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WASHINGTON STATE DEPARTMENT OF ECOLOGY

SEDIMENT RANKING SYSTEM

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PTI
ENVIRONMENTAL SERVICES

SEDIMENT RANKING SYSTEM

Prepared For

Washington Department of Ecology
Olympia, Washington

January 1990

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SEDIMENT RANKING SYSTEM

For

Washington Department of Ecology
Olympia, Washington 98584-8711

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LIST OF ACRONYMS

AET	apparent effects threshold
Authority	Puget Sound Water Quality Authority
BCF	bioconcentration factor
CPF	carcinogenic potency factor
Ecology	Washington Department of Ecology
EILS	Environmental Investigations/Laboratory Services Section
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
HH	human health hazard
HRS	hazardous ranking system
HWICP	Hazardous Waste Investigation and Cleanup Program
IRIS	integrated risk information system
MTCA	Model Toxic Control Act
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
PLP	potentially liable parties
PSDDA	Puget Sound Dredged Disposal Analysis
PSEP	Puget Sound Estuary Program
RAPS	remedial action priority system
SEDRANK	sediment ranking system
the Plan	Puget Sound Water Quality Authority management plan
UBAT	Urban Bay Action Team
WARM	Washington state ranking method

1.0 INTRODUCTION

This report recommends an approach for ranking contaminated sediment sites in Puget Sound. It is an intermediate step in the development of the sediment ranking system (SEDRANK). *A Recommended Approach for Identifying and Ranking Contaminated Sediments* (PTI 1988) described the conceptual basis for SEDRANK and identified several remaining questions that could influence future refinements and potential modifications. *Recommended Approach for Contaminated Sediment Cleanup Decisions* (PTI 1989) described SEDRANK in the context of the overall process for managing sediments in Puget Sound. The ranking system presented in this report incorporates comments and recommendations received to date. Data availability was a major factor in refining SEDRANK as detailed in this report. Field testing of SEDRANK is needed to refine algorithms and adjust weighting factors.

1.1 PURPOSE

SEDRANK is designed to support the prioritization of contaminated sediment sites for subsequent remedial action evaluation. SEDRANK is structured similarly to other hazardous site ranking systems [e.g., the Washington ranking method (WARM), and the federal Superfund hazard ranking system (HRS)]. However, unlike many ranking systems, SEDRANK includes impacts associated with chemicals or waste material that have not been traditionally defined as "toxics" (e.g., debris and excess organic matter). This broader definition of contamination enhances the capabilities of SEDRANK as a resource management tool.

The primary goal of the proposed SEDRANK is to assess the relative hazard to human health and the environment posed by contaminated sediment sites. The ranking system provides information that supports the allocation of resources to remediate contaminated sediments that pose the greatest threat to human and environmental health. Therefore, the ranking system is a tool to facilitate cost-effective sediment remediation with resultant improvement in the overall quality of Puget Sound resources. In developing SEDRANK, additional secondary goals were identified:

- Distinguish the relative magnitude of hazards to both human and environmental health

- Support remedial action prioritization (i.e., include factors that support delineation of source control and sediment remedial activities)

- Relate sediment contamination to water quality effects.

1.2 BACKGROUND

Sediment in several areas of Puget Sound is contaminated with potentially toxic substances such as petroleum-derived hydrocarbons, chlorinated organic compounds, and metals. Sediment quality problems have also been associated with excess organic content. Pollution control programs in Puget Sound have traditionally focused on protecting water quality through effluent discharge limits and water quality standards. Such controls have generally not been effective in preventing sediment contamination because under many circumstances, water quality standards can be met even though sediment quality is compromised. This situation arises because particle-borne contaminants fall to the sediments and become concentrated, while dissolved contaminants are dispersed in the water column.

In the following sections, the program background, regulatory setting, and developmental background of SEDRANK are provided.

1.2.1 Program Background

In the early- and mid-1980s, several studies and programs were initiated to develop tools for evaluating and managing contaminated sediments:

- **Commencement Bay Superfund Investigation**—During the course of this investigation, the apparent effects threshold (AET) approach was developed to assign values to sediment quality. AET are based on observed relationships between sediment contamination and biological effects, including benthic infauna depressions and several bioassays (e.g., amphipod, oyster larvae, and Microtox).

- **Puget Sound Dredged Disposal Analysis (PSDDA)**—PSDDA is a cooperative program of the U.S. Army Corps of Engineers, Seattle District; U.S. Environmental Protection Agency (EPA), Region 10; Washington Department of Ecology (Ecology); and

Washington Department of Natural Resources. The primary objective of PSDDA is to develop environmentally safe and publicly acceptable options for open-water, unconfined dredged material disposal. PSDDA has developed procedures and guidelines for evaluating dredged material and has recommended disposal sites in Puget Sound.

- **Urban Bay Action Program**—The Urban Bay Action Program, a major component of the Puget Sound Estuary Program (PSEP), was begun in 1984 by the EPA Office of Puget Sound with substantial participation by Ecology, Puget Sound Water Quality Authority (Authority), and other state and local government agencies. Under the program, the study of each embayment consists of the identification of contaminated problem areas (predominantly using site-specific biological tests and AET values to assess sediment contamination), identification of potential contaminant sources, development of an action plan for source control, and formation of an action team for action plan implementation.

1.2.2 Regulatory Setting

Sediment cleanup activities in the state of Washington are being driven by two regulatory authorities that were established relatively recently: 1) the Authority and 2) the 1987 Model Toxic Control Act (MTCA). Both of these authorities require the development of ranking systems to assess the relative hazard posed by contaminated sites in the state of Washington. The ranking system required by the Authority focuses on sediments, while the ranking system required by MTCA addresses all hazardous sites in the state.

Actions resulting from the programs described in the previous section were focused by the Authority's management plan (the Plan) for Puget Sound (PSWQA 1988). The Plan integrates and expands a number of existing programs and creates new programs that address the overall environmental quality of Puget Sound resources. The purpose of the Plan is to restore and protect the biological health and diversity of Puget Sound. The strategy selected to achieve this goal is the protection and enhancement of the sound's water and sediment quality, its fish and shellfish populations, and its wetlands. The requirements of the Plan are being promulgated under WAC 173-204. SEDRANK is designed to comply with Element S-8.5 of the Plan, which requires that Ecology develop a system to rank sediment sites in Puget Sound where chemical concentrations exceed sediment standards. It is anticipated that sediment cleanup will be implemented under a variety of regulatory authorities, depending on site-specific characteristics (discussed in greater detail in Section 1.2.4).

MTCA establishes the general requirements for cleanup of hazardous waste sites in the state of Washington, and is being implemented under WAC 173-340. At the present time, the specific requirements for cleanup of contaminated sediment sites are incorporated into these regulations by reference.

MTCA directs Ecology to adopt rules "to establish criteria for determining priorities among hazardous substance sites. These criteria shall assure that sites are ranked by a system that objectively and numerically assesses the relative degree of risk at such sites." [RCW 70.105B.030 (2)(a)]. The Washington state hazard ranking system regulation (WAC 173-340-330) implements this requirement. The regulation defines the general evaluation criteria and scoring procedures that should be used to rank sites but does not describe the ranking system. WARM is being developed simultaneously with the regulation. The public review draft of WARM was released in June 1989 (SAIC and Parametrix 1989a,b). This version of WARM does not score hazards associated with sediment contamination. However, the human health and environmental hazard scoring routes presented here can easily be adapted to WARM by simplifying selected scoring factors and eliminating the scoring of non-hazardous wastes (i.e., excess organic matter and debris).

1.2.3 Developmental Background

Five ranking and decisionmaking approaches were reviewed prior to developing SEDRANK (PTI 1988). Three of the approaches reviewed were hazard ranking systems that were developed for ranking a broad range of hazard types. These three approaches included EPA's HRS, WARM, and the U.S. Department of Energy remedial action priority system (RAPS). The remaining two approaches, the PSDDA evaluation procedures and the EPA Region 10 urban bay approach, are essentially decisionmaking approaches developed specifically for classifying contaminated sediments.

Elements of these ranking systems and decisionmaking approaches that were relevant to the development and implementation of this ranking system were incorporated into SEDRANK when possible. In general, the hazard ranking systems (i.e., WARM, HRS, RAPS) provided information for the overall conceptual structure and scoring method. The interim process for scoring waste characteristics relevant to human health was also borrowed from the WARM assessment of toxicity in surface water. Elements of the PSEP urban bay decisionmaking approach and the PSDDA evaluation procedures were used to refine the characterization of contamination, the site, and affected resources; to delineate ways in which ranking information can be used to support future remedial action; and to provide the overall perspective for implementation of the ranking system.

Much of the proposed SEDRANK is new. The need to develop new ways of defining and evaluating factor categories arose primarily because the synthesis of existing ranking system approaches and existing sediment evaluation procedures revealed a number of shortcomings. For example, the assessment of migration pathways in the proposed SEDRANK includes an assessment of sediment transport and water column impacts. Neither of these pathways was a component of the terrestrial hazard ranking systems (i.e., WARM and HRS), because the pathways are not generally relevant to terrestrial sites. Nor is either of these migration pathways developed in the PSDDA or PSEP evaluation procedures, although PSDDA designates a water column test if water column impacts are anticipated during dredged material disposal.

Following development of the initial SEDRANK (PTI 1988), overall guidelines were developed for contaminated sediment cleanup decisions (PTI 1989). In PTI (1989), the ranking system was described within the overall context of contaminated sediment management. This developmental stage was essential to guide future refinements of the ranking system because several aspects of the overall decisionmaking process relate directly to the ranking system (e.g., the mechanism for deferring action during the screening step that precedes site ranking). In addition, a clear understanding of the timing and purpose of each stage of the process was needed to eliminate redundancy and streamline the evaluation process. For example, the evaluation of the role of natural recovery may be appropriate during both site ranking and cleanup action selection. Consequently, information relating to natural recovery that was identified during site ranking should be incorporated (and if necessary refined) during subsequent cleanup action selection.

Several aspects of SEDRANK have been revised since the initial recommended approach described in PTI (1989). These changes represent a streamlined approach that reflects data availability and consideration of other stages of the sediment management process. Major changes include the following:

- The evaluation of offsite exposure pathways (i.e., offsite sediment transport and water column impacts) is now qualitative rather than quantitative

- An interim human health scoring methodology has been developed

- Scoring factors have been weighted and scaled

- Scoring methodology has been simplified

- Selected reference tables have been prepared.

The next steps in the refinement of the ranking system include completion of reference tables, broad-based review, and field validation.

1.2.4 Relationship to the Overall Sediment Management Process

SEDRANK represents only one stage in the management of contaminated sediments in Puget Sound. The overall sediment quality management process is illustrated in Figure 1 and is discussed in more detail below.

Data from a variety of sources support the sediment management process. These sources include the following:

- PSDDA data, collected during routine dredging projects and baseline surveys
- Hazardous Waste Investigation and Cleanup Program (HWICP) data, collected by urban bay action teams (UBAT) during area and facility investigations
- Water Quality Program data, collected as part of the National Pollutant Discharge Elimination System (NPDES) permits
- Environmental Investigation/Laboratory Services Section (EILS) data
- Other sources [e.g., university research programs, National Oceanic and Atmospheric Administration (NOAA), Municipality of Metropolitan Seattle].

