nutrient loading and algal growth, fish community studies, fish skeletal abnormality and histopathology studies, and benthic community analysis throughout the Willamette River watershed (Tetra Tech, 1995b). Benthic studies were conducted for two types of habitats - riffles and soft-bottom habitats. Since no stations below Willamette Falls were included in the riffle habitats, those evaluations are not discussed here.

  Soft-bottom benthic samples were collected with a van Veen and three replicates were collected at each station. 15 stations were sampled, including 8 stations throughout the watershed above Willamette Falls, and six stations below the Willamette Falls, at approximately RM 25, 22, 17, 9 (near Swan Island), 6.5 (near St. Johns Bridge), and 1 (mouth of Columbia Slough). One station was near the mouth of the Multnomah Channel. 15 different metrics were used to classify the data, including 5 structure metrics, 5 community balance metrics, and 5 functional feeding group metrics. Chemical analyses were not conducted. Of the stations below Willamette Falls, the station in the Columbia Slough was identified as biologically impaired, while the station at RM 22 was also considered slightly impaired. Stations near Swan Island and St. Johns Bridge were reported to have degraded habitats that may limit benthic communities, but were not considered impaired.
- **Portland Shipyard Environmental Audit.** Limited benthic sampling was conducted as part of the Portland Shipyard audit conducted by Cascade General (Dames & Moore, 1998) in January of 1998. Five stations were sampled within the shipyard/lagoon area, three stations were sampled upstream of Swan Island, two were sampled immediately adjacent to Swan Island, two were downstream offshore of the Reidel property, and two were downstream offshore of McCormick & Baxter, for a total of 14 stations. Sediment chemistry results appear to be available for all of these stations except two of the five in the shipyard, DM-21 and DM-23. Benthic

organisms were not identified to the species level, but were summarized by taxonomic group and feeding group, and were grouped by whether they are tolerant or intolerant to contamination. Metrics calculated include total abundance, total number of taxa, dominant taxa, Hilsenhoff Biotic Index, various diversity measures, and feeding group metrics. Interpretation of these data was not provided.

In summary, a total of 20 stations have been sampled for benthic community studies, and the data may be difficult to combine, since the data were collected approximately 5 years apart, at different times of the year. A more comprehensive benthic study of the lower Willamette River would be needed to accomplish any of the objectives set out above.

6.3.3 Tissue Chemistry

Tissue chemistry data are needed for comparison to the bioaccumulation guidelines for protection of fish, humans, and wildlife. Harbor-wide tissue data will be used to screen pathways and chemicals of concern for the Portland Harbor, and to limit the amount of site-specific testing that must be done for these pathways. The following studies on tissue concentrations are currently available:

- **McCormick & Baxter Remedial Investigation.** Largescale sucker and crayfish samples were collected in 1991 from four areas near the site, an area downstream of the site, and an upstream reference area near Wilsonville (PTI, 1992). These samples were analyzed for metals, PAHs, phenols, and dioxins/furans. LPAHs in both fish and crayfish tissues were elevated compared to other areas of the river, probably indicating ongoing exposure. Dioxins/furans were also elevated at site stations relative to reference. The report references two earlier studies of contaminant bioaccumulation in the Willamette River and found dioxin/furan values were generally comparable with the previous literature. The previous study is referenced as the EPA National Bioaccumulation Study, as summarized in DEQ (1990), which has not yet been obtained for review. However, that study would now be more than 10 years old, and may not be representative of current conditions in the Harbor.
- **Willamette River Toxics Study.** Fish collected for analysis in various years (1988-1991) included carp, squawfish, sucker, largemouth bass, cutthroat trout, crayfish, and whitefish, and various tissues were analyzed, including whole body, edible tissues, and liver (DEQ, 1994). Species, tissue types, and chemicals analyzed varied from year to year and from station to station, but generally included metals, pesticides/PCBs, dioxins/furans, and some PAH analyses. Up to 11 samples (depending on analysis) were collected from RM 7, and a few samples were collected near Kellogg Creek at RM 18. Fish tissue data are summarized by chemical and river mile and compared to various action levels and health-based criteria. All levels were below FDA action levels, but levels of DDT and derivatives, PCBs, and dioxins/furans were reportedly above EPA threshold values (derived from water quality criteria) at some stations (tissue data for individual stations has not yet been obtained).
- **DEQ Water Quality Program Data.** Data tables are available from 1997 sampling

for mercury in various fish species at two stations in the Lower Willamette, including RM 7 at the SP&S railroad bridge and RM 24 (DEQ, 1999). Fish sampled at these locations include smallmouth bass, largemouth bass, largescale sucker, carp, and squawfish.

- **DEQ/OSU Fish Tissue Data.** Data for six individual fish samples in the Portland Harbor are reported in Curtis et al. (1993). The fish were analyzed for organochlorine pesticides, PCBs, PAHs, and PCDDs/PCDFs. According to Dr. Curtis, it is no longer possible to obtain the original data or QA information. Therefore, these data will not be entered into the database, as there were significant QA issues with much of the data (Curtis, 1999, personal communication).

Chemical detections in fish tissue from these studies are summarized in Section 2.2.2. None of these data, with the exception of the 1997 mercury data, are recent (within 5 years), and most are approaching 10 years old. No data are available for some chemicals that are widespread in sediments and may bioaccumulate, such as phthalates. Data are limited to bottom-fish and crayfish, which would be expected to be the most highly exposed species. However, data for juvenile salmon and other pelagic species may be of interest from an ESA perspective. A harbor-wide study may be needed to obtain recent tissue concentrations for the bioaccumulative COIs for comparison to tissue guidelines.

6.3.4 Tissue Residue Effects Data

Tissue residue effects data will be used to calculate Tissue Screening Concentrations (TSCs) for protection of fish. A large compilation of tissue-residue effects data is available in an on-line database, ERED, located at the Corps of Engineers Waterways Experiment Station web site. All available data for the bioaccumulative COIs in the database were downloaded and are summarized below in Table G-15. Certain contaminant classes have been summed (e.g., butyltins, PCBs, dioxins/furans) for this review. The following effects types were included: mortality, development, reproduction, and growth. Other effects classes, such as morphology, are sufficiently species- and chemical-specific that the original literature must be reviewed to determine whether population-level effects could be associated with the effect reported (e.g., skin discoloration vs. gross skeletal deformities). Some of these studies may be added after reviewing the literature.

Table G-15: Tissue-residue effects data in ERED for bioaccumulative COIs

	Number of Records		
Chemical	**Fish**	**Invertebrates**	**Total**
Mercury	155	30	**185**
Butyltins	0	23	**23**
Bis(2-ethylhexyl)phthalate	3	6	**9**
Butylbenzyl phthalate	1	0	**1**
Di-n-butyl phthalate	0	2	**2**
Di-n-octyl phthalate	0	0	**0**
DDT	8	12	**20**

Table G-15: Tissue-residue effects data in ERED for bioaccumulative COIs

Chemical	Number of Records		
	Fish	**Invertebrates**	**Total**
DDD	3	0	**3**
DDE	3	2	**5**
PCBs	116	43	**159**
Dioxins/Furans	112	6	**118**

Recent reviews of tissue-residue effects data in the Pacific Northwest provide a variety of additional references for TBT, PCBs, DDT, and mercury (EPA, 1996; EVS, 1996, 1998; Salazar, 1999) that can be used to supplement data in the ERED database. Overall, there will likely be enough tissue-residue effects data to calculate guidelines for mercury, TBT, DDT, PCBs, and dioxins/furans. Phthalates are more problematic, and it has not yet been determined whether phthalates are present in fish tissue in Portland Harbor. However, phthalates are a good candidate for development of narcosis-based criteria, as they are neutral organic compounds that are among the classes of compounds demonstrated to behave according to the narcosis model of toxicity.

6.3.5 Wildlife Information

The following studies on birds and mammals in the Willamette River have been completed or are underway, and will provide information useful to the ecological risk assessment:

- **Great Blue Heron Investigation**. The Oregon Cooperative Research Unit at Oregon State University and the U.S. Fish and Wildlife Service (FWS) conducted an investigation of the effects of environmental contaminants on Great Blue Heron reproductive success and breeding behavior. The objectives of this study were to 1) ascertain whether significant differences among sites in contaminant concentrations and nesting behavior exist; 2) determine certain biological parameters such as clutch size and hatching, fledging, and reproductive success; 3) determine if contaminant concentrations are related to biological parameters, particularly in areas of elevated residue levels; and 4) determine the potencies of contaminants to developing heron embryos through liver enzyme bioassays. Eggs, prey items, and pipping embryos were collected from three colonies on the lower Columbia River, and from two colonies on the lower Willamette River (Ross Island and Mollala) from 1994 to 1995. Concentrations of dioxins, furans, PCBs, and organochlorine pesticides were determined in both heron eggs and prey items; trace element concentrations were also determined in 1994 heron eggs. Embryo livers were used in a bioassay to determine the effects of contaminants on the developing embryos. A thesis publication was completed in 1997 and a manuscript has been submitted to *Environmental Toxicology and Chemistry*.
- **River Otter Study**. USGS, in cooperation with the FWS, is conducting a study on river otters along the Columbia and Willamette rivers. Tissues from live-captured otters and from otter carcasses collected by local trappers have been collected along

the lower Willamette River, including several locations between the Willamette Falls and the mouth, and a number of carcasses were also collected from reference areas. Livers from carcasses are being analyzed for a variety of contaminants, including dioxins and furans, organochlorine pesticides, and polychlorinated biphenyls. Results on chemistry are expected in spring of 1999. However, a paper is in press in *Archives Environmental Contamination and Toxicology* titled "Butyltin compounds in river otters *Lutra canadensis* from the northwestern United States" which includes a series of otters from the Willamette River. Butyltins were found in every animal sampled including those from the Willamette River.

- **Osprey and Osprey Prey Studies**. USGS completed a study on osprey along the Willamette River in 1993 and determined production rates were very good and the population had increased over the last 15 years (Henny and Kaiser, 1996). Ten Osprey eggs were collected along the Willamette River in 1993, although no eggs were collected from nests below Willamette Falls. Ten additional eggs were collected in 1997 and 1998, including eggs from four different nests below Willamette Falls. Residues of contaminants in Osprey eggs collected in 1993 were generally low with the exception of octachlorodibenzo-p-dioxin (OCDD), which was extremely high in many eggs from Osprey nesting along the Willamette River. Results from the recently collected eggs obtained from nests below Willamette Falls should be available soon. They will also be compared with 30 Osprey eggs collected from the Columbia River in 1997 and 1998. Largescale sucker, mountain whitefish, and carp were also collected in the Willamette River (not below Willamette Falls) in 1993 and a final report is now being prepared. This report will include estimates of biomagnification factors (fish to Osprey eggs) for all of the contaminants analyzed.

6.4 Implementation Tasks

This section describes activities that will take place during implementation of the plan to complete the calculation of sediment and tissue guidelines and ensure that they are maintained over time.

6.4.1 Sediment and Tissue Guideline Calculation

Sediment and tissue guidelines will be calculated as the required information becomes available, most likely in the following order:

- Tissue guidelines for human health can be calculated immediately once exposure scenarios have been finalized and up-to-date CSFs and RfDs obtained from IRIS.
- Tissue guidelines for wildlife can be calculated once indicator species have been selected, body weights and ingestion rates identified, and toxicity reference values obtained for the most similar species represented in the literature.
- The development of tissue guidelines for fish will require conducting a literature search for data to supplement ERED data, obtaining and reviewing the original

literature, compiling acceptable data into a spreadsheet, normalizing all data, and calculating the appropriate percentile values for the NOAEL and LOAEL distributions.

- Completion of benthic SQGs requires all existing synoptic sediment chemistry/bioassay data to be obtained, QA'd, and entered into SEDQUAL, hit and no-hit distributions developed for each chemical, development of a spreadsheet or database algorithm to conduct the iterative percentile and error rate calculations, and actual conduct of the calculations themselves. To facilitate this process, electronic data reporting templates will be provided to all entities generating data for Portland Harbor that will allow direct transfer of new data into SEDQUAL. Existing data will be entered by hand. Preliminary guidelines will be calculated using all existing data (including studies in progress), and any remaining data gaps will be filled as part of the Harbor-wide and site-specific investigations. Guidelines will be finalized once these additional studies have been completed and quality assured.