The management process is divided into several stages: 1) inventory of all stations in Puget Sound where chemical concentrations exceed sediment quality standards or biological effects have been documented, 2) pre-screening of inventory stations, 3) site identification (comparable to hazard assessment in the MTCA process), 4) site screening, 5) site ranking, 6) site prioritization (including identification of regulatory authority), and 7) site remedy selection. The interrelationship of these stages is illustrated in Figure 1.

Stages that are included in the sediment cleanup process are enclosed in the dashed box. Sediment cleanup guidelines focus and direct all site-specific activities, ranging from the initial identification of a site to the final selection of a site remedy. In some stages, the evaluation may indicate that deferred action is appropriate. Deferred sediment action encompasses three types of activity, which may or may not be conducted in conjunction with ongoing source control efforts. These activities include 1) formal delisting of the site, 2) collection of additional source information, and 3) collection of additional sediment information (including low-frequency monitoring). The information collected for Actions 2 and 3 may lead to re-evaluation of the site (i.e., screening, ranking, and prioritization).

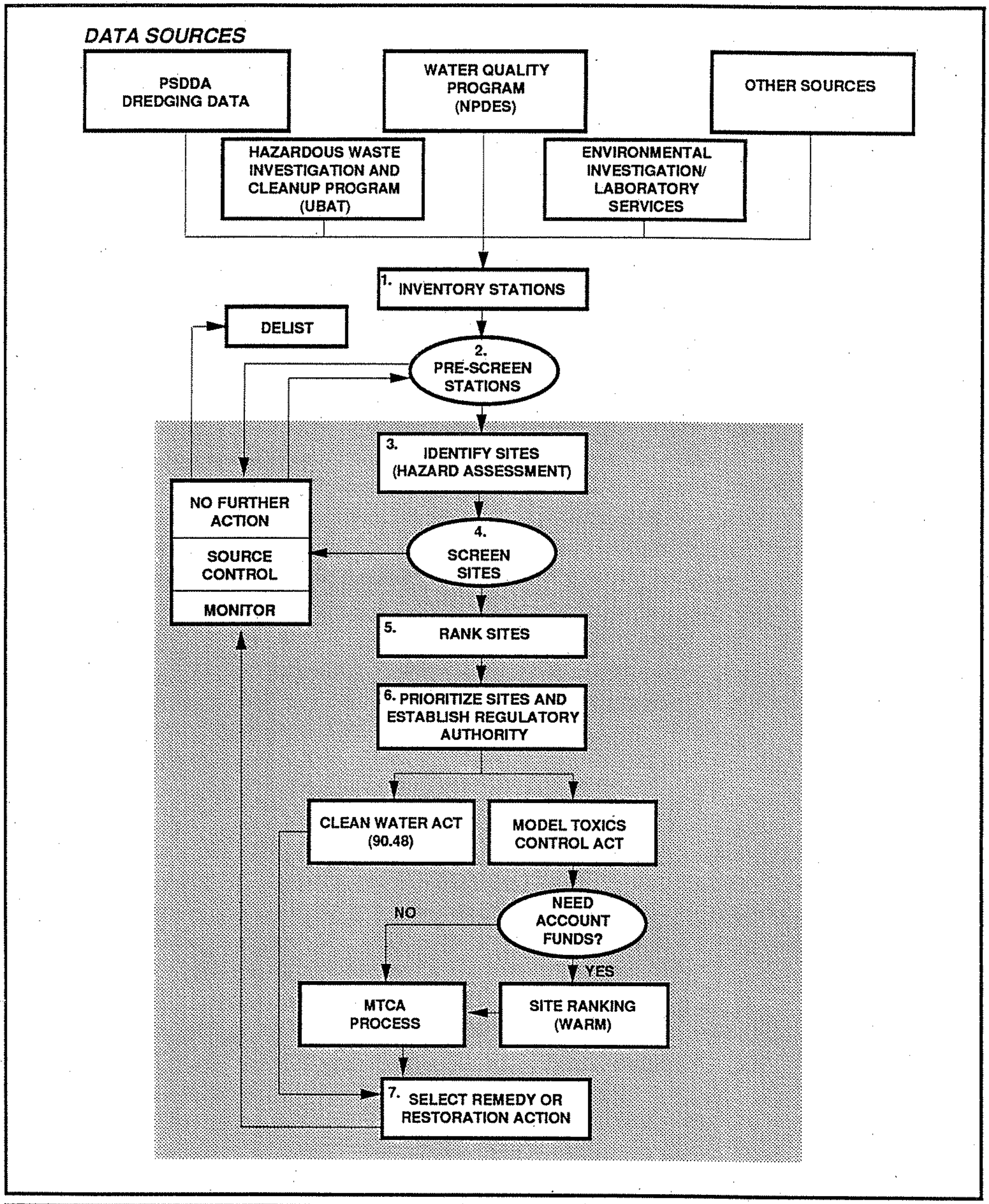

Figure 1. Sediment quality management process.

Regulatory authority is established during site prioritization and may influence site prioritization. Regulatory authority may be closely linked to the type of sources associated with the site and the types of potentially liable parties (PLP) associated with the sources including 1) presence of known sources with identified PLP, 2) types of permits associated with sources, 3) financial resources of PLP, and 4) PLP interest in voluntary action. Two primary regulations direct sediment cleanup activities: the clean Water Act (90.48) and the MTCA (WAC 170-340). Sediment remedial activities proceed under the identified regulation, and may include one or more of the following: use restrictions, monitoring, *in situ* capping, removal and disposal offsite, and treatment.

1.3 REPORT OVERVIEW

The conceptual framework of SEDRANK is presented in Section 2. Section 3 provides the results of the evaluation of data availability. The revised scoring methodology and process for qualitative assessment are described in Section 4. Section 5 describes key issues to be considered during the review and future activities associated with ranking system implementation.

2.0 CONCEPTUAL FRAMEWORK

The conceptual framework of SEDRANK is presented schematically in Figure 2. Human health hazard and ecological hazard are the two fundamental scoring categories. The two scoring categories are assessed independently in recognition of their uniqueness and to provide a balanced assessment of contaminated sediments. This scoring approach also allows a degree of flexibility in evaluating the ways in which these two categories can be combined (i.e., different ways of weighting these two types of hazard). These two scoring categories could be balanced differently in different areas of Puget Sound based on usage considerations. For example, the ultimate ranking of sediments in a protected, environmentally sensitive area could emphasize the ecological hazard, while the ranking of sediments in areas that are heavily used for commercial and recreational fishing could emphasize human health considerations. This distinction could be recognized by a scoring system that alters the way in which the two categories are weighted depending on the location of the contaminated sediment site.

Human health hazard and ecological hazard assessments are structured similarly. Direct exposure to contaminated sediments of aquatic organisms (in the case of ecological hazard) and edible organisms (in the case of human health hazard) are considered the primary exposure pathways for the two hazard categories. Impacts to offsite sediments are evaluated for both hazard categories but are considered a secondary exposure pathway. Offsite sediment impacts are a potential problem only in areas that are susceptible to sediment resuspension or mass movement. Water column impacts, also considered a secondary exposure pathway, are included as an exposure pathway in the ecological hazard assessment to establish the link between sediments and the water column. Water column impacts are most important in areas where soluble contaminants that are present in the sediments can diffuse into the water column and affect water quality. Migration of contaminant-bearing organisms is not included as a migration pathway. This pathway is probably not significant in terms of mass transport of contaminants away from a site. However, it is implicitly included in the human health assessment of site impacts, which assumes direct exposure of an organism and subsequent consumption by a human.

Three categories of factors are used to evaluate all exposure pathways: waste characteristics, site characteristics, and target resources. Elements to be included in these categories are described in the following sections.

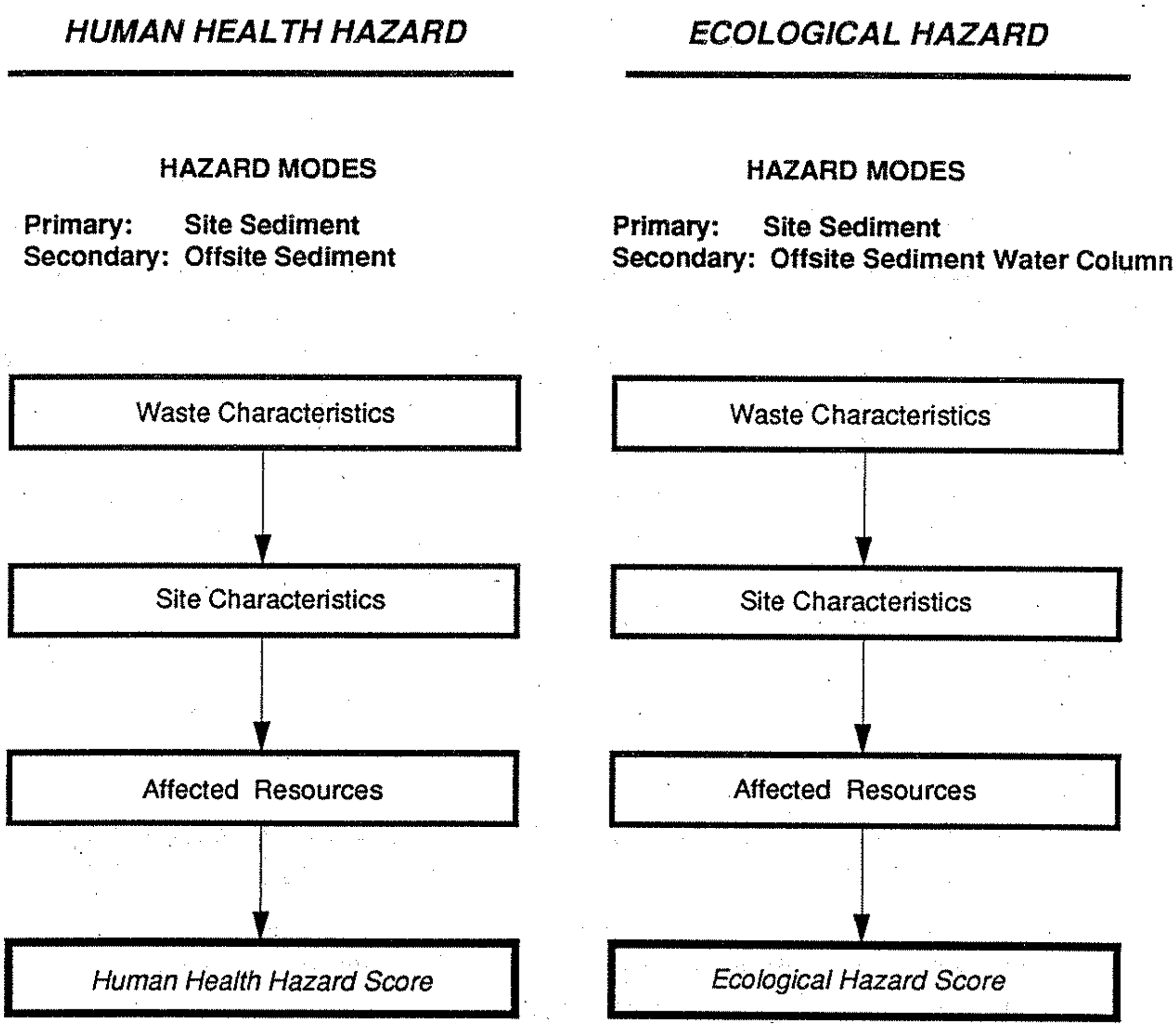

Figure 2. Conceptual framework of the sediment ranking system.

2.1 ECOLOGICAL HAZARD

Three exposure pathways are included in the assessment of the ecological hazard posed by contaminated sediments. The most important pathway is site impacts, which are associated with direct exposure to onsite sediments. This is the only pathway that will be ranked in SEDRANK. Offsite sediment impacts (i.e., impacts from direct exposure to sediments that have migrated offsite) and water column impacts (i.e., impacts from direct exposure to contaminants that have migrated into the water column) are considered secondary pathways, and are evaluated qualitatively. Each of these exposure pathways can be assessed by evaluating relevant waste characteristics, site characteristics, and affected resources. Factors evaluated to characterize ecological hazard are summarized in Figure 3.

2.1.1 Site Impacts

Direct exposure is the most important pathway for assessing the overall ecological hazard posed by a contaminated sediment site because the sediment-water interface is an extremely sensitive environment. Offsite exposure is less important because mechanisms that transport contaminants away from a site generally act to disperse and dilute them.

Waste Characteristics—The key waste characteristics that define ecological hazard are toxicity, persistence, and areal extent. Sediment contamination falls into two general categories: contamination by specific toxic chemicals (i.e., metals and organic compounds) and contamination associated with other types of material (i.e., debris and excess organic matter). The toxicity of an individual toxic chemical is expressed as the ratio of measured concentration to interim sediment quality standards (i.e., as an enrichment factor). Interim sediment quality standards are effects-based values that serve as indices of potential sediment toxicity, and are in use until the final standards are promulgated. Chemical values represented by sediment quality criteria are used in preference to biological test results because 1) individual contaminants can be characterized and evaluated, 2) contaminant diversity can be incorporated into the assessment, and 3) the relative magnitude of contaminant concentration can be evaluated. Furthermore, the use of chemical standards is consistent with the screening nature of the ranking system. However, in areas where biological tests have already been conducted, these results supersede (in cases of no measurable effects) or supplement (in cases where biological effects are confirmed) the toxicity inferred by chemical measurements.

Organic contamination and debris such as wood chips or plastic wastes are included in the characterization of sediment contamination because they can adversely affect aquatic life. While

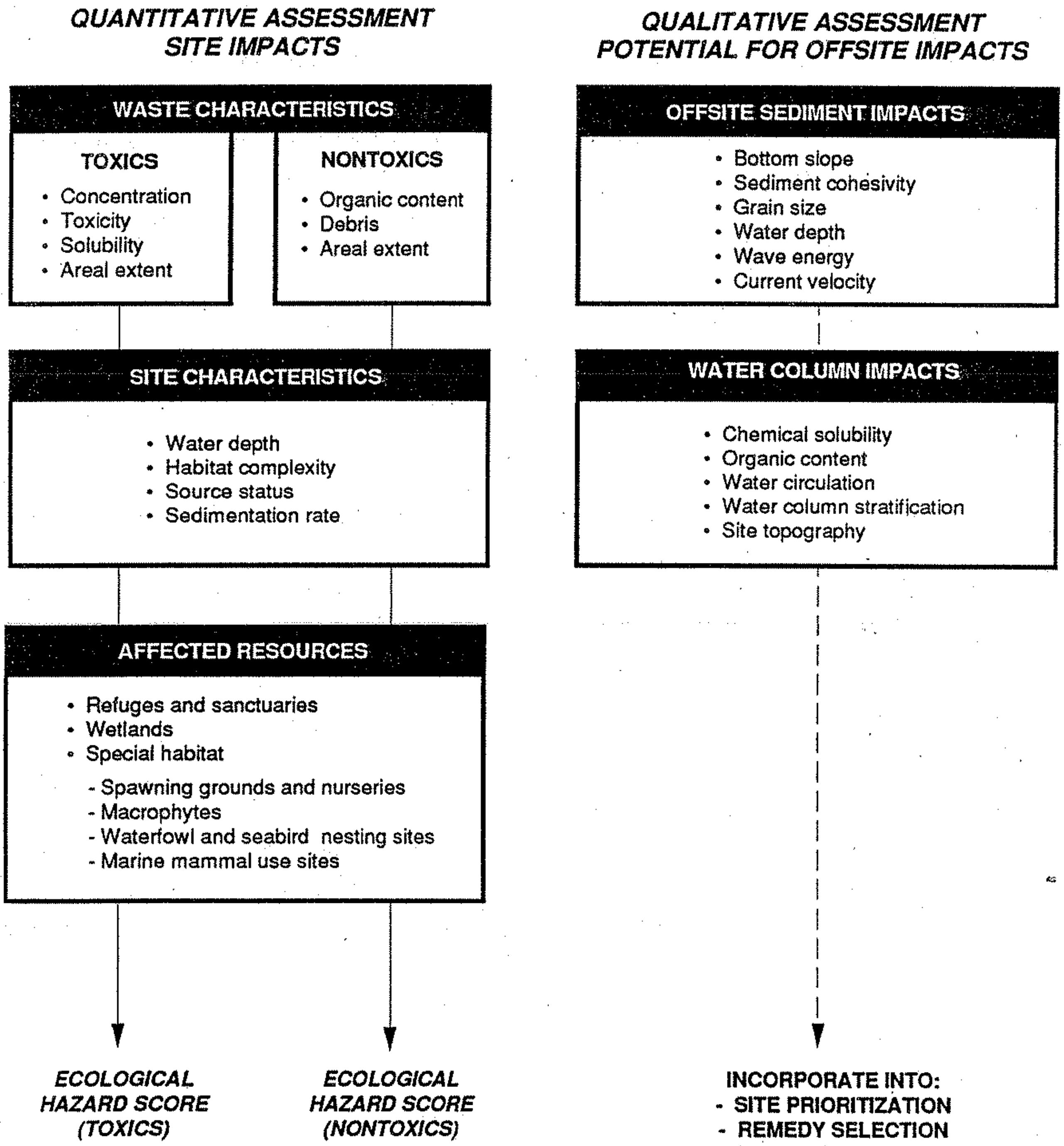

Figure 3. Factors included in the ecological hazard evaluation.

organic matter is essential to the productivity of marine ecosystems, elevated concentrations of organic carbon can cause adverse effects by supporting increased bacterial activity that depletes the oxygen in sediments. This effect decreases the diversity of the benthic community and enhances the productivity of opportunistic organisms. Extremely high organic loading rates can result in complete depletion of oxygen in sediments and in some cases can even deplete the overlying water of oxygen, especially when water circulation is restricted. This process renders the sediments toxic to all higher life forms. Debris such as plastic wastes can result in death due to entanglement or ingestion. While plastic wastes associated with Puget Sound sediments are not known to pose a serious threat to the benthic community or demersal fish, these organisms have been included in the ranking system for future consideration.

The persistence of chemical contaminants is a function of their susceptibility to biodegradation or biotransformation and their tendency to diffuse across the sediment-water interface (based on solubility). A loss factor, derived from an evaluation of these chemical properties, is included in the assessment of contaminant characteristics because these processes influence the rate at which a site will recover naturally after sources of contamination have been controlled. However, very little data on the *in situ* degradation rate of chemical contaminants in sediments are available, which limits the actual application of loss factors. In this ranking system, persistence is represented by solubility.

The areal extent of sediment contamination is defined by a straightforward assessment of the area of sediments that exhibit sediment concentrations exceeding sediment quality standards or that exhibit unacceptable concentrations of organic matter or debris. This simplified definition of spatial magnitude is justified by the fact that biological effects are derived from contamination at or near the sediment-water interface. Deeply buried waste is less ecologically relevant because the biologically active zone typically extends only 10 to 20 cm below the sediment surface.

Site Characteristics—The quality of a site as a potential habitat for aquatic life is the most important site characteristic for assessing ecological hazard. Although many factors can influence the habitat quality of sites in Puget Sound, two of the most important factors are depth and habitat complexity. Animal assemblages in shallow habitats are often more productive and diverse than assemblages in the deeper areas of the sound. Shallow habitats also provide spawning grounds and nursery areas for many species, and are the habitats that are most accessible for human use and misuse. The shallowest habitats are intertidal areas, which support unique animal assemblages and are particularly vulnerable to human impacts. Animal assemblages in habitats characterized by spatial complexity are usually more productive and diverse than habitats that are relatively monotonous in character. Spatial complexity in the form of macrophytes, rocks, and shell hash create numerous microenvironments that are not found in typical soft-bottom habitats. Depth and habitat complexity are therefore used in the ranking scheme as the key characteristics for evaluating the potential habitat quality of a site.

Water depth is a readily available parameter that is well correlated with the potential of a site to support aquatic life. Sediments underlying deep water (i.e., >100 feet) do not generally support diverse communities or sensitive life stages. The extent to which sediments are covered with macrophytes is another important predictor of habitat quality. Aquatic macrophytes provide microenvironments for many species and breeding grounds for some others (e.g., eelgrass are used as breeding grounds for herring). Finally, sites with a high degree of spatial complexity can provide microenvironments for diverse aquatic species. This parameter is represented in the site assessment as the presence or absence of vertical relief (such as underwater rocks or reefs).

The potential for a site to recover naturally is included in the evaluation of site characteristics. This potential is a function of chemical persistence (included under contaminant characteristics), the sediment accumulation rate (i.e., the rate at which clean sediments accumulate and bury contaminated sediments), and the rate and degree of mixing of surface sediments by the activities of benthic organisms. Recovery potential is essential to any assessment of sediment contamination because it may guide the timing and form of potential remedial action at the site. For example, if Sites A and B are contaminated by historical sources and display similar degrees of sediment contamination, but Site B is located in a depositional environment with a high sediment accumulation rate, Site A should be ranked higher for remedial action (because Site B has a greater potential to recover naturally).

Affected Resources—Affected resources are defined as those organisms that occupy or are directly exposed to contaminated sediments at a site. Affected resources include demersal fish, benthic macroinvertebrates, benthic megainvertebrates, and macrophytes. Organisms associated with the types of habitat described in the previous section are assigned a similar status or degree of importance. The primary difference between affected resources and site characteristics is that the potential for a site to support a valuable or sensitive habitat type is assessed for site characteristics, while the existing community is assessed for affected resources. In effect, this scoring category gives greater weight to existing ecosystems that are exposed to sediment contamination than to ecosystems that would be present under ideal conditions.

2.1.2 Offsite Impacts

Any process that transports contaminated sediments offsite has conflicting environmental implications. The impacts of onsite contamination are potentially decreased, but the threat of offsite impacts increases. The remedial action required to solve the problem increases in complexity because the contaminants have been dispersed. Offsite impacts are a potential problem only in areas that are susceptible to sediment resuspension or mass movement. Only areas with relatively high chemical concentrations are of concern because the transport process would dilute and disperse the contamination, thereby decreasing toxicity. Even if no resources are present downstream, the dispersion of contaminants minimizes the feasibility of remedial action and must be considered when prioritizing and timing remedial actions.