Guideline development workgroups will be established to provide peer review and assistance during development of the sediment and tissue guidelines. Workgroups will provide input at key points in the process, including selection of endpoints and interpretation criteria, quality assurance and finalization of the data set, calculation and statistical methods, and sensitivity analysis.

In each case, a technical background report will be prepared documenting the source of all data used and detailing the procedures used in calculating the criteria. All spreadsheet and database algorithms developed will be provided to DEQ as part of the SEDQUAL deliverable or as companion spreadsheets. Sufficient documentation and automated calculation tools will be provided to allow agency staff to update the criteria as more data become available.

6.4.1.1 Periodic Guideline Re-calculation

While the methods described above represent the current state of the science with respect to guideline calculation, in some cases, the data will be less complete than might be wished. As additional data become available, including updates to human health and wildlife toxicity values, tissue-residue effects data, and synoptic chemistry/bioassay data, the guidelines should be updated to reflect this more recent information. The guidelines should be reviewed and updates conducted as appropriate no less frequently than every five years.

6.4.1.2 Columbia River DMEF SL/ML/BT Updates

Currently, marine AETs are being used to set SL and ML values in the Columbia River Dredged Material Evaluation Framework. In addition, the current bioaccumulation triggers (BTs) are based on fractions of the AETs, and are not based on the types of bioaccumulation endpoints and data developed in this plan. The CSMP agencies that participated in developing the DMEF are aware of and participating in reviewing the criteria developed under this plan, and it is the intention of the agencies that the DMEF and the Portland Harbor cleanup process remain compatible and consistent. With that in mind, once freshwater criteria for benthic toxicity are

calculated, the marine AETs in the DMEF could be replaced with the equivalent freshwater guidelines, and the BTs could be updated with values that are back-calculated from the TTLs and TSCs developed in this plan. Any such changes would need to be coordinated with the CSMP agencies through the annual review process. The CSMP agencies are planning a review of the existing BTs in 1999, and the development of bioaccumulative guidelines under this plan will continue to coordinate with that effort to ensure consistency between the cleanup and dredging programs.

7.0 DATABASE DEVELOPMENT

A sediment quality database will be developed to support the implementation of the PHSMP, specifically to:

- Provide a single centralized repository for sediment chemistry, bioassay, benthic, and tissue chemistry data
- Provide a user-friendly interface for database queries and generation of reports
- Allow the data to be viewed and displayed in a GIS-compatible format, along with other GIS data layers
- Conduct data manipulations, such as TOC- and lipid-normalization, comparison to sediment and tissue guidelines, calculation of exceedance factors, and calculation of area-weighted averages
- Support calculation of sediment and tissue guidelines, including hit/no-hit calculations, development of data distributions, statistical comparison, and error rate calculations.

Various existing database formats were reviewed to identify the approach that would best support these goals, and modification of Ecology's SEDQUAL database was selected as the most appropriate and cost-effect alternative. An overview of SEDQUAL is provided below, along with modifications anticipated to be needed to support the PHSMP.

7.1 SEDQUAL Overview

SEDQUAL was originally developed under contract to the Washington State Department of Ecology by PTI Environmental Services in 1989. The system was designed to support development and implementation of Washington State's Sediment Management Standards (Chapter 173-204 WAC), including data storage, development of numeric sediment quality standards, and data analysis tasks supporting the assessment and remediation of marine and freshwater sediments.

In 1995, Ecology initiated a SEDQUAL redevelopment project to address a number of operations issues including licensing, application maintenance, distribution, geographic information system (GIS) integration, and enhancements to sediment source control and cleanup support functions. In June 1998, Ecology introduced SEDQUAL Release 2, an integrated sediment quality information system comprised of a database component, an interface component and a GIS component.

SEDQUAL is designed to be used by scientists and environmental decision makers for performing specific chemical and biological sediment quality characterization analyses. Impact area identification and regulatory criteria development are the primary sediment management functions the system was designed to support.

7.1.1 Data Entry and Retrieval

SEDQUAL's database interface provides several forms for data browsing, searching for specific records and selection of multiple records. These tools provide a familiar way to select user-specified subsets of data without an extensive knowledge of the underlying structure of the database. Many forms provide the ability to save results as a Microsoft Excel or comma-delimited ASCII protocol variable-length text files. Users can also optionally choose to save a delimited list of just the stations associated with a retrieval result.

7.1.1.1 Predefined Reports

SEDQUAL provides a number of predefined reports for common data retrieval tasks. Examples of these reports are listed below:

- Inventory report – data type sample count by survey (see Table G-16 for example)
- Inventory report – bioassay test type by survey (see Table G-17 for example)
- Summary report – chemical detection frequency by station and sample
- Summary report – chemistry, species abundance and bioassay results by station and sample

7.1.1.2 Query Interfaces

The interface used to select record subsets from the database is displayed by clicking the Query/Report tab on the main system window. Users can interactively specify which *tables* they are interested in retrieving data from, which *fields* they wish to have displayed in the result and what *selection criteria* they wish to have applied to their retrieval. Query definitions can be saved and reused during subsequent SEDQUAL sessions. Two query approaches are available:

- **Query tool** - This is the primary data selection interface. It is designed to provide easy access to all environmental data without requiring an understanding of the underlying structural hierarchy. The query tool result form supports a menu function entitled "View Stations in ArcView", which allows users to view their data superimposed on a map or photo of the study area. This is a key GIS integration feature of the system.
- **Query wizard** - This is a secondary data selection interface designed to support more explicit user-specified selection criteria. Use of this interface requires a greater awareness of the underlying structural hierarchy and data relationships but supports greater flexibility for definition of complex data retrievals.

7.1.1.3 Browser Interface

The interface to browse or view data is displayed by clicking the Contents tab on the main system window. Users can easily scroll through record groups, view relationships, and search for specific records. For example, users can quickly obtain the following types of information:

- Surveys and their associated stations
- Samples and their associated environmental test results, including sediment

chemistry, benthic infauna, bioassay results, and tissue data
- Bioassay test results and their associated reference and control records
- Reference and bibliographic information associated with a survey

7.1.2 Data Entry and Handling

If SEDQUAL is started using the "datawriter" user account specified in the configuration file, sedqual.ini, the data entry and editing interface objects are enabled.

7.1.2.1 Single Record Interactive Editing Using the Browser Interface

The user can navigate to any desired database record. Clicking the Edit button begins editing the current record. The value of any selected field can now be entered from the keyboard. Clicking the Save button ends an editing session. The current record can be removed from the file by clicking the Delete button. Similarly, a new empty record is inserted into the file by clicking the Add button. The system applies data integrity and validation rules to the newly entered data prior to saving the record to the file. These same rules are enforced during the batch data entry process.

7.1.2.2 Batch Import Multiple Records

This important system feature ensures data integrity and facilitates entry of large volumes of data in an efficient and controlled manner. Data is loaded into SEDQUAL using a comma-delimited ASCII protocol variable-length text file for each system data type: survey, station, sediment sample, trawl sample, sediment trap sample, sediment chemistry data, bioassay data, bioassay control data, infauna abundance data, trawl abundance data, tissue data, bioaccumulation data, and histopathology data. A record which fails to pass any of numerous data validation and integrity tests is written to a user-specified exception file along with the rejection error. In this manner, large volumes of data can be processed without interruption while problem data are identified and saved for further processing. Examples of data integrity tests include:

- **Taxonomic identification system -** This test is used to identify the specified phylum, class, family, genus, and species of a bioassay or infaunal organism. The current identification method is an extension of the NODC system developed by NOAA. An anticipated future modification of this function will be to incorporate the Integrated Taxonomic Information System (ITIS) developed by a partnership of federal agencies, which can be found at http://www.itis.usda.gov/plantproj/itis/itispage.html.
- **Chemical identification system -** This test is used to identify the specified analyte for a sediment chemical data record. Various types of identifiers can be evaluated for this field; the function will accept a SEDQUAL chemical code value, the entire scientific chemical name, or the Chemical Abstract Service (CAS) code value.

7.1.3 Environmental Statistical Analysis

7.1.3.1 Chemical Hit Identification

This function compares selected chemical data with specified sediment quality guidelines and calculates a ratio of these two items referred to as the *exceedence factor*. Two additional processes may take place prior to this comparison:

- **Data normalization -** TOC normalization is the process of dividing (normalizing) the concentration of a chemical by the amount of total organic carbon present in a sample (Michelsen 1992). Data can also be normalized to other values, e.g., lipid-normalization.
- **Significant digits -** The significant figures field in the chemistry table represents the precision of the test method. Zeros reported in a measurement can be a meaningful part of the result and should not be arbitrarily ignored. Under-reporting of significant digits has a substantial effect on the results of calculations performed by SEDQUAL. SEDQUAL truncates the non-significant digits of averaged numbers. If the precision is not known, two significant figures for organics and three for metals are assumed.

7.1.3.2 Bioassay Hit Identification

SEDQUAL performs statistical comparisons among test, reference, and control stations to identify stations exhibiting adverse effects. This is a key first step in calculating sediment quality guidelines and in identifying areas that may require cleanup or source control. Test data may be compared to either reference data or control data. Records are distinguished as reference/control data or test data by the sample use code. Statistical and data analysis features include:

- Wilks-Shapiro test for normality
- Levene's test for equality of variances
- Student's t-test, approximate t-test, Mann-Whitney, and rankits
- User-specified reference station when a survey has more than one reference
- Comparison of reference or control data to numeric performance standards
- Optional use of negative control instead of reference if a survey has no reference stations or reference stations fail performance standards

7.1.3.3 Station Similarity Index

The similarity index (SIMI) is a tool used to group stations into discrete cleanup sites within a large area such as a watershed or harbor, where contamination from different sites may overlap and chemical fingerprinting is needed to differentiate among sources. The similarity index represents the rank order of detected chemicals and their exceedance factors between pairs of spatially adjacent stations (see below). Two stations will be assessed as perfectly similar by SIMI only if all of the chemicals exceeding the sediment quality guidelines do so at both stations, and the rank order of the exceedance factors at both stations is the same. Values of SIMI are calculated as shown below, and range from 0-1.0, where 1.0 indicates perfect similarity. A distance modifier may be applied to give greater weight to nearby stations.

$$SIMI = \frac{\sum_{i=1}^{C_{AB}} \left[2.0 - \frac{|R_{Ai} - R_{Bi}|}{\left(\frac{R_{Ai} + R_{Bi}}{2} \right)} \right]}{C_{AB}}$$

Where: SIMI = Similarity index
A,B = Adjacent stations
C_{AB} = The number of chemicals that exceed the SQG at both Stations A and B
R_{Ai} = The proportional rank of chemical i at Station A
R_{Bi} = The proportional rank of chemical i at Station B

7.1.3.4 Derived Summary Values

Some chemical names used by SEDQUAL are actually calculated summary values of groups of chemicals, congeners, or isomers. The chemical summary values currently supported by SEDQUAL include LPAHs, HPAHs, total PCBs, total benzofluoranthenes, and grain size percentages.

7.1.3.5 Chemical Detection Frequency

Detection frequency can be calculated for a single chemical or for an entire chemical group. Surveys, stations, and date ranges may be specified for this calculation.

7.1.3.6 Calculate Sediment Quality Guidelines

The database supports the following steps in calculating AETs or other similar criteria, such as the SQGs that are proposed for Portland Harbor:

- Identify stations showing adverse effects and no adverse effects
- Develop chemical distributions for hit and no-hit stations
- Identify AET values
- Sensitivity and efficiency calculations

The interface supports two types of sensitivity and efficiency calculation: sensitivity and efficiency, and sensitivity and efficiency from an SQG group, an SQG hit file, or list of stations. The purpose of the first type of calculation is to determine how dependent the SQG value is on individual samples that could be outliers to the distribution.

7.1.4 Geographic Information Systems Integration

7.1.4.1 Data Integration

The GIS component of the system is provided by a customized ArcView extension. GIS data distributed with Ecology's version of SEDQUAL include: sediment station point locations, sediment cleanup site areas, Washington State rivers, Washington State lakes, Washington State marine water, and Washington State land. One of the key benefits of GIS integration is the ability to display other GIS data in relation to sediment quality data. Examples include:

- Ownership parcel boundaries
- Discharge points, outfalls and diffuser locations
- Sensitive natural resource areas
- Geo-rectified orthophotography images

The standard projection method used by Ecology is Washington State Plane Zone 5626 (U.S. Geological Survey), North American Datum of 1927 (NAD27) with units of feet.

7.1.4.2 Spatial Analysis

GIS provides powerful and efficient analytical tools which provide an ability to calculate and display relationships between sediment quality data and the physical environment. Three types of GIS data specific to sediment quality characterization that are developed and maintained using various aspects of SEDQUAL are:

- **Sample collection location points (point topology) -** Sediment sample location points are created using a query result containing latitude and longitude coordinates associated with the SEDQUAL stations. The SEDQUAL ArcView extension provides tools to create and maintain this GIS data layer. This is a key data file which is integral to the GIS integration features of the information system.
- **Contaminated sediment impact areas (contours and polygon topology) -** Tools to view the geographic location associated with analysis results and to query the database using selected stations are provided by SEDQUAL's ArcView extension. The software tools required to perform surface analysis are provided by the commercial ArcView extension *Spatial Analyst*, published by E.S.R.I. Surface data modeling techniques can be applied using empirical sediment measurements to estimate a two-dimensional representation of the data. Bathymetric soundings, currents and sediment chemical concentrations can each be expressed as discrete data points, linear gradient contours or extrapolated two-dimensional surfaces, sometimes referred to as grids. Surface methods used to estimate contaminated sediment impact areas include inverse distance weighted grid and triangulated irregular network.
- **Adjacent station similarity index (line topology) -** The chemical similarity analysis function is dependent upon a data file containing an adjacency listing for all station pairs within a specified station group. The station pairs file is produced by an Arc Macro Language (AML) program running the triangulated irregular network surface analysis method provided by E.S.R.I.'s ArcInfo GIS utility. This file is one required argument for calculating the chemical similarity index. A GIS data layer is then

developed that visually describes the chemical similarity index between adjacent station pairs. Arcs drawn between sample collection points are color shaded based on a gradient representing the similarity index value calculated for the pair of points.

7.1.4.3 Spatial Display

The SEDQUAL ArcView extension provides the user with a "view template" designed for display on a desktop personal computer. This sediment quality data "view" contains all of the elements necessary to perform database queries and display analysis results on a map or aerial photograph. The tool is designed for use as a "starter template" for the numerous analysis and display tasks required during site characterization. Some benefits provided by using ArcView to display sediment quality analysis results include:

- Ability to "zoom" or interactively change the display to a closer or farther visual perspective. This is a key advantage over paper maps which use the less effective technique of insets to provide the user a spatial orientation regarding the map extent.
- Extent-dependent feature display – some GIS data are so densely populated that it is inappropriate to display the feature when the map extent is large or "far away". As the map extent is "moved closer", densely populated features become enabled by the interface for display.
- Paper map cartographic features - The SEDQUAL ArcView extension provides the user with a "map template" designed for production of paper maps. This template contains all of the basic cartographic elements necessary to display sediment quality data and analysis results. Features include scale bar, north arrow indicator, map title, map legend, logo graphic and other descriptive labels.

7.1.4.4 Temporal Analysis

Using impact area characterization techniques described above and mitigation and remediation tracking attributes in the database, analysts can evaluate changes in the environment over time based on events such as dredging or capping.

7.1.5 Utility Functions

Maintenance tasks must be performed on a periodic basis to maintain integrity and facilitate the flow of data into and out of the system.

- **Export Selected Data into SEDQUAL Data Templates** - This tool is used to write user specified data sets into SEDQUAL data template format files. This is useful for transporting data sets between various SEDQUAL data files.
- **Set Survey Begin and End Dates** - This can be thought of as a synchronization tool. The survey begin and end dates are automatically calculated based on the minimum and maximum sample collection dates associated with that survey.
- **Group Definition Interface** - SEDQUAL supports the use of the following groups

during comparisons, queries, detection frequency analysis, and SQG calculation: station groups, chemical groups, sediment quality guideline groups.

- **Lookup Tables** - About 40 forms list each system code along with its descriptive information. These reference forms can be extremely useful to new users as they examine analysis results, develop queries and perform data entry.

7.1.6 Database Administration

At periodic intervals, usually driven by data entry or analysis events, the system administrator must perform many of the following tasks to maintain the integrity of the system:

- Backup the transaction file SEDQUAL.MDB
- Backup the administrative file SEDQUAL.MDW
- Compact the transaction file SEDQUAL.MDB using Microsoft Access utility
- Calculate derived summary values

7.1.6.1 GIS Integration Key Synchronization

The master stations administrative query is used to run a predefined query to build a comma delimited file of all valid station point coordinates in the system. This file is used by the SEDQUAL extension's *make points* tool to create the station points ArcView shape file. This is a primary data file used to support the GIS integration features of the information system.

7.1.6.2 Initialization and Configuration File – SEDQUAL.INI

This file is designed to be edited by system operators. The path location of the active transaction data file and the active system administrative file is specified here. The configuration file can be used to switch between various copies of the SEDQUAL transaction file. SEDQUAL will prompt users to login at startup unless a user id is specified in the configuration file. SEDQUAL is configured to recognize the following system users:

- User ID = guest read only access
- User ID = datawriter write access, administration functions
- User ID = admin developer acces

7.1.6.3 Year 2000 Compliance

SEQUAL processes dates in a MM/DD/YYYY format, and for this reason, Year 2000 compliance problems are not anticipated. SEDQUAL is currently undergoing Year 2000 certification, which should be completed by April, 1999.

7.2 Implementation of the Database for Portland Harbor

7.2.1 Database Modifications

The following modifications will be made to Ecology's version of SEDQUAL for use by DEQ in Portland Harbor and other areas of the state.

- **Remove selected sets of existing data.** SEDQUAL is populated with data representing a broad range of sediment sampling events and sponsoring organizations. Significant amounts of data were collected from geographically diverse locations, including the entire east coast of the United States, through the Gulf of Mexico, continuing up the southern coast of California north to southern Alaska. The Washington coast and Puget Sound have the greatest sampling density. In addition to over 7000 data points that fully support GIS integration tools, more than 600 stations represent historic data which are high quality and usable for analysis functions such as development of sediment quality guidelines, but do not have spatial values representing their geographic location. Depending on how DEQ plans to use SEDQUAL, data sets outside of western Oregon and Washington can be removed to reduce file sizes, or can be retained in the database but not used for Portland Harbor applications.
- **Modify AET elements to reflect Sediment Quality Guideline approach.** Some programming and design work would be required to support the SQG analysis approach proposed for Portland Harbor. Many of the initial steps described above are the same, including defining biological hits and developing hit and no-hit distributions for the chemicals of interest. An analysis tool will be developed that allows selection of specific percentiles of the data distributions as well as an iterative solution that selects a percentile based on minimization of error rates.
- **Add Portland Harbor data.** Most new study area sediment characterization projects begin with a carefully controlled data collection process. This can include new sampling events or an inventory of historic sampling which has occurred within the boundaries of the study area. Historic data for Portland Harbor will be obtained, reviewed, QA'd, and entered into the database. In addition, recent synoptic chemistry/bioassay data sets from western Washington will be collected and entered into the database by Ecology's contractor, SAIC, and made available to this effort. Newly collected data from ongoing and planned Portland Harbor studies should be provided in electronic format using SEDQUAL data entry templates.
- **Build station groups.** Default station groups will be defined for the Portland Harbor project. These groups define collections of stations which are all located within a common geographic sub-area such as drainage basin, water body, ownership boundary or land use/land cover. Use of station groups significantly increases query and analysis speed because the number of records the system needs to process is limited and predefined. Stations groups will likely be defined at three spatial levels – one that includes all data used to develop sediment quality guidelines, one that includes all data within the geographic focus area (Willamette Falls to mouth of the Willamette), and additional groups that represent individual cleanup sites within Portland Harbor.
- **Build chemical groups.** Default chemical groups will also be identified. These

groups define collections of chemicals which share a common element or theme. Examples include chemical classes such as metals, organics, or PAHs; or groups of regulatory interest, such as contaminants of interest (COIs) or contaminants of potential concern (COPCs). Use of chemical groups significantly increases query and analysis speed because the number of chemical records the system needs to process is limited.

- **Build guideline groups.** Default sediment and tissue quality guideline groups will be defined once SQGs, TSCs, and TTLs have been developed for Portland Harbor. These groups define collections of regulatory chemical concentration values which share a common element. Examples of existing guideline groups include the 1991 Washington State Sediment Quality Standards & Cleanup Screening Levels (WAC 173-204, Tables I, III) and Columbia River DMEF Screening Levels and Maximum Levels. Typical usage includes definition of new SQG groups.
- **Add bioassay type and endpoint definitions.** Some of the bioassays being proposed for the Portland Harbor project are new to the region and may require the addition of new bioassay type codes and endpoint codes, which are easily added to the database. All of the acute bioassays currently in use are already supported by the database, but chronic freshwater bioassays have not yet been used in the region and are therefore not defined in the system.
- **System installation.** SEDQUAL can be installed to run from the distribution CDROM. This is the slowest way to operate SEDQUAL and the data files cannot be edited. This option requires the least amount of disk space. The second supported method installs SEDQUAL to a user-specified location on a local PC workstation's hard disk. This is the default install mode. This option operates SEDQUAL the most efficiently because all disk access is on the local computer. The last installation option installs SEDQUAL for use on a network where many users share a common data file located on a file server. The benefit of this option is that as data entry and maintenance transactions occur, all users have immediate access to the latest changes. Features such as automated backup processing can also be a benefit of operating on a network. Staffing, organization and other operation considerations may require the definition of additional user accounts and/or user groups each with varying degrees of access and administrative privileges to the system.

7.2.2 GIS Modifications

The system will be configured to use a different maximum geographic extent. The extent definition could encompass all of Oregon or just the western half. The extent could also include an area of southwest Washington. It is the largest physical geographic area within which the sediment spatial analysis will be applied. The system should also be configured to use a standard projection method which is appropriate for the maximum geographic extent determined above.

- **Develop ArcView shape files for land and water areas using the defined system extent and projection.** Very often the data used to delineate the land area is the same

underlying data used to delineate the water area. Care should be taken to select the highest available resolution available. 1:24,000 scale is the minimum acceptable resolution. The line of separation between land and water areas, the shoreline, must also be defined. In coastal areas, the mean high tide water line is often used. Other essential GIS data layers which must be similarly developed are:

- ❑ ArcView shape file for lakes using the system extent and projection
- ❑ ArcView shape file for rivers using the system extent and projection

Many other types of geographic data can be incorporated into the SEDQUAL GIS project. This is, of course, one of the fundamental benefits of using GIS to examine sediment quality in the natural environment. Other useful GIS data layers include:

- ❑ Bathymetry represented as point data
- ❑ Geo-rectified orthophotography of the shoreline or urban bays can be procured from a variety of private and government organizations
- ❑ Natural resource inventories
- ❑ Endangered and sensitive habitat and species
- ❑ Ownership boundaries
- ❑ Discharge and outfall locations, diffuser locations

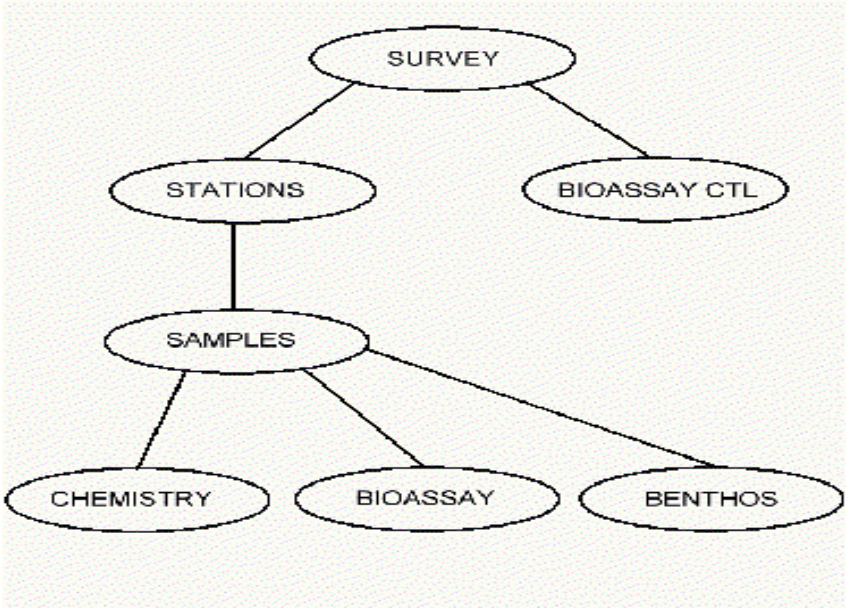
- **The SEDQUAL ArcView extension <u>Make Points</u> feature must be modified to incorporate the selected projection method.** At periodic intervals, often driven by data entry events, a system administrator uses this tool to create an ArcView shape file representing sediment sample station location points. This is a key data file which is integral to the GIS integration features of the information system.