The waste characteristics used to assess site impacts are also used to assess offsite impacts. The potential for offsite impacts is a function of site characteristics that enhance sediment resuspension or large-scale transport. The primary processes that act to move sediments are current flow (including river flow), storm and wave energy, and slumping. The size of particles that can be transported by currents is directly related to current velocity (i.e., greater current velocities transport larger particles). This is reflected in observed distribution patterns of sediment grain sizes. Only coarse-grained sand can accumulate in areas where current velocities are high, while fine-grained sediments accumulate in relatively quiescent environments. Storms, wave energy, and shipping traffic resuspend sediments in relatively shallow environments where sediments are more easily transported by currents. Sediment slumping may occur as gravity acts to stabilize sediments that have accumulated on a slope.

Downgradient resources could be impacted by contaminated sediments that have migrated offsite. The sensitive resources described in the *Site Impacts* section are also of concern for offsite impacts. Hence, the downstream or downgradient proximity of sensitive resources is another factor that must be included in the assessment of offsite impacts. The distance to sensitive resources downstream of the site is also included in the assessment of affected resources.

2.1.3 Water Column Impacts

Water column impacts are most important in areas where soluble contaminants present in the sediments can diffuse into the water column and affect water quality. The two major categories of water column impact are oxygen depletion and chemical contamination. In general, these effects would be of greatest concern in areas where water is relatively stagnant and the residence time of water is relatively long.

The solubility of contaminants is the primary characteristic that indicates the potential impact on water quality. EPA water quality criteria for aquatic life (i.e., seawater) are the most appropriate index of potential water column toxicity of organic chemicals and metals. Oxygen depletion, the most common water quality impact in Puget Sound, is related to the organic loading rate and water circulation. This condition occurs naturally in some areas (e.g., Dabob Bay). Organic matter is only included as a contaminant when elevated loading rates are attributed to anthropogenic activities (e.g., sediments underlying salmon pens).

Site characteristics are extremely important in determining if sediment contamination will impact the quality of overlying water. In general, any condition that increases the residence time of water (i.e., the length of time a parcel of water stays in a given area) will increase the likelihood of water column impacts. Areas with poor circulation that are constrained by topography (e.g., isolated inlets or fjord-like inlets with sills that restrict the exchange of deep water) are candidates for water column impacts. Stratified conditions, where the vertical exchange of water is restricted by steep density gradients, can also enhance water quality degradation.

In addition to the same sensitive resources described for site impacts, resources that would be impacted by deteriorated water quality include all fish, plants, marine mammals, and zooplankton.

2.2 HUMAN HEALTH HAZARD

The two exposure pathways included in the assessment of human health hazard are site impacts and offsite impacts. Both of these exposure pathways can be assessed by evaluating relevant waste characteristics, site characteristics, and affected resources. Offsite-related exposure is considered a secondary exposure pathway because mechanisms that transport chemicals that can be bioaccumulated generally act to disperse and dilute them. The primary differences between human health hazard and ecological hazard assessments are derived from differences in the contaminants and resources of concern. Factors evaluated to characterize human heath risk are summarized in Figure 4.

2.2.1 Site Impacts

The fundamental assumption about the relationship between contaminated sediments and human health effects is that seafood consumption is the most sensitive indicator of human health hazard. The bioaccumulation of chemicals by edible organisms exposed to sediment contamination at a site is the primary exposure pathway for assessing the overall human health hazard posed by a contaminated sediment site. The exposure rate from other pathways is low relative to that resulting from seafood consumption (Becker et al. 1989).

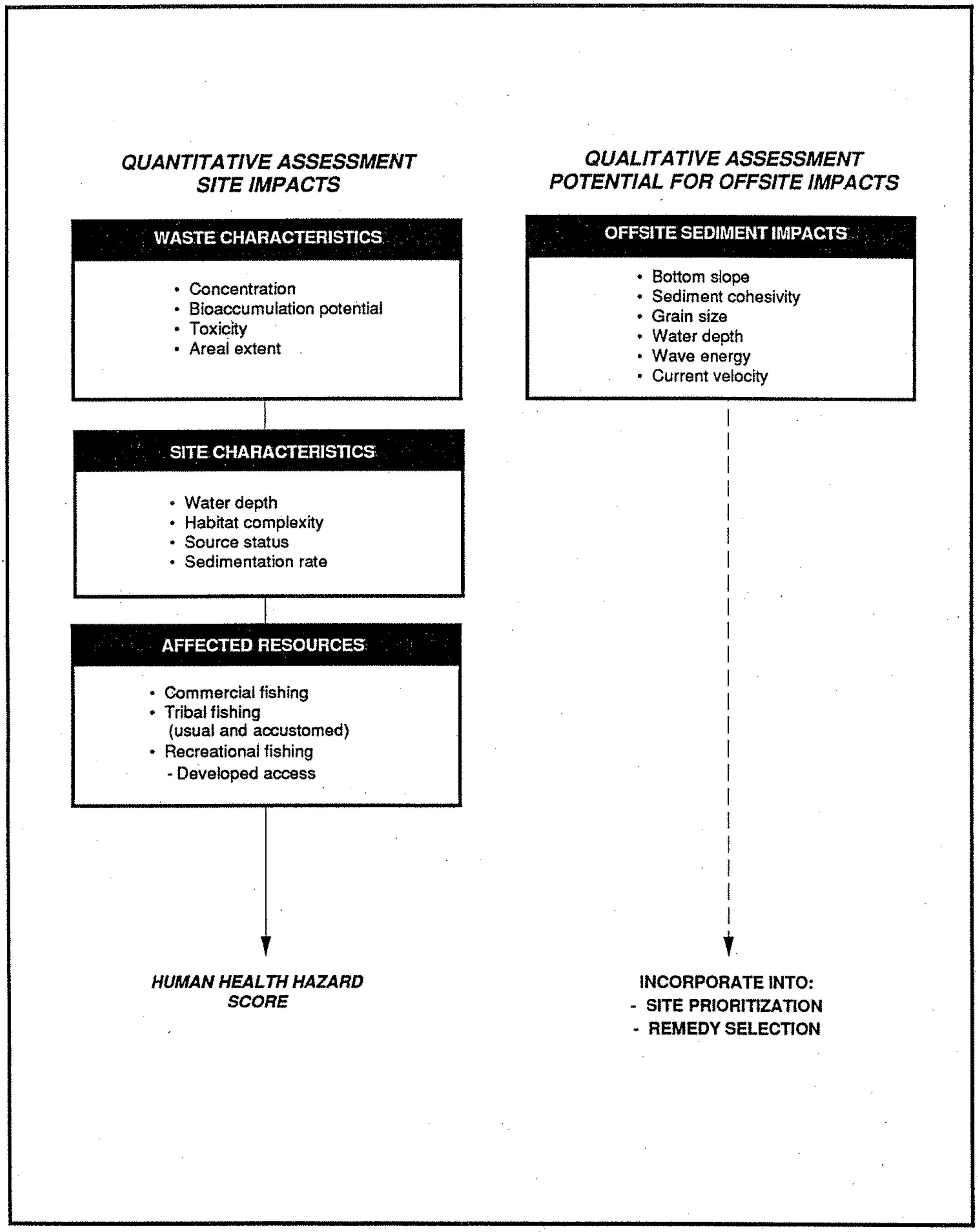

Figure 4. Factors included in the human health hazard evaluation.

Waste Characteristics—The key characteristics of contamination that determine the threat posed to human health are concentration, bioaccumulation potential, toxicity, persistence, and areal extent. Persistence is not included in the interim approach presented here. The assessment of waste characteristics for human health is less straightforward than ecological hazard assessment because sediment quality standards representative of human health hazard have not yet been established. The interim approach presented here will be revised when sediment quality standards for human health are developed.

In the absence of sediment quality standards, net toxicity of a given chemical can be assessed by evaluating relative concentration, bioaccumulation potential, and toxicity. The concentration of a given chemical is assessed relative to reference conditions. For naturally occurring chemicals (e.g., metals, polycyclic aromatic hydrocarbon) or ubiquitous man-made chemicals (e.g., polychlorinated biphenyls), reference concentrations are often measurable by conventional analytical techniques. For other chemical contaminants (e.g., dioxins, chlorinated hydrocarbons) reference concentrations are often defined by analytical detection limits. In the latter case, elevation above reference concentrations is less meaningful because it does not provide an index of relative magnitude (or risk), but is instead an artifact of analytical limitations.

Bioaccumulation potential is the degree to which living organisms will take up and retain chemical contaminants from all exposure pathways including intake of food and water and contact with sediments. Bioaccumulation potential is determined by environmental influences on bioavailability (e.g. dispersion sedimentation and degradation), physiologic mechanisms of uptake and elimination, and the chemical properties of the substance. Chemical properties are the most important of these three factors and influence the other two factors. The octanol-water partition coefficient (K_{ow}) is considered to be the best indicator of bioaccumulation potential for organic chemicals (Tetra Tech 1985) on the basis of the following:

- Empirical tests using octanol-water partition coefficients produced an order of magnitude estimate of the bioconcentration of discharged substances in fish liver

- It is a reasonable model for partitioning between water and biological tissues

- It can be used to predict soil sorption coefficients and is thereby useful in predicting equilibrium partitioning among sediments, water, and biota.

Chemical indices, such as log K_{ow}, have not been developed for metals, so the system must be adjusted in order to rank organic chemicals and metals together. Bioconcentration factors (BCFs) can be used because they have been empirically determined for many metals and organics that are present as contaminants in sediments. Tetra Tech (1985) calculated BCFs as the ratio of the concentrations of organic contaminants in fish liver to the concentrations in sewage discharge effluent. BCFs are empirically derived and can vary widely, introducing uncertainty into the ranking. Consequently, they are not used in a direct quantitative evaluation. However, BCFs are the best relative measure of bioaccumulation potential for chemicals for which K_{ow} are not available or relevant (e.g., chemicals that undergo biotransformations that influence their potential to bioaccumulate).

Relative toxicity is based on the toxicity ranking for surface water developed in the WARM Scoring Manual. The WARM system derives scoring based on values developed by EPA including drinking water standards, guidelines of chronic oral toxicity, acute toxicity values, and carcinogenic potency factors.

The rationale for including areal extent in the assessment of contamination characteristics is the same as that described for ecological hazard assessment (Section 2.1.1).

Site Characteristics—Site characteristics that enhance or diminish the potential for human exposure to local resources are important elements of the site assessment. The factors used to assess site characteristics that are relevant to human health are the same as those described for ecological hazard. Both the depth and habitat complexity of a site can influence human exposure to local resources. Because of their proximity to shore, shallow habitats are usually more accessible to humans than are deeper habitats. Because of the diverse fauna that usually resides in complex habitats, humans are often attracted to those environments (rather than relatively monotonous soft-bottom habitats) for fishing or scuba diving.

Affected Resources—Resources that are relevant to the assessment of human health hazard include all edible species that are harvested commercially or recreationally. Resources must be present at or near the site to be considered affected. Developed access points that encourage recreational fishermen to fish in particular locations are a special concern because they increase potential contaminant exposure.

2.2.2 Offsite Exposure

Offsite impacts are a secondary concern for human health because the processes that transport sediment-borne contamination away from a site also act to disperse and dilute the chemical constituents, resulting in a decrease in chemical concentration in exposed organisms. The rationale for including offsite impacts in the assessment of human health hazard is essentially the same as that described for ecological hazards. The primary differences are the distinctions made in defining downgradient resources that are harvested commercially or recreationally as edible species.

The contamination characteristics used to assess site impacts (Section 2.2.1) are also pertinent to offsite impacts. The potential for offsite impacts is a function of site characteristics that enhance sediment resuspension or large-scale motion. The transport processes described in Section 2.1.2 are also pertinent to the evaluation of offsite-related exposure to human health. Resources that are relevant to the assessment of human health hazard include all edible species harvested commercially or recreationally that could be exposed to sediments transported offsite.

3. DATA AVAILABILITY

An evaluation of the availability of data needed to conduct site ranking was performed 1) to identify appropriate formats for organizing information, 2) to constrain the ranking system to include only information that was readily available or obtainable, and 3) to develop reference tables of readily available information. Scoring criteria that rely on incomplete or unobtainable information will be eliminated from SEDRANK. Availability of the following types of scoring criteria was assessed:

- Data pertinent to waste characterization
  - Sample-specific measurements (chemical concentrations, sediment grain size, organic content)
  - Areal extent of contamination
  - Sediment standards
  - Chemical solubility
  - Octanol-water coefficients (K_{ow})
  - Chemical degradability
  - Presence of debris.
- Data pertinent to site characterization
  - Bathymetry (i.e., water depth and vertical relief)
  - Sediment grain size
  - Organic content of sediments
  - Current velocity

- Sediment accumulation rate.

■ Data pertinent to definition and location of affected resources

  - Shellfish resources
  - Bottomfish resources
  - Spawning grounds
  - Eel grass and kelp beds
  - Coastal wetlands
  - Waterfowl and seabird nesting areas
  - Wildlife refuges and sanctuaries
  - Major mammal usage areas
  - Usual and accustomed tribal fishing areas.

Sources of this information are described in the following sections.

3.1 DATA ASSOCIATED WITH WASTE CHARACTERISTICS

Data associated with waste characteristics address both the actual distribution of chemicals and the physical characteristics of individual chemicals. Therefore, these characteristics are both chemical-specific and site-specific in nature.

3.1.1 Chemical Concentration

The concentration of a contaminant of interest is a site-specific characteristic. Chemical concentration can be presented on maps [preferably using a geographic information system (GIS)] or as a reference data file or table. SEDQUAL, the Puget Sound database of chemical contaminant concentrations (Nielsen 1989) is a source for much of the available chemical data. SEDQUAL includes data generated under the PSDDA program, PSEP, reference area studies, and selected Superfund investigations. The most comprehensive studies included in the SEDQUAL database are described in Barrick et al. (1988). All of the data in SEDQUAL were validated based on associated quality assurance/quality control information before they were entered into the database.

3.1.2 Areal Extent of Contamination

Areal extent of contamination is a site-specific scoring characteristic and is best portrayed on maps (e.g., with GIS). Chemical data and associated station locations are available in SEDQUAL.

3.1.3 Sediment Standards

Sediment standards are chemical-specific values that represent a long-term goal for the protection of the quality of Puget Sound sediments. The sediment quality standards are designed to establish levels of sediment contamination that would be acceptable throughout Puget Sound and to provide a basis for preventing future contamination. Interim sediment quality standards were established in December 1989 (Ecology 1989). These values are presented in Appendix A.

3.1.4 Chemical Solubility

Chemical solubility in water is a chemical-specific characteristic that is determined experimentally. This type of data is best presented in tables or reference data files. This information is available in *Superfund Public Health Evaluation Manual* (U.S. EPA 1986) and the National Library of Medicine *Hazardous Substances Data Bank* (HSDB 1989). The data contained in HSDB (1989) are derived from standard texts and updated with information from government documents, technical reports, and primary journal literature. HSDB (1989) has records for over 4,100 potentially toxic chemicals. Solubility data relevant to problem chemicals in Puget Sound will be summarized in a subsequent version of SEDRANK.

3.1.5 Octanol-Water Partition Coefficients

K_{ow} values (i.e., the measure of chemical distribution between water and octanol at equilibrium) are chemical-specific data that are determined experimentally. This type of data is best presented in tables or reference data files when available. K_{ow} data are available in HSDB

(1989) and U.S. EPA (1986). Octanol-water partition coefficients relevant to problem chemicals in Puget Sound will be summarized in a subsequent version of SEDRANK.

3.1.6 Chemical Degradability

Chemicals can be degraded by chemical and biological processes. The rate of degradation can be both chemical-specific and site-specific. Data on chemical degradability are best presented in tables or reference data files when available. Much of the existing data has been determined experimentally under very controlled conditions, and may not be applicable to *in situ* conditions. Chemical degradability data obtained under environmental conditions are very sparse. Because so little data on the degradability of chemicals exists, this parameter should not be considered in SEDRANK. Tetra Tech (1987) contains a thorough review of existing degradation studies for many organic compounds of concern in Puget Sound.

3.1.7 Debris

No effort has been made to quantify the amount of nontoxic debris in the sediments of Puget Sound (Hauger, B., 27 November 1989, personal communication). Information has been gathered on the amount of beach debris in the Puget Sound area, but the amount of debris was not scientifically quantified (e.g., number of bags of debris on a given stretch of beach; Hauger, B., 27 November 1989, personal communication).

3.2 DATA ASSOCIATED WITH SITE CHARACTERISTICS

Data associated with site characteristics address composition and physical properties of the sediments at a site and the hydrodynamics associated with the site. Therefore, all criteria in this section are site-specific.

3.2.1 Bathymetry

Bathymetry is best presented on a contour GIS map of the area of interest. Digitized contour map tapes of Puget Sound are available through the National Geophysical Data Center in Boulder, Colorado (Lavelle, J.W., 21 November 1989, personal communication). To obtain a tape, one must specify the required grid size, and the National Geophysical Data Center will provide the tape for approximately $300.

3.2.2 Sediment Grain Size

Sediment grain size distributions are site-specific data that are best presented on maps. The most complete synthesis of grain size information in Puget Sound is contained in maps compiled by Roberts (1974). These maps are published in the *Puget Sound Environmental Atlas* (PSEP 1987). Grain size data were also compiled on a site-specific basis for the studies included in SEDQUAL, described in greater detail in Section 3.1.1.

3.2.3 Organic Content of Sediments

Organic content of sediments or total organic carbon analyses are routinely performed along with chemical analyses, because chemical data are often normalized to total organic carbon levels. These data are available in SEDQUAL.

3.2.4 Current Velocity

The velocities of currents in Puget Sound have been summarized in two of three volumes of *Synthesis of Current Measurements in Puget Sound, Washington* (Cox et al. 1984; Ebbesmeyer et al. 1984). These volumes contain current data collected from 1908 to 1980. The data are presented as vertical profiles. Because these data were collected under many conditions (e.g., from platform moored and moored buoy instruments), an estimate of the data quality was provided with the respective measurements. Additional data were collected from 1982 to 1986. These data have not been published, but have been archived. It is available through the National Oceanographic Data Center, Washington, D.C. (Stillwaugh, S., 27 November 1989, personal communication). Net water currents are also presented in PSEP (1987).

3.2.5 Sediment Accumulation Rates

Sediment accumulation rates in Puget Sound have been inferred through the interpretation of ^{210}Pb activity profiles in sediment cores. Sediment accumulation rates are best presented on GIS maps. Two major studies (Carpenter et al. 1985; Lavelle et al. 1986) contain most of the sediment accumulation rate data for Puget Sound (a total of 43 stations). Sediment accumulation rates were also determined as part of the Commencement Bay Superfund investigation (Tetra Tech 1987) and the Eagle Harbor Superfund investigation (CH2M Hill 1989).

3.3 DATA ASSOCIATED WITH SENSITIVE RESOURCES

The proximity of sensitive resources to a site can be best evaluated using detailed maps of different types of sensitive resources. Sensitive resources considered in the ecological hazard assessment include shellfish, groundfish, spawning grounds, eelgrass and kelp beds, coastal wetlands, waterfowl and seabird nesting areas, wildlife refuges and sanctuaries, and marine mammal use areas. Sensitive resources included in the human health assessment include edible resources used by tribal, recreational, and commercial fisheries.

3.3.1 Shellfish Resources

Locations of shellfish (i.e., oysters, clams and geoducks, shrimp, and Dungeness crab) resources in Puget Sound are contained in PSEP (1987). These data are contained in maps by geographic section of Puget Sound. Data contained in PSEP (1987) are the most current information available for shellfish resources in Puget Sound (Carman, R., 1 December 1989, personal communication). Locations of shellfish resources are also mapped in the *Second Annual Inventory of Commercial and Recreational Shellfish Areas in Puget Sound* (DSHS 1989). Shellfish resources that are susceptible to oil spills (i.e., in ≤60 feet of water) are contained in NOAA (1987).

3.3.2 Bottomfish Resources

Locations of major bottomfish (e.g., flatfish, rockfish, etc.) resources in Puget Sound are mapped in PSEP (1987).

3.3.3 Spawning Grounds

Locations of herring and surf smelt spawning areas in Puget Sound are mapped in PSEP (1987) and NOAA (1987).

3.3.4 Eelgrass and Kelp Beds

Locations of eel grass and kelp beds in Puget Sound are mapped in PSEP (1987) and NOAA (1987).

3.3.5 Coastal Wetlands

Locations of coastal wetlands in Puget Sound are mapped in PSEP (1987). Additional information are presented in NOAA (1987).

3.3.6 Waterfowl and Seabird Nesting Areas

Locations of waterfowl and seabird nesting areas in Puget Sound are mapped in PSEP (1987). Data for locations of waterfowl habitats are also mapped in PSWQA (1988) and NOAA (1987).

3.3.7 Wildlife Refuges and Sanctuaries

Locations of Puget Sound wildlife areas and sanctuaries in Puget Sound are mapped in PSEP (1987).

3.3.8 Major Marine Mammal Use Areas

Locations of major marine mammal use areas in Puget Sound are mapped in PSEP (1987). Major marine mammals for which data are reported include harbor seals, northern sea lions, California sea lions, Dall's porpoises, harbor porpoises, and Minke whales. Locations of seal and sea lion haulouts in Puget Sound are mapped in PSWQA (1988). Locations of harbor seals and river otters are presented in NOAA (1987).

3.3.9 Usual and Accustomed Tribal Fishing Areas

Locations of usual and accustomed tribal fishing areas in Puget Sound are mapped in U.S. PSEP (1987). Salmon harvesting areas are also mapped in the *State of the Sound 1988 Report* (PSWQA 1988).

4. SCORING METHODOLOGY AND QUALITATIVE ASSESSMENT

The assessment of ecological and human health hazards is conducted both quantitatively and qualitatively. Hazards directly related to site exposure are assigned numerical scores. Hazards associated with the migration of site contaminants (i.e., offsite sediment or water column impacts) are assessed qualitatively. An interim scoring process was developed to quantify chemical toxicity for the human health hazard assessment. An interim approach was needed because sediment quality standards, which form the basis of the ecological hazard assessment, have not yet been developed for human health.

The questionnaire/checklist approach to scoring and assessment was selected because it is consistent, simple, and easy to use. This simplified approach to hazard assessment is also appropriate because it is likely that available data on contamination, the site, and sensitive organisms will be limited. Data limitations constrain the applicability of complex models, which generally require a great deal of site-specific information. However, more complex approaches to characterizing specific factors (e.g., the use of the AET approach to characterize contamination) are simplified and incorporated into the scoring process.

A few general rules are followed in defining and combining mathematical relationships:

- **Multiplicative relationships**—In general, multiplicative relations are used to combine closely interrelated categories. For example, scores for major factor categories (i.e., waste characteristics, site characteristics, and affected resources) are multiplied to derive the total exposure pathway score.