7.2.3 Importing Data from Other Environmental Databases

7.2.3.1 Data Selection

If the objective of the data collection project is to support sediment quality criteria development, data quality assurance parameters will help define which data are appropriate to include in the study. If the objective of the data collection project is to support a general chemical characterization within a specific study area then sample collection location may drive the selection of data to be imported. In every case, however, the data will have to conform to the basic underlying relational model. Fortunately, most sediment sampling data the user may wish to import should be easy to represent using this model.

Figure G-8: SEDQUAL's Fundamental Structural Hierarchy



7.2.3.2 Data Organization

When organizing the selected data for use by SEDQUAL, the user should adopt a hierarchical approach as dictated by the structural model of the database. To assist with organization of the data, review the data elements, particularly the required data elements, specified in each of SEDQUAL's batch electronic data entry templates. For example, the Survey template will help identify the minimum required information that will need to be selected for export from the source environmental information system in order to define a new survey record in SEDQUAL.

7.2.3.3 Import File Format Support

SEDQUAL performs a number of data integrity and data validation procedures designed to assure the structural relationship of the data and to enforce constraints on the field values. In support of these features, SEDQUAL is designed to import data from a standard ASCII comma-delimited variable-length text file representing each data type depicted in the structural model figure above. Alternatively, SEDQUAL data entry templates (Excel spreadsheets) can be used to expedite importation of newly acquired data.

7.2.4 Exporting Data for Use by Other Software

- **Export file formats currently supported by SEDQUAL.** Query and analysis results are formatted as ASCII protocol comma-delimited variable-length text files. This standard data file format can be imported by a wide range of application software and operating systems. In addition, some result forms have an export option supporting Microsoft Excel file format. ArcView GIS products can be exported as Windows bitmap file format, JPEG graphics file format, Windows Meta-file format, Adobe Illustrator, Encapsulated Postscript and others.
- **Exporting data to LASAR.** LASAR is DEQ's newly developed centralized database, supported by DEQ's laboratory. LASAR currently supports some, but not all, of the data types being used for sediment data analysis. It is anticipated that LASAR will eventually support all data types included in SEDQUAL, and at that time, the two databases could be integrated. Once a complete set of project data for the Portland Harbor region has been collected, data will be exported from SEDQUAL in ASCII comma-delimited format for input into LASAR, to ensure that all data are available in the centralized system.
- **Exporting data to STORET.** One method for users to provide data to EPA is by populating an "empty" copy of the locally installed database using Oracle 7 software and SQL. Another method is via direct terminal access after establishing an organizational relationship with EPA and obtaining account access. In either case, to facilitate iterative data upload events, automated routines can be developed using SQL to append records read from SEDQUAL's exported text files into STORET's Oracle tables. There are many tools and methods available to achieve this task if it is a priority for DEQ.
- **Exporting data to the NOAA system.** Data will be transferred between the NOAA database and SEDQUAL using standard ARCINFO file formats (for GIS data layers) and ASCII comma-delimited files or Excel spreadsheets (for database files).

7.3 Data Quality Assurance

Data quality objectives are statements about what you expect to use the data for, and what quality the data need to be to allow that use. There are many elements comprising data QA including: completeness, accuracy, precision, confidence intervals, control limits, detection limits, holding times, chain of custody and calibration limits. Three levels of data quality are generally recognized: screening level, regulatory decision-making (QA1), and rule-making/litigation (QA2) (PTI, 1989a,b). Credible and scientifically defensible environmental analysis results from greater control over data quality and assurance. Uncertainty associated with analysis results can be directly correlated with confidence in the underlying data quality. Collection of data using consistent sampling and analysis protocols, as defined in this Plan, is important. All data used in the development of sediment quality guidelines will be subjected to QA2-level quality assurance, as described in PTI (1989b). QA1 level quality assurance is generally considered sufficient for day-to-day data entry and use in a regulatory context, but must be upgraded to QA2 if the

additional data is used to update regulatory guidelines in the future.

7.4 User Support

7.4.1 SEDQUAL Users Group

A contact list of system recipients is maintained by Ecology. Periodic notification of system updates, technical notes and training opportunities are distributed by electronic mail.

7.4.2 Telephone Support

Telephone technical support is provided by Ecology during regular business hours. Contact information is listed on SEDQUAL's main interface window about menu.

7.4.3 SEDQUAL Technical References

- **User documentation.** This technical reference describes many aspects of operating SEDQUAL and navigating the user interface. The utility is a collection of hypertext documents which are accessed using a standard internet browser such as Microsoft's Internet Explorer or Netscape Navigator. Use a browser to open the file named "index.htm" located in the "docs" subdirectory under the SEDQUAL installation directory.
- **System technical documentation.** This technical reference describes many of the structural components, algorithms and other programming documentation notes used to develop SEDQUAL. The utility is a collection of hypertext documents which are accessed using a standard internet browser such as Microsoft's Internet Explorer or Netscape's Navigator. Use a browser to open the file named "index.htm" located in the "codedocs" subdirectory under the SEDQUAL installation directory. This directory also contains a data dictionary document and an entity/relationship diagram for the system.
- **On-line help.** Some fundamental operations documentation is available within the SEDQUAL interface by selecting the help menu item from SEDQUAL's main window. SEDQUAL's release version and other useful information is displayed when the about item is selected under this menu.
- **Batch data entry template help tools.** This technical reference describes how to use SEDQUAL's batch data entry templates. The utility is a collection of hypertext documents which are accessed using a standard internet browser such as Microsoft's Internet Explorer or Netscape's Navigator. The tool displays lookup tables for easy reference when populating code values during data entry. Use a browser to open the file named "index.htm" located in the "docs" subdirectory under the SEDQUAL installation directory. There are also a number of descriptive "read me" files located within various data entry template subdirectories.

7.4.4 Training

Significant effort went into design of the interface and GIS integration features to assure the system was as "self-documenting" and easy to understand and navigate as possible. However, the broad range of scientific disciplines and complex nature of the application often require training in order to become proficient at performing sediment quality analysis. An ideal training scenario would include a comprehensive site characterization project conducted over an extended period. Activities would include data collection, quality assurance review, data configuration and entry, sediment and GIS analysis, study area characterization and display.

A 2-day training session will be presented in Portland for agency staff and other users once the database has been configured for use on the Portland Harbor project. The workshop will include the following elements:

- Day One
  - System administration
  - Data entry and quality assurance
  - Data import and export tools
  - Sediment quality guideline development tools and methods
- Day Two
  - Query tools and data retrieval
  - Bioassay analysis tools and methods
  - Impact area identification tools and methods
  - GIS integration, sediment quality analysis, and display

Day One is intended for high-level users and administrators of the database, who need access to and training on system tools and complex analytical functions. Day Two is intended for more casual users of the database who primarily want to perform data queries and use data presentation and analysis tools to support site-specific decision-making.

Table G - 16: SEDQUAL Data Type Sample Count By Survey

Survey	Total	Chemistry	Bioassay	Benthic	Bioaccumulation
HYLE9496	517	380	137	0	0
ROBERT74	377	377	0	0	0
KEYPORT	313	215	0	0	49
EBCHEM	233	107	106	20	0
CBMS_BPS	222	0	0	0	111
BIOEFF97	205	105	100	0	0
EHCHEM94	189	189	0	0	0
SITCUMRI	182	97	85	0	0
EIGHTBAY	176	128	48	0	0
PSAMP91	172	61	63	48	0
PSDDA1	168	91	16	9	26
CBMSQS	167	115	52	0	0
PSAMP90	166	50	66	50	0
SCLAIR94	161	47	0	0	57
WHATRI96	160	133	27	0	0
DOHSFISH	152	0	0	0	76
PSAMP89	150	50	50	50	0
HIRIPH2	135	135	0	0	0
KEYPRT92	135	135	0	0	0
NOAA84	135	135	0	0	0
CASCADRI	130	122	2	0	3
LANDOLT1	128	0	0	0	64
DUDI9496	118	111	7	0	0
SED18804	113	75	12	0	13
MBCREOS1	112	61	51	0	0
EVCHEM	111	60	32	19	0
AR-94-02	108	108	0	0	0

Table G - 17: SEDQUAL Bioassay Data Types By Survey

		FRESH WATER TEST TYPES											
Survey	**TOTAL**	**CDD10**	**CERIO**	**CHIRM**	**CHR10**	**DAP02**	**DAPP2**	**HEX10**	**HYA04**	**HYA07**	**HYA10**	**HYA14**	**MICTX**
SITCUMRI	128	0	0	0	0	0	0	0	0	0	0	0	0
PIER_D91	120	0	0	0	0	0	0	0	0	0	0	0	30
PGHO&M96	54	0	0	0	0	0	0	0	0	0	0	0	15
CBMSQS	52	0	0	0	0	0	0	0	0	0	0	0	0
MBCREOS1	***51***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***51***	***0***	***0***
EVRNCD96	50	0	0	0	0	0	0	0	0	0	0	0	0
EIGHTBAY	48	0	0	0	0	0	0	0	0	0	0	0	0
MILLCRP2	***38***	***0***	***0***	***19***	***0***	***0***	***0***	***0***	***0***	***0***	***19***	***0***	***0***
EVCHEM	32	0	0	0	0	0	0	0	0	0	0	0	0
EVRT12TH	27	0	0	0	0	0	0	0	0	0	0	0	7
OLYHAR88	27	0	0	0	0	0	0	0	0	0	0	0	0
WHATRI96	***27***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
LWRCOLUM	***24***	***0***	***0***	***0***	***0***	***12***	***0***	***0***	***12***	***0***	***0***	***0***	***0***
USOILVLF	24	0	0	0	0	0	0	0	0	0	0	0	0
DUDI9496	21	0	0	0	0	0	0	0	0	0	0	0	0
CBSLOUGH	***20***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***20***	***0***	***0***
QUEBAX2	**20**	**0**	**4**	**4**	**0**	**4**	**0**	**4**	**0**	**0**	**0**	**4**	**0**
STEILLK2	**20**	**0**	**4**	**4**	**0**	**4**	**0**	**4**	**0**	**0**	**4**	**0**	**0**
DUWO&M90	19	0	0	0	0	0	0	0	0	0	0	0	5
PIERD293	19	0	0	0	0	0	0	0	0	0	0	0	0
BREMTP98	18	0	0	0	0	0	0	0	0	0	0	0	0