- **Additive relationships**—Additive relationships are used to combine scores for factors that are in the same factor category. For example, chemical-specific enrichment ratios (relative to sediment quality standards) are summarized in the waste characterization for ecological hazard.

- **Scoring tables**—Scoring tables are used to convert more complex information to a simple numerical score or to quantify a qualitative characteristic. There are two types of scoring tables, those that relate a monotonically increasing or decreasing physical characteristic to a numerical score (e.g., organic carbon content), and those that relate a qualitative assessment of a characteristic to a score (e.g., habitat quality).

- **Scoring matrices**—Scoring matrices are similar to scoring tables, except that they assign a single score to two or more related characteristics. For example, scores for waste characteristics under human health hazard are derived from the relationship between concentration, toxicity, and potential to bioaccumulate (i.e., a 3-dimensional matrix).

- **Reference tables**—Reference tables present data needed to assign chemical-specific scores. For example, chemical loss factors are based on chemical-specific solubility ratings, which are summarized in Appendix A.

In general, the scoring algorithms presented here are preliminary, and will be refined during the field validation of the ranking system. The mathematical relationships selected to represent the complex relationship between scoring categories and factors are simplifications. The relationship between major scoring categories (i.e., waste characteristics, site characteristics, and affected resources) are in part based on the mathematical relationships developed for the federal hazard ranking system. Future refinements to SEDRANK will include an evaluation of the interdependence of weighting factors, scales, and mathematical relationships. The mathematical relationship developed to represent chemical toxicity for the ecological hazard score was developed by evaluating the number and magnitude of sediment quality standard exceedances for each station in the existing SEDQUAL database. Details of this analysis are provided in Appendix B.

Techniques for mathematically combining the ranking factors described in Section 2 are discussed in Sections 4.1 and 4.2. The process for the qualitative assessment of offsite impacts is described in Section 4.3.

4.1 ENVIRONMENTAL HAZARD SCORE

The score for ecological hazard (EH) is derived from the values assigned to waste characteristics, site characteristics, and affected resources using the following algorithm:

$$EH = [\text{Waste Characteristics}] \times [\text{Site Characteristics} + \text{Affected Resources}] \qquad (1)$$

The maximum score for ecological hazard is 100. The maximum scores for waste characteristics, site characteristics, and affected resources are 10, 5, and 5, respectively.

4.1.1 Waste Characteristics

For each site, three different waste characteristic scores can be assigned. The highest of these will be used to develop a site hazard score. Waste characteristics scores are based on the following equation:

$$\text{Waste Characteristics} = \begin{matrix} \frac{10}{30} \text{ Chemical Toxicity or} \\ \frac{10}{30} \text{ Organic Content or} \\ \frac{5}{15} \text{ Debris} \end{matrix} \times \text{Areal Extent} \quad (2)$$

The factor $\frac{10}{30}$ scales the waste characteristics score (based on chemical toxicity or organic content) to a maximum value of 10. The factor $\frac{5}{15}$ normalizes the waste characteristics score (based on debris) to a maximum value of 5.

Chemical Toxicity—The chemical toxicity value is derived from the chemical toxicity index, which is a function of all chemical contaminants that exceed sediment quality criteria. It is derived from the following equation:

$$\text{Chemical Toxicity} = (1/N) \times (L_1C_1/P2_1 + L_2C_2/P2_2 + L_3C_3/P2_{X3} \ldots + L_XC_X/P2_X) \quad (3)$$

where: L_x = Loss Factor of chemical x
C_x = Measured concentration of chemical x
$P2_x$ = Interim sediment quality standard of chemical x
N = Scaling factor.

The maximum score for chemical toxicity is 10. All values greater then 10 are assigned a value of 10. The value selected for N will be determined after field testing of the sediment ranking system. Preliminary, station-specific scores for chemical toxicity were determined for all stations in the SEDQUAL database that had chemical concentrations exceeding interim sediment quality standards (see Appendix B for details). This exercise was conducted to determine if a preliminary value for the scaling factor, N, could be determined prior to field testing the ranking system. Because the distribution of values was highly skewed, it was determined that N would be refined after conducting site-specific evaluations of toxicity factors. It is likely that the refined chemical toxicity score will be based on an average of several stations rather than the highest ranking station. In effect, using average concentrations would narrow the observed distribution of toxicity scores.

Chemical toxicity is calculated by the following steps:

Step 1: Identify all chemicals that exceed sediment quality criteria and calculate the ratio (C/P2) for each chemical. The maximum value for C is selected from all stations on the site. Values for P2 are summarized in Table A-1 in Appendix A.

Step 2: Determine the loss factor assigned to each chemical by determining the classification (i.e., high, medium, or low) and assigning the appropriate loss factor summarized in Table 1.

Step 3: Calculate chemical toxicity from Equation 3. All scores greater than 10 are assigned a 10.

Organic Content—The score for organic content is selected from Table 1 on the basis of the concentration of total organic carbon.

Debris—The score for debris is selected from Table 1. The concentration of debris is not considered to be an appropriate index, so debris is simply determined to be either present (5) or absent (no score).

Areal Extent—The score for areal extent is developed independently for each of the different indices of toxicity. For chemical toxicity, areal extent is the area encompassing all stations that exceed P2 standards. Areal extent (yd^2) is then divided by 100,000 yd^2 to obtain the areal extent score. All scores that exceed 3 are assigned a score of 3.

Total Waste Characteristics Scores—The final score for waste characteristics is calculated from Equation 2. For each site, three different waste characteristics scores can be assigned: 1) chemical toxicity, 2) elevated organic content, and 3) debris. These three scores are treated separately because most sites will only qualify for a single score. In cases where a site receives a waste characteristics score in more then one of these categories, the highest score is assigned. Waste characteristics scores that are based on organic content or debris are assigned qualifiers (C or D, respectively) that are carried through all subsequent calculations. The final ecological hazard score is qualified accordingly.

TABLE 1. ECOLOGICAL HAZARD SCORE–
WASTE CHARACTERISTICS

Loss Factor

Solubility	Assigned Value
Low	1.0
Medium	0.9
High	0.8

Organic Matter

Concentration Range (percent)	Assigned Value
<3	0
3-5	5
>5	10

Debris

Concentration Range	Assigned Value
Absent	0
Present	5

4.1.2 Site Characteristics

The site characteristics score is determined from an assessment of the quality of habitat at the site and the potential for the site to recover naturally. The site characteristics score is calculated from the following relationship:

$$\text{Site Characteristics} = \text{Habitat Quality} \times \text{Recovery Factor} \tag{4}$$

The maximum score for site characteristics is 5.

Habitat Quality—The habitat quality score is selected from Table 2. Habitat quality is represented by two factors: depth and habitat complexity. The score for depth can range from 1 to 4, and increases with decreasing depth. The maximum score of 4 is given to any site that includes intertidal areas because these ecologically important habitats are relatively rare in Puget Sound.

The score for habit complexity can range from 1 to 3, and increases with increasing complexity. The characteristics of the three scores are as follows:

- **Minimal Complexity = 1:** Primarily a relatively homogenous soft-bottom habitat with little or no relief; areal extent of macrophytes, rocks, shell hash, or other habitat enhancing material is less than 10 percent; few microenvironments are available outside of those found in a typical soft-bottom environment

- **Moderate Complexity = 2:** A soft-bottom habitat with a moderate degree of spatial complexity; areal extent of habitat enhancing material is between 10 and 50 percent; some relief; a moderate number of microenvironments are available

- **High complexity = 3:** A soft-bottom habitat with a relatively high degree of spatial complexity or a primarily hard-bottom habitat; areal extent of habitat enhancing material is greater than 50 percent; diverse relief; a relatively large number of microenvironments is available.

Recovery Factor—The recovery factor is selected from Table 2. The maximum possible recovery factor is 1.0 and the minimum recovery factor is 0.1. Recovery factors generally decrease

TABLE 2. SITE CHARACTERISTICS SCORE

Habitat Quality (Depth)

Value	Score
>100 feet	1
50-100 feet	2
0-50 feet	3
Site includes intertidal	4

Habitat Quality (Habitat Complexity)

Characteristics	Score
Little or no relief, <10 percent habitat enhancement, few microhabitats	1
Some relief, 10-50 percent habitat enhancement, moderate number of microhabitats	2
Diverse relief, >50 percent habitat enhancement, many microhabitats	3

Recovery Factor

Source Status	Sediment Accumulation Rate (cm/year)	Assigned Value
Ongoing	<0.2	1.0
	0.2-2	0.9
	>2	0.8
Historical	0.2-0.4	0.8
	0.4-0.6	0.6
	0.6-0.8	0.5
	0.8-1.0	0.4
	1.0-1.4	0.3
	1.4-1.8	0.2
	>1.8	0.1

the total site characteristics score to explicitly recognize the potential at a particular site for natural recovery in the absence of remedial action. Recovery factors are developed for two categories of sources; ongoing and historical. The range in values for recovery factors for ongoing sources is severely constrained (i.e., the minimum recovery factor is 0.8) because the potential for a site to recover naturally is highly dependent on the degree of source control that is ultimately achieved. It is also dependent on the complex suite of processes that control the relationship between the release of contamination from a source and the net accumulation of contamination in sediments. In most cases this information will not be known prior to or during site ranking. For historical sources, the values assigned to the different sediment accumulation rates is based on the mathematical formula used in the SEDCAM model (Tetra Tech 1987):

$$C = \frac{M}{(M+kS)} \times CI \times \left[1 - e^{\left[\frac{-(kS+M)t}{S}\right]} \right] + CO \times e^{\left[\frac{-(kS+M)t}{S}\right]} \qquad (5)$$

where:

C = Concentration ($\mu g/g$) of contaminant in the surface mixed layer at t

CO = Concentration ($\mu g/g$) of contaminant in the surface mixed layer at t=0

CI = Concentration of contaminant in freshly deposited material after source control (mg/g)

M = Rate of mass accumulation of solid material in the sediments after source control ($g/cm^2/yr$)

S = Total accumulation of sediments in the surface mixed layer (g/cm^2)

k = Combined first-order rate constant for contaminant loss by *in situ* degradation and diffusive loss (1/year)

t = time (years).

If the concentration of incoming contamination is reduced to zero, and if it is assumed that the first order degradation constant in the formulation is 0, the SEDCAM equation reduces to the following:

$$C/C0 = \exp\left[-(M/Z)t\right] \qquad (6)$$

where:

M = Sediment accumulation rate (cm/yr)
Z = Thickness of the mixed layer (cm)
t = Time (years).

Units have been adjusted in Equation 6 to eliminate sediment bulk density from the equation. For the purpose of developing recovery factors (i.e., C/C0) appropriate to the different ranges in sediment accumulation rate, it was assumed that 10 years is an acceptable time frame, and that the average thickness of the mixed layer is 10 cm.

The habitat quality score is calculated from the following equation:

$$\text{Habitat Quality} = \frac{5}{7}\ [\text{Depth (score)} + \text{Habitat Complexity}] \qquad (7)$$

The factor $\frac{5}{7}$ scales the habitat quality score to a maximum value of 5.

Total Site Characteristics Score—The total site characteristics score is calculated from Equation 4.

4.1.3 Affected Resources

The affected resources score is based on an assessment of the proximity of sensitive resources to the site. The affected resources score is selected from Table 3. Affected resources are represented by three general categories: wetlands, wildlife refuges and sanctuaries, and special marine habitats. Special marine habitats include important and sensitive areas such as spawning grounds, nursery areas, bird nesting areas, macrophyte beds, and areas used extensively by marine mammals. The score for these three categories can range from 1 to 3 for wetlands and special marine habitats, and from 1 to 2 for wildlife refuges and sanctuaries. The score increases with increasing probability that contamination at a site could influence one or more of the affected resources. This influence can occur in several ways. Onsite contamination could 1) directly affect resources that occupy the site, 2) affect offsite resources by being transported from the site, or 3) affect migratory organisms that periodically move into the site.

TABLE 3. ECOLOGICAL HAZARD SCORE—AFFECTED RESOURCES

Wetlands

Characteristics	Score
No wetland near or within site	1
Wetland near site	2
Wetland within site	3

Special Marine Habitats

Characteristics	Score
No special marine habitat near or within site	1
Special marine habitat near site	2
Special marine habitat within site	3

Wildlife Refuges and Sanctuaries

Characteristics	Score
No refuge or sanctuary near site	1
Designated refuge or sanctuary near or within site	2

For wildlife refuges and sanctuaries, a score of 1 is given to sites that have a low probability of affecting a refuge or sanctuary. A score of 2 is given to sites that have a moderate or high probability of affecting a government designated refuge or sanctuary. For wetlands and special marine habitats, scores of 1, 2, and 3 are given to sites that have low, moderate, and high probabilities (respectively) of affecting a wetland or special marine habitat.

The total score for affected resources is calculated from the following equation:

$$\text{Affected Resources} = (\text{Wetlands or Special Habitat}) + (\text{Refuge/Sanctuary}) \tag{8}$$

The maximum score for affected resources is 5.

4.2 HUMAN HEALTH HAZARD SCORE

The score for human health hazard (HH) is derived from the values assigned to waste characteristics, site characteristics, and affected resources using the following algorithm:

$$\text{HH} = (\text{Waste Characteristics}) \times (\text{Site Characteristics} + \text{Affected Resources}) \tag{9}$$

The maximum score for human health hazard is 100.

4.2.1 Waste Characteristics

The waste characteristics score is based on the following algorithm:

$$\text{Waste Characteristics} = \frac{10}{30}\,(\text{Net Chemical Toxicity} \times \text{Areal Extent}) \tag{10}$$

The factor $\frac{10}{30}$ scales the waste characteristics score to a maximum value of 10.

Net Chemical Toxicity—The net chemical toxicity value is derived from the chemical toxicity index, which is a function of enrichment ratio (i.e., observed concentration at the site normalized to reference concentration), bioaccumulation potential, and chemical toxicity. The toxicity score is based on a 3-dimensional matrix developed to interrelate these three chemical-specific characteristics.

Net chemical toxicity is calculated by the following steps:

Step 1: Identify all chemicals that have enrichment ratios ≥ 2. Calculate enrichment ratios on the basis of the maximum chemical concentration measured at any station on the site, divided by the reference area concentration (assumed to represent an acceptable level of risk to human health). Assemble all chemicals and associated enrichment ratios in the chemical toxicity scoring matrix (Table 4).

Step 2: For each chemical, determine the rating for bioaccumulation potential (i.e., high, medium, low). Summarize this information in the chemical toxicity scoring matrix.

Step 3: For each chemical, determine the rating for toxicity (i.e., very high, high, medium, low, very low) from Table A-2 in Appendix A and the associated reference sources. Summarize this information in the chemical toxicity scoring matrix.

Step 4: Determine the score for net chemical toxicity for each chemical on the basis of the three-dimensional matrix relating enrichment ratio, bioaccumulation potential, and chemical toxicity (Table 5). The maximum possible score for net chemical toxicity is 10.

Areal Extent—Calculate the score for areal extent by dividing the total area of sediments that exceed sediment quality standards by 100,000 yd^2. All scores for areal extent that exceed 3 are assigned a score of 3.

Total Waste Characteristics Score—The final score for waste characteristics is calculated using Equation 10.

4.2.2 Site Characteristics

The site characteristics score is determined from an assessment of the quality of habitat at the site and the potential for the site to recover naturally. The site characteristics score for human health hazard is the same as that for ecological hazard (Section 4.1.2).

TABLE 4. CHEMICAL TOXICITY SCORING MATRIX

Chemical	Enrichment		Bioaccumulation Potential		Toxicity		Total Score
	Ratio	Score	Rating	Score	Rating	Score	

TABLE 5. HUMAN HEALTH HAZARD SCORE—WASTE CHARACTERISTICS

High Chemical Concentration[a]

	Bioconcentration		
	Low	Medium	High
Very high	8	9.5	10
High	7.5	8	9.5
Medium	6.5	7.5	8
Low	5.5	6.5	7.5
Very low	5	5.5	6.5

Medium Chemical Concentration[b]

	Bioconcentration		
	Low	Medium	High
Very high	6	7	8
High	5	6	7
Medium	4	5	6
Low	3	4	5
Very low	3	3	4

Low Chemical Concentration[c]

	Bioconcentration		
	Low	Medium	High
Very High	3	3.5	4
High	2.5	3	3.5
Medium	2	2.5	3
Low	1.5	2	2.5
Very low	1	1.5	2

[a] Concentrations in sediments 100-1,000 times greater than reference concentrations.

[b] Concentrations in sediments 10-100 times greater than reference concentrations.

[c] Concentrations in sediments 1-10 times greater than reference concentrations.

4.2.3 Affected Resources

The affected resources score is based on an assessment of the proximity of edible resources to the site. The total possible score for affected resources is 3. The affected resources score is selected from Table 6. Affected resources are represented by two general categories: commercial and recreational fisheries. The score for commercial fisheries can range from 1 to 4. Scores of 1 to 3 increase with increasing probability that contamination at a site could influence a fishery resource. A score of 4 is given to a site that has a high probability of affecting a tribal fishing area, because a substantial amount of tribal fishing is focused on such areas. The score for recreational fisheries can also range from 1 to 4. Scores of 1 to 3 are based on criteria identical to those described for commercial fisheries. A score of 4 is given to a site that has a high probability of affecting a recreational fishing site that has developed access points, because such fishing sites tend to attract large numbers of fishermen and therefore increase potential exposure to contaminants. The influence of contamination on a fishery can occur in several ways. Onsite contamination could 1) directly affect a fishery that occupies the site, 2) affect an offsite fishery by being transported off the site, or 3) affect migratory organisms that periodically move into the site.

The total score for affected resources is calculated from the following equation:

$$\text{Affected resources} = \frac{5}{8}\,(\text{Commercial Fishery} + \text{Recreational Fishery}) \qquad (11)$$

The factor $\frac{5}{8}$ scales the affected resource score to a maximum value of 5.

4.3 QUALITATIVE ASSESSMENT OF WATER COLUMN IMPACTS AND OFFSITE MIGRATION

The qualitative assessment of water column impacts and offsite migration will be summarized on questionnaires. This information will be considered during site prioritization. For example, if offsite migration is anticipated, a highly contaminated (but small) site may be assigned a higher priority than warranted by the ranking score alone. Information on potential water column impacts and offsite sediment migration will also be considered during remedy selection.

TABLE 6. HUMAN HEALTH HAZARD–AFFECTED RESOURCES

Commercial Fisheries

Characteristics	Score
No fishery near or within site	1
Fishery near site	2
Fishery within site	3
Tribal fishery within site	4

Recreational Fisheries

Characteristics	Score
No fishery near or within site	1
Fishery near site	2
Fishery within site	3
Enhanced access	4

4.3.1 Water Column Impacts

Three types of water column impacts can potentially be attributed to a contaminated sediment site: oxygen depletion, water quality impacts associated with toxic chemicals, and excessive turbidity.

Oxygen depletion occurs naturally as organic matter falls through the water column and accumulates in the sediments. Oxygen depletion is associated with the microorganisms that degrade organic carbon and use oxygen as an electron acceptor, converting it to water. Extreme oxygen depletion can occur when insufficient oxygen is resupplied by diffusion across the air-sea interface or by exchange with oxygen-rich water parcels. Conditions that enhance the possibility of oxygen depletion in the water column should be explicitly noted during site evaluation. These conditions include excessive organic carbon in the sediments, low current velocity, geographically restricted circulation (e.g., a restricted waterway, basin, or fjord; presence of a sill isolating a basin from the large water body). Key questions relevant to oxygen depletion that should be considered during site evaluation are summarized in Table 7.

Water quality degradation associated with toxic chemicals cannot usually be attributed to contaminated sediments because in most cases the flux of contaminant from the sediments is readily diluted by the overlying water column. In general, water quality degradation must be attributed to terrestrial-based sources (e.g., outfalls, storm drains). However, under certain conditions the potential for sediment-derived impacts is enhanced, and these conditions should be explicitly noted during site evaluation. Key questions relevant to water quality degradation that should be considered during site evaluation are summarized in Table 7.

Excessive turbidity would be associated with relatively fine-grained sediment located in a high energy environment not conducive to accumulation of fine-grained material. This condition would be expected to persist only where an ongoing source continued to discharge fine-grained material to a high energy site, creating conditions of disequilibrium. This condition is not known to occur in Puget Sound, but should be recognized as a possibility for relatively fine-grained sites in areas of high current velocity or wave energy. Key questions relevant to turbidity that should be considered during site evaluation are summarized in Table 7.

4.3.2 Offsite Sediment Impacts

Offsite sediment impacts are associated with three sediment transport mechanisms: sediment slumping, resuspension associated with wave energy, and resuspension and reworking associated with current velocity. The particle size of sediments is important in all of these processes.

TABLE 7. EXAMPLES OF KEY QUESTIONS FOR THE ASSESSMENT OF WATER COLUMN IMPACTS

Assessment of the Potential for Water Quality Impacts

Have water quality impacts (oxygen depletion or elevated chemical concentrations) been documented in the area?

Are any of the chemicals that exceed sediment standards highly soluble in water?

Does the organic carbon content of the sediments exceed 5 percent?

Is the water column highly stratified? (can be seasonal)

Is the site located in a natural depression?

Is the site located in a fjord or basin with restricted circulation?

Is there a sill restricting circulation between the site and an adjacent water body?

Assessment of the Potential for Excess Turbidity

Are site sediments primarily of silt and clay?

Are site sediments generally finer-grained than adjacent sediments?

Is the maximum measured current velocity greater than 10 cm/sec?

Any process that transports contaminated sediments offsite has conflicting environmental implications. The impacts of onsite contamination are potentially decreased. However, the threat of offsite impacts increases, and the remedial action required to solve the problem increases in complexity, because contaminants have been dispersed. Offsite impacts are a potential problem only in areas that are susceptible to sediment resuspension or mass movement. Only areas with relatively high chemical concentrations are of concern because the transport process would dilute and disperse the contamination, decreasing toxicity. Even if no resources are present downstream, the dispersion of contaminants minimizes the feasibility of remedial action and will be considered in the site assessment.