ITALIC = Lotic stations **BOLD** = Lentic stations

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ATTACHMENT A

Table G - 18: Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Sediments

Chemical Parameter	Preparation Method[a]	Cleanup Method[b]	Analytical Method[c]
CONVENTIONALS			
Total Organic Carbon	--[e]	--	9060
Grain Size	--[e]	--	Plumb (1981)
Total Solids	--[e]	--	PSEP
Total Sulfides	AVS SEM	--	Plumb (1981)/9030
Ammonia	--[e]	--	Plumb (1981)
METALS			
Priority Pollutant Metals			
Antimony	3050	--	6020/6010/7041
Arsenic	3050	--	6020/6010/7061
Cadmium	3050/AVS SEM	--	6020/6010/7131
Chromium	3050	--	6020/6010/7191
Copper	3050/AVS SEM	--	6020/6010
Lead	3050	--	6020/6010/7421
Mercury	AVS SEM/ --[d]	--	7471
Nickel	3050/AVS SEM	--	6020/6010
Silver	3050	--	6020/6010
Zinc	3050/AVS SEM	--	6020/6010
Ancillary Metals			
Aluminum	3050	--	6020/6010
Barium	3050	--	6020/6010
Calcium	3050	--	6020/6010
Cobalt	3050	--	6020/6010
Iron	3050	--	6020/6010
Magnesium	3050	--	6020/6010
Manganese	3050	--	6020/6010
Potassium	3050	--	6020/6010
Sodium	3050	--	6020/6010
Vanadium	3050	--	6020/6010
SEMIVOLATILE ORGANICS			
Phenols			
2,4-Dimethylphenol	3540/3550	3640/3660	8270/GC MS SIM
2-Methylphenol	3540/3550	3640/3660	8270/GC MS SIM
4-Methylphenol	3540/3550	3640/3660	8270/GC MS SIM
Phenol	3540/3550	3640/3660	8270/GC MS SIM
Chlorinated and Nitro-substituted Phenols			
4-Chloro-3-methylphenol	3540/3550	3640/3660	8270/GC MS SIM
2-Chlorophenol	3540/3550	3640/3660	8270/GC MS SIM
2,4-Dichlorophenol	3540/3550	3640/3660	8270/GC MS SIM
4,6-Dinitro-2-methylphenol	3540/3550	3640/3660	8270/GC MS SIM
2,4-Dinitrophenol	3540/3550	3640/3660	8270/GC MS SIM
2-Nitrophenol	3540/3550	3640/3660	8270/GC MS SIM
4-Nitrophenol	3540/3550	3640/3660	8270/GC MS SIM
Pentachlorophenol	3540/3550	3640/3660	8270/GC MS SIM

Table G - 18: Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Sediments

Chemical Parameter	Preparation Method[a]	Cleanup Method[b]	Analytical Method[c]
2,4,5-Trichlorophenol	3540/3550	3640/3660	8270/GC MS SIM
2,4,6-Trichlorophenol	3540/3550	3640/3660	8270/GC MS SIM
Low Molecular Weight PAH			
Acenaphthene	3540/3550	3640/3660	8270/GC MS SIM
Acenaphthylene	3540/3550	3640/3660	8270/GC MS SIM
Anthracene	3540/3550	3640/3660	8270/GC MS SIM
Fluorene	3540/3550	3640/3660	8270/GC MS SIM
2-Methylnaphthalene	3540/3550	3640/3660	8270/GC MS SIM
Naphthalene	3540/3550	3640/3660	8270/GC MS SIM
Phenanthrene	3540/3550	3640/3660	8270/GC MS SIM
High Molecular Weight PAH			
Benzo(*a*)anthracene	3540/3550	3640/3660	8270/GC MS SIM
Benzo(*a*)pyrene	3540/3550	3640/3660	8270/GC MS SIM
Benzo(*b)*fluoranthene	3540/3550	3640/3660	8270/GC MS SIM
Benzo(*g,h,i*)perylene	3540/3550	3640/3660	8270/GC MS SIM
Benzo(*k*)fluoranthene	3540/3550	3640/3660	8270/GC MS SIM
Chrysene	3540/3550	3640/3660	8270/GC MS SIM
Dibenzo(*a,h*)anthracene	3540/3550	3640/3660	8270/GC MS SIM
Fluoranthene	3540/3550	3640/3660	8270/GC MS SIM
Indeno(1,2,3-*c,d*)pyrene	3540/3550	3640/3660	8270/GC MS SIM
Pyrene	3540/3550	3640/3660	8270/GC MS SIM
Chlorinated Aromatic Compounds			
1,2-Dichlorobenzene	3540/3550	3640/3660	8270/8240/GC MS SIM
1,3-Dichlorobenzene	3540/3550	3640/3660	8270/8240/GC MS SIM
1,4-Dichlorobenzene	3540/3550	3640/3660	8270/8240/GC MS SIM
1,2,4-Trichlorobenzene	3540/3550	3640/3660	8270/8240/GC MS SIM
2-Chloronaphthalene	3540/3550	3640/3660	8270/8240/GC MS SIM
Hexachlorobenzene	3540/3550	3640/3660	8270/8240/GC MS SIM
Chlorinated Alkanes/Alkenes			
Hexachloroethane	3540/3550	3640/3660	8270/GC MS SIM
Hexachlorobutadiene	3540/3550	3640/3660	8270/GC MS SIM
Hexachlorocyclopentadiene	3540/3550	3640/3660	8270/GC MS SIM
Phthalate Esters			
bis(2-Ethylhexyl)phthalate	3540/3550	3640/3660	8270/GC MS SIM
Butyl benzyl phthalate	3540/3550	3640/3660	8270/GC MS SIM
di-*n*-Butyl phthalate	3540/3550	3640/3660	8270/GC MS SIM
di-*n*-Octyl phthalate	3540/3550	3640/3660	8270/GC MS SIM
Diethyl phthalate	3540/3550	3640/3660	8270/GC MS SIM
Dimethyl phthalate	3540/3550	3640/3660	8270/GC MS SIM
Miscellaneous Extractable Compounds			
Benzoic acid	3540/3550	3640/3660	8270/GC MS SIM
Benzyl alcohol	3540/3550	3640/3660	8270/GC MS SIM

Table G - 18: Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Sediments

Chemical Parameter	Preparation Method[a]	Cleanup Method[b]	Analytical Method[c]
Dibenzofuran	3540/3550	3640/3660	8270/GC MS SIM
Isophorone	3540/3550	3640/3660	8270/GC MS SIM
Tributyltin	--[e]	--	Krone et al. (1989)
Organonitrogen Compounds			
4-Chloroaniline	3540/3550	3640/3660	8270/GC MS SIM
3,3'-Dichlorobenzidine	3540/3550	3640/3660	8270/GC MS SIM
2,4-Dinitrotoluene	3540/3550	3640/3660	8270/GC MS SIM
2,6-Dinitrotoluene	3540/3550	3640/3660	8270/GC MS SIM
N-nitrosodiphenylamine	3540/3550	3640/3660	8270/GC MS SIM
2-Nitroaniline	3540/3550	3640/3660	8270/GC MS SIM
3-Nitroaniline	3540/3550	3640/3660	8270/GC MS SIM
4-Nitroaniline	3540/3550	3640/3660	8270/GC MS SIM
Nitrobenzene	3540/3550	3640/3660	8270/GC MS SIM
N-nitrosodi-*n*-propylamine	3540/3550	3640/3660	8270/GC MS SIM
Ethers			
4-Bromophenyl-phenyl ether	3540/3550	3640/3660	8270/GC MS SIM
4-Chlorophenyl-phenyl ether	3540/3550	3640/3660	8270/GC MS SIM
Dichloroethyl ether [bis(2-chloroethyl) ether]	3540/3550	3640/3660	8270/GC MS SIM
CHLORINATED PESTICIDES			
Aldrin	3540/3550	3620/2640/3660	8080/8081
alpha-Chlordane	3540/3550	3620/2640/3660	8080/8081
alpha-Endosulfan (Endosulfan I)	3540/3550	3620/2640/3660	8080/8081
alpha-HCH (alpha-hexachlorocyclohexane, alpha-BHC, alpha benzene hexachloride)	3540/3550	3620/2640/3660	8080/8081
beta-Endosulfan (Endosulfan II)	3540/3550	3620/2640/3660	8080/8081
beta-HCH (beta-BCH)	3540/3550	3620/2640/3660	8080/8081
delta-HCH (delta-BHC)	3540/3550	3620/2640/3660	8080/8081
Dieldrin	3540/3550	3620/2640/3660	8080/8081
Endosulfan sulfate	3540/3550	3620/2640/3660	8080/8081
Endrin	3540/3550	3620/2640/3660	8080/8081
Endrin aldehyde	3540/3550	3620/2640/3660	8080/8081
Endrin ketone	3540/3550	3620/2640/3660	8080/8081
gamma-Chlordane	3540/3550	3620/2640/3660	8080/8081
gamma-BHC (Lindane)	3540/3550	3620/2640/3660	8080/8081
Heptachlor	3540/3550	3620/2640/3660	8080/8081
Heptachlor epoxide	3540/3550	3620/2640/3660	8080/8081
Methoxychlor	3540/3550	3620/2640/3660	8080/8081
p,p'-DDD	3540/3550	3620/2640/3660	8080/8081
p,p'-DDE	3540/3550	3620/2640/3660	8080/8081
p,p'-DDT	3540/3550	3620/2640/3660	8080/8081
Toxaphene	3540/3550	3620/2640/3660	8080/8081
PCB CONGENERS			

Table G - 18: Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Sediments

Chemical Parameter	Preparation Method[a]	Cleanup Method[b]	Analytical Method[c]
2,4' diCB	3540/3550	3620/2640/3660	8082
2,2',5 triCB	3540/3550	3620/2640/3660	8082
2,4,4' triCB	3540/3550	3620/2640/3660	8082
3,4,4' triCB	3540/3550	3620/2640/3660	8082
2,2',3,5' tetraCB	3540/3550	3620/2640/3660	8082
2,2',4,5' tetraCB	3540/3550	3620/2640/3660	8082
2,2',5,5' tetraCB	3540/3550	3620/2640/3660	8082
2,3',4,4' tetraCB	3540/3550	3620/2640/3660	8082
2,3',4',5 tetraCB	3540/3550	3620/2640/3660	8082
2,4,4',5 tetraCB	3540/3550	3620/2640/3660	8082
3,3',4,4' tetraCB	3540/3550	3620/2640/3660	8082
3,4,4',5 tetraCB	3540/3550	3620/2640/3660	8082
2,2',3,4,5' pentaCB	3540/3550	3620/2640/3660	8082
2,2',3,4',5 pentaCB	3540/3550	3620/2640/3660	8082
2,2',4,5,5' pentaCB	3540/3550	3620/2640/3660	8082
2,3,3',4,4' pentaCB	3540/3550	3620/2640/3660	8082
2,3,4,4',5 pentaCB	3540/3550	3620/2640/3660	8082
2,3',4,4',5 pentaCB	3540/3550	3620/2640/3660	8082
2,3',4,4',6 pentaCB	3540/3550	3620/2640/3660	8082
2',3,4,4',5 pentaCB	3540/3550	3620/2640/3660	8082
3,3',4,4',5 pentaCB	3540/3550	3620/2640/3660	8082
2',3,3',4,4' hexaCB	3540/3550	3620/2640/3660	8082
2,2',3,4,4',5' hexaCB	3540/3550	3620/2640/3660	8082
2,2',3,5,5',6 hexaCB	3540/3550	3620/2640/3660	8082
2,2',4,4',5,5' hexaCB	3540/3550	3620/2640/3660	8082
2,3,3',4,4',5 hexaCB	3540/3550	3620/2640/3660	8082
2,3,3',4,4',5 hexaCB	3540/3550	3620/2640/3660	8082
2,3,3',4,4',6 hexaCB	3540/3550	3620/2640/3660	8082
2,3',4,4',5,5' hexaCB	3540/3550	3620/2640/3660	8082
2,3',4,4',5',6 hexaCB	3540/3550	3620/2640/3660	8082
3,3',4,4',5,5' hexaCB	3540/3550	3620/2640/3660	8082
2,2',3,3',4,4',5 heptaCB	3540/3550	3620/2640/3660	8082
2,2',3,4,4',5,5' heptaCB	3540/3550	3620/2640/3660	8082
2,2',3,4,4',5',6 heptaCB	3540/3550	3620/2640/3660	8082
2,2',3,4,4',6,6' heptaCB	3540/3550	3620/2640/3660	8082
2,2',3,4',5,5',6 heptaCB	3540/3550	3620/2640/3660	8082
2,3,3',4,4',5,5' heptaCB	3540/3550	3620/2640/3660	8082
2,2',3,3',4,4',5,6 octaCB	3540/3550	3620/2640/3660	8082
2,2',3,3',4,5,5',6 octaCB	3540/3550	3620/2640/3660	8082
2,2',3,3',4,4',5,5',6 nonaCB	3540/3550	3620/2640/3660	8082
2,2',3,3',4,4',5,5',6,6' decaCB	3540/3550	3620/2640/3660	8082
DIOXINS AND FURANS			
2,3,7,8-TCDF	--[e]	--[e]	1613
1,2,3,7,8-PeCDF	--[e]	--[e]	1613
2,3,4,7,8-PeCDF	--[e]	--[e]	1613
1,2,3,4,7,8-HxCDF	--[e]	--[e]	1613
1,2,3,6,7,8-HxCDF	--[e]	--[e]	1613

Table G - 18: Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Sediments

Chemical Parameter	Preparation Method[a]	Cleanup Method[b]	Analytical Method[c]
2,3,4,6,7,8-HxCDF	--[e]	--[e]	1613
1,2,3,4,8,9-HxCDF	--[e]	--[e]	1613
1,2,3,4,6,7,8-HpCDF	--[e]	--[e]	1613
1,2,3,4,7,8,9-HpCDF	--[e]	--[e]	1613
2,3,7,8-TCDD	--[e]	--[e]	1613
1,2,3,7,8-PeCDD	--[e]	--[e]	1613
1,2,3,4,7,8-HxCDD	--[e]	--[e]	1613
1,2,3,6,7,8-HxCDD	--[e]	--[e]	1613
1,2,3,7,8,9-HxCDD	--[e]	--[e]	1613
1,2,3,4,6,7,8-HpCDD	--[e]	--[e]	1613
OCDD	--[e]	--[e]	1613
OCDF	--[e]	--[e]	1613
HERBICIDES			
2,4,5-T	--[e]	--[e]	8151
2,4,5-TP (Silvex)	--[e]	--[e]	8151
2,4-D	--[e]	--[e]	8151
2,4-DB	--[e]	--[e]	8151
Dalapon	--[e]	--[e]	8151
Dicambia	--[e]	--[e]	8151
Dichloroprop	--[e]	--[e]	8151
Dinoseb	--[e]	--[e]	8151
MCPA	--[e]	--[e]	8151
MCPP	--[e]	--[e]	8151

[a] Recommended sample preparation methods are:

- PSEP (1997ab)
- Method 3500 series - sample preparation methods from SW-846 (EPA 1992c) and updates.

[b] Recommended sample cleanup methods are:

- All sample extracts should be subjected to GPC cleanup in accordance with procedures specified by EPA SW-846 Method 3640. Special care should be used during GPC to minimize loss of analytes.
- If sulfur is presented in the samples, cleanup procedures specified by EPA SW-846 Method 3660 should be used.
- All PCB extracts should be subjected to florisil column cleanup as specified by EPA SW-846 Method 3620.
- Additional cleanup procedures may be necessary on a sample-by-sample basis. Alternative cleanup procedures are described in PSEP (1997ab) and EPA (1992c).

[c] Recommended analytical methods are:

- Method 6000, 7000, 8000, and 9000 series - analytical methods from SW-846 (EPA 1992c) and updates.
- Method 1624C/1625C - isotope dilution method (EPA 1992c).
- Plumb (1981) - U.S. EPA/U.S. Army Corps of Engineers Technical Report EPA/CE-81-1.
- PSEP (1997ab).
- AVS SEM - Acid volatile sulfides and simultaneously extracted metals method for sediment (EPA 1991a).
- Tributyltin by Krone et al. (1989, 1995), Muller (1987).
- GC MS SIM.

[d] The sample digestion method for mercury is described in the analytical method (Method 7471, SW-846 [EPA 1992c] and updates).

[e] Sample preparation methods for sediment conventional analyses are described in the analytical methods.

To achieve the recommended detection limits for organic compounds, it may be necessary to use a larger sample size (approximately 100 g), a smaller extract volume for gas chromatography/mass spectrometry analyses (0.5 mL), and one of the recommended sample cleanup methods, as necessary, to reduce interference. For sediment samples with low TOC, it may be necessary to achieve lower detection limits for certain analytes in order to compare the TOC-normalized concentrations with applicable numerical criteria.

Table G-19: Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Tissues

Chemical Parameter	Preparation Method[a]	Cleanup Method[b]	Analytical Method[c]
LIPIDS			Bligh & Dyer (1959)
METALS			
Priority Pollutant Metals			
Antimony	200.3	--	6020/6010/7041
Arsenic	200.3	--	6020/6010/7061
Cadmium	200.3	--	6020/6010/7131
Chromium	200.3	--	6020/6010/7191
Copper	200.3	--	6020/6010
Lead	200.3	--	6020/6010/7421
Mercury	--[d]	--	245.6
Nickel		--	6020/6010
Silver		--	6020/6010
Zinc		--	6020/6010
SEMIVOLATILE ORGANICS			
Phenols			
2,4-Dimethylphenol	3540/3550	3640	8270/GC MS SIM
2-Methylphenol	3540/3550	3640	8270/GC MS SIM
4-Methylphenol	3540/3550	3640	8270/GC MS SIM
Phenol	3540/3550	3640	8270/GC MS SIM
Chlorinated and Nitro-substituted Phenols			
4-Chloro-3-methylphenol	3540/3550	3640	8270/GC MS SIM
2-Chlorophenol	3540/3550	3640	8270/GC MS SIM
2,4-Dichlorophenol	3540/3550	3640	8270/GC MS SIM
4,6-Dinitro-2-methylphenol	3540/3550	3640	8270/GC MS SIM
2,4-Dinitrophenol	3540/3550	3640	8270/GC MS SIM
2-Nitrophenol	3540/3550	3640	8270/GC MS SIM
4-Nitrophenol	3540/3550	3640	8270/GC MS SIM
Pentachlorophenol	3540/3550	3640	8270/GC MS SIM
2,4,5-Trichlorophenol	3540/3550	3640	8270/GC MS SIM
2,4,6-Trichlorophenol	3540/3550	3640	8270/GC MS SIM
Low Molecular Weight PAH			
Acenaphthene	3540/3550	3640	8270/GC MS SIM
Acenaphthylene	3540/3550	3640	8270/GC MS SIM
Anthracene	3540/3550	3640	8270/GC MS SIM
Fluorene	3540/3550	3640	8270/GC MS SIM
2-Methylnaphthalene	3540/3550	3640	8270/GC MS SIM
Naphthalene	3540/3550	3640	8270/GC MS SIM
Phenanthrene	3540/3550	3640	8270/GC MS SIM
High Molecular Weight PAH			
Benzo(*a*)anthracene	3540/3550	3640	8270/GC MS SIM
Benzo(*a*)pyrene	3540/3550	3640	8270/GC MS SIM
Benzo(*b)*fluoranthene	3540/3550	3640	8270/GC MS SIM
Benzo(*g,h,i*)perylene	3540/3550	3640	8270/GC MS SIM
Benzo(*k*)fluoranthene	3540/3550	3640	8270/GC MS SIM
Chrysene	3540/3550	3640	8270/GC MS SIM
Dibenzo(*a,h*)anthracene	3540/3550	3640	8270/GC MS SIM

Table G-19: Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Tissues

Chemical Parameter	Preparation Method[a]	Cleanup Method[b]	Analytical Method[c]
Fluoranthene	3540/3550	3640	8270/GC MS SIM
Indeno(1,2,3-*c*,*d*)pyrene	3540/3550	3640	8270/GC MS SIM
Pyrene	3540/3550	3640	8270/GC MS SIM
Chlorinated Aromatic Compounds			
1,2-Dichlorobenzene	3540/3550	3640	8270/8240/GC MS SIM
1,3-Dichlorobenzene	3540/3550	3640	8270/8240/GC MS SIM
1,4-Dichlorobenzene	3540/3550	3640	8270/8240/GC MS SIM
1,2,4-Trichlorobenzene	3540/3550	3640	8270/8240/GC MS SIM
2-Chloronaphthalene	3540/3550	3640	8270/8240/GC MS SIM
Hexachlorobenzene	3540/3550	3640	8270/8240/GC MS SIM
Chlorinated Alkanes/Alkenes			
Hexachloroethane	3540/3550	3640	8270/GC MS SIM
Hexachlorobutadiene	3540/3550	3640	8270/GC MS SIM
Hexachlorocyclopentadiene	3540/3550	3640	8270/GC MS SIM
Phthalate Esters			
bis(2-Ethylhexyl)phthalate	3540/3550	3640	8270/GC MS SIM
Butyl benzyl phthalate	3540/3550	3640	8270/GC MS SIM
di-*n*-Butyl phthalate	3540/3550	3640	8270/GC MS SIM
di-*n*-Octyl phthalate	3540/3550	3640	8270/GC MS SIM
Diethyl phthalate	3540/3550	3640	8270/GC MS SIM
Dimethyl phthalate	3540/3550	3640	8270/GC MS SIM
Miscellaneous Extractable Compounds			
Benzoic acid	3540/3550	3640	8270/GC MS SIM
Benzyl alcohol	3540/3550	3640	8270/GC MS SIM
Dibenzofuran	3540/3550	3640	8270/GC MS SIM
Isophorone	3540/3550	3640	8270/GC MS SIM
Tributyltin	--[e]	--	Krone et al. (1989)
Organonitrogen Compounds			
4-Chloroaniline	3540/3550	3640	8270/GC MS SIM
3,3'-Dichlorobenzidine	3540/3550	3640	8270/GC MS SIM
2,4-Dinitrotoluene	3540/3550	3640	8270/GC MS SIM
2,6-Dinitrotoluene	3540/3550	3640	8270/GC MS SIM
N-nitrosodiphenylamine	3540/3550	3640	8270/GC MS SIM
2-Nitroaniline	3540/3550	3640	8270/GC MS SIM
3-Nitroaniline	3540/3550	3640	8270/GC MS SIM
4-Nitroaniline	3540/3550	3640	8270/GC MS SIM
Nitrobenzene	3540/3550	3640	8270/GC MS SIM
N-nitrosodi-*n*-propylamine	3540/3550	3640	8270/GC MS SIM
Ethers			
4-Bromophenyl-phenyl ether	3540/3550	3640	8270/GC MS SIM
4-Chlorophenyl-phenyl ether	3540/3550	3640	8270/GC MS SIM
Dichloroethyl ether [bis(2-chloroethyl) ether]	3540/3550	3640	8270/GC MS SIM
CHLORINATED PESTICIDES			
Aldrin	3540/3550	3620/2640	8080/8081

Table G-19: Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Tissues

Chemical Parameter	Preparation Method[a]	Cleanup Method[b]	Analytical Method[c]
alpha-Chlordane	3540/3550	3620/2640	8080/8081
alpha-Endosulfan (Endosulfan I)	3540/3550	3620/2640	8080/8081
alpha-HCH (alpha-hexachlorocyclohexane, alpha-BHC, alpha benzene hexachloride)	3540/3550	3620/2640	8080/8081
beta-Endosulfan (Endosulfan II)	3540/3550	3620/2640	8080/8081
beta-HCH (beta-BCH)	3540/3550	3620/2640	8080/8081
delta-HCH (delta-BHC)	3540/3550	3620/2640	8080/8081
Dieldrin	3540/3550	3620/2640	8080/8081
Endosulfan sulfate	3540/3550	3620/2640	8080/8081
Endrin	3540/3550	3620/2640	8080/8081
Endrin aldehyde	3540/3550	3620/2640	8080/8081
Endrin ketone	3540/3550	3620/2640	8080/8081
gamma-Chlordane	3540/3550	3620/2640	8080/8081
gamma-BHC (Lindane)	3540/3550	3620/2640	8080/8081
Heptachlor	3540/3550	3620/2640	8080/8081
Heptachlor epoxide	3540/3550	3620/2640	8080/8081
Methoxychlor	3540/3550	3620/2640	8080/8081
p,p'-DDD	3540/3550	3620/2640	8080/8081
p,p'-DDE	3540/3550	3620/2640	8080/8081
p,p'-DDT	3540/3550	3620/2640	8080/8081
Toxaphene	3540/3550	3620/2640	8080/8081
PCB CONGENERS			
2,4' diCB	3540/3550	3620/2640	8082
2,2',5 triCB	3540/3550	3620/2640	8082
2,4,4' triCB	3540/3550	3620/2640	8082
3,4,4' triCB	3540/3550	3620/2640	8082
2,2',3,5' tetraCB	3540/3550	3620/2640	8082
2,2',4,5' tetraCB	3540/3550	3620/2640	8082
2,2',5,5' tetraCB	3540/3550	3620/2640	8082
2,3',4,4' tetraCB	3540/3550	3620/2640	8082
2,3',4',5 tetraCB	3540/3550	3620/2640	8082
2,4,4',5 tetraCB	3540/3550	3620/2640	8082
3,3',4,4' tetraCB	3540/3550	3620/2640	8082
3,4,4',5 tetraCB	3540/3550	3620/2640	8082
2,2',3,4,5' pentaCB	3540/3550	3620/2640	8082
2,2',3,4',5 pentaCB	3540/3550	3620/2640	8082
2,2',4,5,5' pentaCB	3540/3550	3620/2640	8082
2,3,3',4,4' pentaCB	3540/3550	3620/2640	8082
2,3,4,4',5 pentaCB	3540/3550	3620/2640	8082
2,3',4,4',5 pentaCB	3540/3550	3620/2640	8082
2,3',4,4',6 pentaCB	3540/3550	3620/2640	8082
2',3,4,4',5 pentaCB	3540/3550	3620/2640	8082
3,3',4,4',5 pentaCB	3540/3550	3620/2640	8082
2',3,3',4,4' hexaCB	3540/3550	3620/2640	8082
2,2',3,4,4',5' hexaCB	3540/3550	3620/2640	8082

Table G-19: Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Tissues

Chemical Parameter	Preparation Method[a]	Cleanup Method[b]	Analytical Method[c]
2,2',3,5,5',6 hexaCB	3540/3550	3620/2640	8082
2,2',4,4',5,5' hexaCB	3540/3550	3620/2640	8082
2,3,3',4,4',5 hexaCB	3540/3550	3620/2640	8082
2,3,3',4,4',5 hexaCB	3540/3550	3620/2640	8082
2,3,3',4,4',6 hexaCB	3540/3550	3620/2640	8082
2,3',4,4',5,5' hexaCB	3540/3550	3620/2640	8082
2,3',4,4',5',6 hexaCB	3540/3550	3620/2640	8082
3,3',4,4',5,5' hexaCB	3540/3550	3620/2640	8082
2,2',3,3',4,4',5 heptaCB	3540/3550	3620/2640	8082
2,2',3,4,4',5,5' heptaCB	3540/3550	3620/2640	8082
2,2',3,4,4',5',6 heptaCB	3540/3550	3620/2640	8082
2,2',3,4,4',6,6' heptaCB	3540/3550	3620/2640	8082
2,2',3,4',5,5',6 heptaCB	3540/3550	3620/2640	8082
2,3,3',4,4',5,5' heptaCB	3540/3550	3620/2640	8082
2,2',3,3',4,4',5,6 octaCB	3540/3550	3620/2640	8082
2,2',3,3',4,5,5',6 octaCB	3540/3550	3620/2640	8082
2,2',3,3',4,4',5,5',6 nonaCB	3540/3550	3620/2640	8082
2,2',3,3',4,4',5,5',6,6' decaCB	3540/3550	3620/2640	8082
DIOXINS AND FURANS			
2,3,7,8-TCDF	--[e]	--[e]	1613
1,2,3,7,8-PeCDF	--[e]	--[e]	1613
2,3,4,7,8-PeCDF	--[e]	--[e]	1613
1,2,3,4,7,8-HxCDF	--[e]	--[e]	1613
1,2,3,6,7,8-HxCDF	--[e]	--[e]	1613
2,3,4,6,7,8-HxCDF	--[e]	--[e]	1613
1,2,3,4,8,9-HxCDF	--[e]	--[e]	1613
1,2,3,4,6,7,8-HpCDF	--[e]	--[e]	1613
1,2,3,4,7,8,9-HpCDF	--[e]	--[e]	1613
2,3,7,8-TCDD	--[e]	--[e]	1613
1,2,3,7,8-PeCDD	--[e]	--[e]	1613
1,2,3,4,7,8-HxCDD	--[e]	--[e]	1613
1,2,3,6,7,8-HxCDD	--[e]	--[e]	1613
1,2,3,7,8,9-HxCDD	--[e]	--[e]	1613
1,2,3,4,6,7,8-HpCDD	--[e]	--[e]	1613
OCDD	--[e]	--[e]	1613
OCDF	--[e]	--[e]	1613
HERBICIDES			
2,4,5-T	--[e]	--[e]	8151
2,4,5-TP (Silvex)	--[e]	--[e]	8151
2,4-D	--[e]	--[e]	8151
2,4-DB	--[e]	--[e]	8151
Dalapon	--[e]	--[e]	8151
Dicambia	--[e]	--[e]	8151
Dichloroprop	--[e]	--[e]	8151
Dinoseb	--[e]	--[e]	8151
MCPA	--[e]	--[e]	8151
MCPP	--[e]	--[e]	8151

[a] Recommended sample preparation methods are:

- PSEP (1997ab)
- Method 3500 series - sample preparation methods from SW-846 (EPA 1992c) and updates.

[b] Recommended sample cleanup methods are:

- All sample extracts should be subjected to GPC cleanup in accordance with procedures specified by EPA SW-846 Method 3640. Special care should be used during GPC to minimize loss of analytes.
- If sulfur is presented in the samples, cleanup procedures specified by EPA SW-846 Method 3660 should be used.
- All PCB extracts should be subjected to florisil column cleanup as specified by EPA SW-846 Method 3620.
- Additional cleanup procedures may be necessary on a sample-by-sample basis. Alternative cleanup procedures are described in PSEP (1997ab) and EPA (1992c).

[c] Recommended analytical methods are:

- Method 6000, 7000, 8000, and 9000 series - analytical methods from SW-846 (EPA 1992c) and updates.
- Method 1624C/1625C - isotope dilution method (EPA 1992c).
- Plumb (1981) - U.S. EPA/U.S. Army Corps of Engineers Technical Report EPA/CE-81-1.
- PSEP (1997ab).
- Tributyltin by Krone et al. (1989, 1995), Muller (1987).
- GC MS SIM.

[d] The sample digestion method for mercury is described in the analytical method (245.6, EPA 1991a).

To achieve the recommended detection limits for organic compounds, it may be necessary to use a larger sample size (approximately 100 g), a smaller final extract volume for gas chromatography/mass spectrometry analyses (0.5 mL), and one of the recommended sample cleanup methods, as necessary, to reduce interference.

Table G-20: Recommended Sample Preparation Methods, Cleanup Methods, and Analytical Methods for Pore water

Chemical Parameter	Preparation Method	Analytical Method[a]
CONVENTIONALS		
Total Sulfides		Plumb (1981)
Ammonia		Plumb (1981)
METALS		
Priority Pollutant Metals		
Antimony	--	6020/6010/7040
Arsenic	--	6020/6010/7060
Cadmium	--	6020/6010/7130
Chromium	--	6020/6010/7190
Copper	--	6020/6010
Lead	--	6020/6010/7420
Mercury	--[b]	7470
Nickel	--	6020/6010
Silver	--	6020/6010
Zinc	--	6020/6010
Ancillary Metals		
Aluminum	--	6020/6010
Barium	--	6020/6010
Calcium	--	6020/6010
Cobalt	--	6020/6010
Iron	--	6020/6010
Magnesium	--	6020/6010
Manganese	--	6020/6010
Potassium	--	6020/6010
Sodium	--	6020/6010
Vanadium	--	6020/6010
Tributyltin	--[d]	Krone et al. (1989)

[a] Recommended analytical methods are:

- Method 6000, 7000, 8000, and 9000 series - analytical methods from SW-846 (EPA 1992c) and updates.
- Method 1624C/1625C - isotope dilution method (EPA 1992c).
- Plumb (1981) - U.S. EPA/U.S. Army Corps of Engineers Technical Report EPA/CE-81-1.
- PSEP (1997ab).
- Tributyltin by Krone et al. (1989, 1995), Muller (1987).
- GC MS SIM.

[b] The sample digestion method for mercury is described in the analytical method (Method 7470, SW-846 [EPA 1992c] and updates).

[c] Sample preparation methods for conventional analyses are described in the analytical methods.

Table G - 21: Chemical Parameters and Detection Limits				
		RECOMMENDED DETECTION LIMITS		
CHEMICAL PARAMETER	**COI †**	**Pore water**	**Sediment**	**Tissue**
CONVENTIONALS				
Total solids			0.1%	
Total volatile solids			0.1%	
Total organic carbon			0.1%	
Grain size			----	
Total sulfides		0.05 mg/L	1 mg/Kg	
Ammonia		0.1 mg/L	1 mg/Kg	
METALS		**(mg/L)**	**(mg/kg dw)**	**(mg/kg ww)**
Priority Pollutant Metals				
Antimony		0.01	0.1 - 0.3	0.1 - 0.3
Arsenic	☹	0.01	0.1	0.1
Beryllium		----	----	----
Cadmium	☹	0.01	0.05 - 0.1	0.05 - 0.1
Chromium	☹	0.01	1.0	1.0
Copper	☹	0.01	0.1 - 0.5	0.1 - 0.5
Lead	☹	0.002-0.005	0.1 - 0.5	0.1 - 0.5
Mercury	☹	0.0002	0.005 - 0.01	0.005 - 0.01
Nickel	☹	0.008	0.1 - 0.5	0.1 - 0.5
Selenium		0.025	----	----
Silver		0.005	0.06 - 0.1	0.06 - 0.1
Thallium		----	----	----
Zinc	☹	0.010	0.2	0.2
Ancillary Metals				
Aluminum		0.01	10	
Barium		----	----	
Calcium		----	----	
Cobalt		----	----	
Iron		0.07-0.001	0.7 - 1.0	
Magnesium		----	----	
Manganese		0.001-0.002	1.0 - 2.0	
Potassium		----	----	
Sodium		----	----	
Vanadium		----	----	
SEMIVOLATILE ORGANICS			**(µg/kg dw)**	**(µg/kg ww)**
Phenols				
2,4-Dimethylphenol			6	20
2-Methylphenol			6	20
4-Methylphenol	☹		20	20
Phenol			20	20
Chlorinated and Nitro-substituted Phenols				
4-Chloro-3-methylphenol			20	20
2-Chlorophenol			20	20
2,4-Dichlorophenol			20	20
4,6-Dinitro-2-methylphenol			20	20
2,4-Dinitrophenol			20	20
2-Nitrophenol			20	20
Chlorinated and Nitro-substituted Phenols				

Table G - 21: Chemical Parameters and Detection Limits				
		RECOMMENDED DETECTION LIMITS		
CHEMICAL PARAMETER	**COI †**	**Pore water**	**Sediment**	**Tissue**
4-Nitrophenol			20	20
Pentachlorophenol	☹		20	20
2,4,5-Trichlorophenol			20	20
2,4,6-Trichlorophenol			20	20
Low Molecular Weight PAH				
Acenaphthene	☹		20	20
Acenaphthylene	☹		20	20
Anthracene	☹		20	20
Fluorene	☹		20	20
2-Methylnaphthalene	☹		20	20
Naphthalene	☹		20	20
Phenanthrene	☹		20	20
High Molecular Weight PAH				
Benzo(*a*)anthracene	☹		20	20
Benzo(*a*)pyrene	☹		20	20
Benzo(*b)*fluoranthene	☹		20	20
Benzo(*g,h,i*)perylene	☹		20	20
Benzo(*k*)fluoranthene	☹		20	20
Chrysene	☹		20	20
Dibenzo(*a,h*)anthracene	☹		20	20
Fluoranthene	☹		20	20
Indeno(1,2,3-*c,d*)pyrene	☹		20	20
Pyrene	☹		20	20
Chlorinated Aromatic Compounds				
1,2-Dichlorobenzene			20	20-150
1,3-Dichlorobenzene			20	20-150
1,4-Dichlorobenzene			20	20-150
1,2,4-Trichlorobenzene			20	20-150
2-Chloronaphthalene			20	20-150
Hexachlorobenzene			20	20-150
Chlorinated Alkanes/Alkenes				
Hexachloroethane			20	20
Hexachlorobutadiene			20	20
Hexachlorocyclopentadiene			20	20
Phthalate Esters				
bis(2-Ethylhexyl)phthalate	☹		20	20
Butyl benzyl phthalate	☹		20	20
di-*n*-Butyl phthalate	☹		20	20
di-*n*-Octyl phthalate	☹		20	20
Diethyl phthalate			20	20
Dimethyl phthalate	☹		20	20
Miscellaneous Extractable Compounds				
Benzoic acid	☹		200	20
Benzyl alcohol			6	20
Dibenzofuran	☹		20	20
Isophorone			20	20
Tributyltin	☹	0.02	10	10

Table G - 21: Chemical Parameters and Detection Limits				
		RECOMMENDED DETECTION LIMITS		
CHEMICAL PARAMETER	**COI †**	**Pore water**	**Sediment**	**Tissue**
Organonitrogen Compounds				
4-Chloroaniline			20	20
3,3'-Dichlorobenzidine			20	20
2,4-Dinitrotoluene			20	20
2,6-Dinitrotoluene			20	20
N-nitrosodiphenylamine			20	20
2-Nitroaniline			20	20
3-Nitroaniline			20	20
4-Nitroaniline			20	20
Nitrobenzene			20	20
N-nitrosodi-*n*-propylamine			12	20
Ethers				
4-Bromophenyl-phenyl ether			20	20
4-Chlorophenyl-phenyl ether			20	20
Dichloroethyl ether [bis(2-chloroethyl) ether]			20	20
CHLORINATED PESTICIDES			**(µg/kg dw)**	**(µg/kg ww)**
Aldrin	☹		1.7	0.1-2
alpha-Chlordane			1.7	0.1-2
alpha-Endosulfan (Endosulfan I)			20	0.1-2
alpha-HCH (alpha-hexachlorocyclohexane,			20	0.1-2
alpha-BHC, alpha benzene hexachloride)			20	0.1-2
beta-Endosulfan (Endosulfan II)			20	0.1-2
beta-HCH (beta-BCH)			20	0.1-2
delta-HCH (delta-BHC)			20	0.1-2
Dieldrin	☹		2.3	0.1-2
Endosulfan sulfate			20	0.1-2
Endrin			20	0.1-2
Endrin aldehyde	☹		20	0.1-2
Endrin ketone			20	0.1-2
gamma-Chlordane			20	0.1-2
gamma-BHC (Lindane)			1.7	0.1-2
Heptachlor			1.7	0.1-2
Heptachlor epoxide			20	0.1-2
Methoxychlor			20	0.1-2
4,4'-DDD	☹		2.3	0.1-2
4,4'-DDE	☹		3.3	0.1-2
4,4'-DDT	☹		6.7	0.1-2
Toxaphene			50	0.1-2
PCB AROCLORS			**(µg/kg dw)**	**(µg/kg ww)**
Aroclor-1016			20	1-5
Aroclor-1221			20	1-5
Aroclor-1232			20	1-5
Aroclor-1242			20	1-5
Aroclor-1248			20	1-5
Aroclor-1254	☹		20	1-5
Aroclor-1260	☹		20	1-5
PCB CONGENERS	☹		**(µg/kg dw)**	**(µg/kg ww)**

Table G - 21: Chemical Parameters and Detection Limits				
		RECOMMENDED DETECTION LIMITS		
CHEMICAL PARAMETER	**COI †**	**Pore water**	**Sediment**	**Tissue**
2,4’ diCB			20	1-5
2,2’,5 triCB			20	1-5
2,4,4’ triCB			20	1-5
3,4,4’ triCB			20	1-5
2,2’,3,5’ tetraCB			20	1-5
2,2’,4,5’ tetraCB			20	1-5
2,2’,5,5’ tetraCB			20	1-5
2,3’,4,4’ tetraCB			20	1-5
2,3’,4’,5 tetraCB			20	1-5
2,4,4’,5 tetraCB			20	1-5
3,3’,4,4’ tetraCB			20	1-5
3,4,4’,5 tetraCB			20	1-5
2,2’,3,4,5’ pentaCB			20	1-5
2,2’,3,4’,5 pentaCB			20	1-5
2,2’,4,5,5’ pentaCB			20	1-5
2,3,3’,4,4’ pentaCB			20	1-5
2,3,4,4’,5 pentaCB			20	1-5
2,3’,4,4’,5 pentaCB			20	1-5
2,3’,4,4’,6 pentaCB			20	1-5
2’,3,4,4’,5 pentaCB			20	1-5
3,3’,4,4’,5 pentaCB			20	1-5
2’,3,3’,4,4’ hexaCB			20	1-5
2,2’,3,4,4’,5’ hexaCB			20	1-5
2,2’,3,5,5’,6 hexaCB			20	1-5
2,2’,4,4’,5,5’ hexaCB			20	1-5
2,3,3’,4,4’,5 hexaCB			20	1-5
2,3,3’,4,4’,5 hexaCB			20	1-5
2,3,3’,4,4’,6 hexaCB			20	1-5
2,3’,4,4’,5,5’ hexaCB			20	1-5
2,3’,4,4’,5’,6 hexaCB			20	1-5
3,3’,4,4’,5,5’ hexaCB			20	1-5
2,2’,3,3’,4,4’,5 heptaCB			20	1-5
2,2’,3,4,4’,5,5’ heptaCB			20	1-5
2,2’,3,4,4’,5’,6 heptaCB			20	1-5
2,2’,3,4,4’,6,6’ heptaCB			20	1-5
2,2’,3,4’,5,5’,6 heptaCB			20	1-5
2,3,3’,4,4’,5,5’ heptaCB			20	1-5
2,2’,3,3’,4,4’,5,6 octaCB			20	1-5
2,2’,3,3’,4,5,5’,6 octaCB			20	1-5
2,2’,3,3’,4,4’,5,5’,6 nonaCB			20	1-5
2,2’,3,3’,4,4’,5,5’,6,6’ decaCB			20	1-5
DIOXINS AND FURANS	☹		**(ng/kg dw)**	**(ng/kg ww)**
2,3,7,8-TCDF			1	0.05
1,2,3,7,8-PeCDF			5	0.25
2,3,4,7,8-PeCDF			5	0.25
1,2,3,4,7,8-HxCDF			5	0.25
1,2,3,6,7,8-HxCDF			5	0.25

Table G - 21: Chemical Parameters and Detection Limits				
		RECOMMENDED DETECTION LIMITS		
CHEMICAL PARAMETER	**COI †**	**Pore water**	**Sediment**	**Tissue**
2,3,4,6,7,8-HxCDF			5	0.25
1,2,3,4,8,9-HxCDF			5	0.25
1,2,3,4,6,7,8-HpCDF			5	0.25
1,2,3,4,7,8,9-HpCDF			5	0.25
2,3,7,8-TCDD			1	0.05
1,2,3,7,8-PeCDD			5	0.25
1,2,3,4,7,8-HxCDD			5	0.25
1,2,3,6,7,8-HxCDD			5	0.25
1,2,3,7,8,9-HxCDD			5	0.25
1,2,3,4,6,7,8-HpCDD			5	0.25
OCDD			5	0.25
OCDF			5	0.25
HERBICIDES			**(mg/kg dw)**	**(mg/kg ww)**
2,4,5-T			5	0.1-1
2,4,5-TP (Silvex)			5	0.1-1
2,4-D			20	1-10
2,4-DB			50	5-50
Dalapon			100	5-50
Dicambia			10	0.5-5
Dichloroprop			10	0.5-5
Dinoseb			50	5-50
MCPA			200	10-100
MCPP			200	10-100

† COI = Contaminant of interest listed in Tables D-1 & D-2

Table G-22: Summary of Published Test Acceptability Standards

Test Procedure	Test Acceptability Requirements	Water Quality Performance Standards
H. azteca 10-day Survival	Animals at test initiation should be between 7-14 days old.	Hardness, alkalinity, pH, and ammonia in overlying water within a treatment should not vary by more than 50% during the test.
	Mean Control Survival ≥80% at test termination.	Test temperature must average 23±1°C over the duration of the test and the instantaneous temperature should be 23±3°C
		Daily measures of dissolved oxygen should be between 40 and 100%.
C. tentans 10-day Survival & Growth	50% of test animals should be 3rd instar or younger with head capsule widths between 0.35 – 0.45 mm.	Hardness, alkalinity, pH, and ammonia in overlying water within a treatment should not vary by more than 50% during the test.
	Mean control survival must be ≥70% at test termination.	Test temperature must average 23±1°C over the duration of the test and the instantaneous temperature should be 23±3°C
	Mean size of control animals must be ≥0.6 mg at test termination.	Daily measures of dissolved oxygen should be between 40 and 100%.
H. azteca 28-day Survival & Growth	Animals at test initiation should be between 7-14 days old. (tentative)[a]	Hardness, alkalinity, pH, and ammonia in overlying water within a treatment should not vary by more than 50% during the test.
	Mean Control Survival ≥80% at test termination. (tentative)[a]	Test temperature must average 23±1°C over the duration of the test and the instantaneous temperature should be 23±3°C
		Daily measures of dissolved oxygen should be between 40 and 100%.
H. limbata 21-day Survival and Growth	Test must be initiated with early instar nymphs 3-4 months in age (5mg wet weight, <1 cm in length)	Hardness, alkalinity, pH, and ammonia in overlying water within a treatment should not vary by more than 50% during the test.
	Mean Control Survival ≥80% at test termination.	Test temperature must average 20±1°C over the duration of the test and the instantaneous temperature should be 20±3°C
		Daily measures of dissolved oxygen should be between 40 and 100%.
T. Tubifex 28-day Survival & Reproduction	Test must be initiated with sexually mature animals as indicated by presence of testes or ovaries.	Hardness, alkalinity, pH, and ammonia in overlying water within a treatment should not vary by more than 50% during the test.
	Mean survival must be ≥ 90% at test termination	Test temperature must average 23±1°C over the duration of the test and the instantaneous temperature should be 23±3°C
		Daily measures of dissolved oxygen should be between 40 and 100%.
28-day Bioaccumulation Tests	Infaunal test organisms must borrow into the test sediment (*no evidence of avoidance)	Hardness, alkalinity, pH, and ammonia in overlying water within a treatment should not vary by more than 50% during the test.
		Test temperature should average ±1°C of specified temperature for test species over the duration of the test and the instantaneous temperature should be within ±3°C of the specified test temperature.
		Daily measures of dissolved oxygen should be between 40 and 100%.

[a] Test acceptability criteria based on proposed draft methods (EPA, in review).

Table G-23: Summary of Test Deviations and Suggested Responses.		
Deviation	**Suggested Response**	
	Re-testing Required	**Re-testing May Be Required**
Lack of test array randomization		✓
Testing was not blind		✓
Required references or controls were not tested	✓	
Test chambers not identical		✓
Test container(s) broken or misplaced		✓
Test organism mortality in controls exceeds acceptable limits	✓	
Excessive test organism mortality in a single replicate of a control		✓
Test organisms were not randomly assigned to test chambers		✓
Test organisms were not from the same population		✓
Test organisms were not all the same species (or species complex)	✓	
Test organism holding times were exceeded		✓
Water quality parameters consistently out of range	✓	
Brief episodes of out-of-range water quality parameters		✓
Test monitoring was not documented		✓
Test monitoring was incomplete		✓
Sediment holding times were exceeded	✓	
Sediment storage conditions were out of acceptable ranges		✓

Table taken from Moore et al. (1994)