The waste characteristics used to assess site impacts are also used to assess offsite impacts. The potential for offsite impacts is a function of site characteristics that enhance sediment resuspension or large-scale transport. The primary processes that act to move sediments are current flow (including river flow), storm and wave energy, and slumping. The size of particles that can be transported by currents is directly related to current velocity (i.e., greater current velocities transport larger particles). This is reflected in observed distribution patterns in sediment grain size. Only coarse-grained sand can accumulate in areas where current velocities are high, while fine-grained sediments accumulate in relatively quiescent environments. Storms, wave energy, and shipping traffic resuspend sediments in relatively shallow environments where sediments are more easily transported by currents. Sediment slumping may occur as gravity acts to stabilize sediments that have accumulated on a slope.

Downgradient resources could be impacted by contaminated sediments that have migrated offsite. The sensitive resources described for site impacts are also of concern for offsite impacts. Hence, the downstream or downgradient proximity of sensitive resources is another factor that must be included in the assessment of offsite impacts. The distance to sensitive resource downstream of the site is included in the assessment of affected resources.

5. RECOMMENDATIONS

The sediment ranking system presented in this report is an intermediate step in the development of the final sediment ranking system. This section identifies issues for focused review, proposed strategies for information management of the ranking system, and recommended field testing.

5.1 OUTSTANDING ISSUES FOR FOCUSED REVIEW

The following issues should be considered during review of this document:

Qualitative Assessment of Offsite Impacts—The qualitative assessment of offsite impacts was determined to be appropriate because a great deal of the information needed to quantify offsite impacts was not readily available or easy to obtain, and because the analysis would not necessarily be meaningful in light of the numerous assumptions required. Whether this simplification was appropriate should be assessed during review of this report.

Human Health Hazard Toxicity Indices—The process for scoring waste toxicity for human health hazard presented in this report represents an interim approach. It is recommended that future refinements incorporate risk assessment methodology. Risk assessment could also be used to validate results. In order to incorporate risk assessment into the ranking system, an algorithm relating tissue bioaccumulation to chemical concentrations in sediments would have to be developed. Such models have been developed, but have not been verified with empirical data.

Adoption of Ranking System for Freshwater Sites—Until sediment standards are adopted for freshwater sediments, an interim approach will need to be developed for the assessment of both human health and ecological hazard. It is recommended that the interim method for assessing human health hazard presented in this report be considered for freshwater human health assessment. Ecological hazard could be assessed using a similar method that excluded consideration of bioaccumulation potential.

Erosion—Erosion is not explicitly included in the scoring of site impacts; it is simply treated as the absence of significant sediment deposition. It is, however, included qualitatively in the assessment of the potential for offsite impacts. It may be appropriate to explicitly score site erosion because, although it aggravates offsite impacts, it enhances the potential for a site to recover.

Biological Test Results—Biological impacts are the major indicator of sediment contamination. In the ranking system presented here, the actual measurement of adverse biological effects is explicitly recognized (i.e., biological test results supersede the predictions of chemical measurements when they are contradictory), but is not heavily weighted. It may be appropriate to increase the site score if the biological effects predicted by chemical measurements are confirmed. It may also be appropriate to weigh heavily the confirmation of a diversity of adverse biological effects at a site.

Dangerous Waste Designation—Assessment of sediments using state dangerous waste regulations has not been incorporated into the ranking system. If the dangerous waste designation is considered to be a major factor in subsequent sediment management, an algorithm that determined dangerous waste status of site sediments (e.g., by the mixed waste designation process) could be incorporated into the ranking system. Alternatively, sediment testing procedures (i.e., EP-Toxicity testing) could be incorporated into future site investigations.

Excess Sedimentation—Excess sedimentation associated with anthropogenic activities can potentially damage sensitive resources such as shellfish beds. Excess sedimentation may be associated with a river outflow, where poor soil management practices within the drainage basin have increased soil erosion. It may be appropriate to include sites where excess sedimentation is a problem to fully utilize the ranking system as a resource management tool.

Scoring Process—Most of the information needed to score sites could be summarized in reference tables and maps. The scoring process could be standardized using a computerized database to support the evaluation (see Section 5.2).

Plant Bioassays—The degree to which sediment contamination can adversely impact aquatic plant species is not well characterized in this ranking system. A literature survey of sediment factors that impact plants would be an initial step in the refinement of the ranking system. Factors not considered here that may impact plants include pH, turbidity, and effects of sedimentation. Critical literature would be used to develop simple plant bioassays to evaluate sediment phytotoxicity.

5.2 PROPOSED STRATEGY FOR INFORMATION MANAGEMENT

Site ranking uses stored data (e.g., scoring tables) and a deterministic set of calculations (equations 1-7), both of which can be computerized. All of the data and the manipulations needed for the first two steps of assessment of chemical toxicity are currently available in the SEDQUAL database. Field trials of the scoring methods will use biological effects data, which also are stored in SEDQUAL. Other data and calculations may also be most appropriately computerized. The prospects for development of a specialized, computerized hazard ranking tool will be evaluated during refinement and field trials of the ranking methods.

Three approaches to computerization of the ranking process are: 1) enhance SEDQUAL, 2) create spreadsheets with customized formulas and macros, and 3) develop a stand-alone application. The existence of some data and appropriate capabilities in SEDQUAL qualify it as a base to build upon, but much of the additional data (scoring matrices, loss factors, chemical toxicity) and capabilities are not consistent with SEDQUAL's principal purpose (i.e., storage and analysis of chemical and biological effects data). An alternative approach to the use of SEDQUAL is to develop routines that will report the required data in a convenient format for another hazard ranking tool (or calculation by hand). The advantages of spreadsheets are that the tabular data can be easily represented in them, and that data and formulas can be easily modified by users. The latter point is particularly important during refinement and testing of ranking methods. Ease of modification is actually a disadvantage after development is complete, as spreadsheets have no absolute protection against modification by any user, and changes often cannot be seen. Stand-alone software can provide the protection that spreadsheets do not, and are easier to link with databases (e.g., SEDQUAL), statistical software, GIS, models, or other special tools. However, their implementation requires substantially more effort.

During refinement and testing of ranking approaches, spreadsheets will be used to store some data and perform some calculations. The relatively small effort required to create custom spreadsheets, and the flexibility they will allow during testing, is expected to provide consistent and reliable site characterizations. SEDQUAL's existing functions (to compare data to sediment criteria and to export data to spreadsheets and statistical software) will be used to carry out other calculations. The usage and applicability of these tools will be evaluated to help determine whether development of stand-alone hazard ranking software would be feasible and cost-effective.

Information regarding the most useful features of the spreadsheet/SEDQUAL approach and the additional features most needed in a specialized hazard ranking tool will be presented to Ecology.

5.3 FIELD TESTING

SEDRANK has not yet been field tested. However, limited tests have been conducted using the SEDQUAL database. Tests conducted to date (summarized in Appendix B) have focused on the toxicity algorithm for the ecological hazard assessment, particularly on the number, type, and severity of chemical exceedances of sediment quality standards in Puget Sound. It is recommended that a more comprehensive field test be conducted to further refine proposed algorithms and scoring scales. Prior to conducting these tests, it is recommended that reference tables containing key scoring data be prepared (e.g., chemical-specific solubility data) and reference maps for sensitive resources (e.g., the location of eelgrass beds) be compiled.

It is recommended that field tests be conducted on 10-12 representative sites. Site should be selected to represent a broad range of site types (e.g., represent both human health and ecological hazard, include both toxic and nontoxic contamination). They should also include sites that are anticipated to rank high and sites that are anticipated to rank low. Where possible, sites that have been addressed and prioritized under other programs (e.g., PSEP; Comprehensive Environmental Response, Compensation and Liability Act) should be included in the field test to provide an alternative basis for interpreting rank scores.

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APPENDIX A

Reference Tables

REFERENCE TABLES

This appendix provides selected reference tables used in the ranking section. The reference tables presented here include data that was readily available and easily compiled during the assessment of data availability, and do not represent the complete set of reference tables required for site ranking. Tables presented here include interim sediment quality standards and human health hazard toxicity criteria.

INTERIM SEDIMENT QUALITY STANDARDS

The interim sediment quality standards (chemical criteria) summarized in Table A-1 provide the basis for developing toxicity indices for the assessment of human health hazard. Final sediment quality criteria will be promulgated in June of 1990. These chemical criteria represent one aspect of the sediment quality evaluation process: the initial evaluation of sediment quality.

HUMAN HEALTH TOXICITY CRITERIA

The criteria for evaluation of toxicity are adapted from those presented in the *Washington Ranking Method Scoring Manual* (SAIC and Parametrix 1989). Oral exposures [as represented in the surface water route of the Washington state ranking method (WARM)] are the most relevant and are used here. The WARM system derives toxicity scores from the U.S. Environmental Protection Agency (EPA) regulatory standards and guidelines including drinking water standards, acceptable intake for chronic oral exposure and carcinogenic potency factors (CPFs). Acute toxicity values, including LD_{50} and LD_{Lo} values, are also used. Chemicals will be ranked based on available data; most chemicals will not have all four of these types of data. The human toxicity classifications based on these values are presented in Table A-2 and the sources and selection of these data are described below.

Table A-2 presents oral toxicity data used to place chemicals in the following categories of toxicity: very high, high, medium, low, and very low. For the purpose of this ranking scheme, all available data are ranked and the single highest categorization is used. For example, if a chemical is categorized as having low toxicity based on LD_{50} values, but it is categorized as having high toxicity based on acceptable intake levels, it should be categorized as having high toxicity.

TABLE A-1. INTERIM SEDIMENT QUALITY STANDARDS—CHEMICAL CRITERIA

Metal/Metalloid	mg/kg Dry Weight (ppm dry)
Antimony	150
Arsenic	57
Cadmium	5.1
Chromium	260
Copper	390
Lead	450
Mercury	0.41
Nickel	NV[a]
Silver	6.1
Zinc	410

Non-ionic Organic Chemical	mg/kg Organic Carbon (ppm TOC)
LPAH[b]	370
Naphthalene	99
Acenaphthylene	66
Acenaphthene	16
Fluorene	23
Phenanthrene	100
Anthracene	220
2-Methylnaphthalene	64
HPAH[c]	960
Fluoranthene	160
Pyrene	1,000
Benz(a)anthracene	110
Chrysene	110
Total benzofluoranthenes[d]	230
Benzo(a)pyrene	99
Indeno(1,2,3,-c,d)pyrene	33
Dibenzo(a,h)anthracene	33
Benzo(g,h,i)perylene	31
1,2-Dichlorobenzene	2.3
1,3-Dichlorobenzene	NV
1,4-Dichlorobenzene	3.1
1,2,4-Trichlorobenzene	0.81
Hexachlorobenzene	0.38
Dimethylphthalate	53
Diethyl phthalate	61

TABLE A-1. (Continued)

Non-ionic Organic Chemical	mg/kg Organic Carbon (ppm carbon)
Di-n-butyl phathalate	220
Butyl benzyl phthalate	4.9
Bis(2-ethylhexyl)phthalate	47
Di-n-ocytl phthalate	58
Dibenzofuran	15
Hexachlorobutadiene	3.9
N-nitrosodiphenylamine	11
Tetrachloroethene	NV
Ethylbenzene	NV
Total xylene	NV
Total PCB	12

Ionizable Organic Chemical	µg/kg Dry Weight (ppb dry)
Phenol	420
2-Methylphenol	63
4-Methylphenol	670
2,4-Dimethyl phenol	29
Pentachlorophenol	360
Benzyl alcohol	57
Benzoic acid	650

[a] NV indicates that a defined AET could not be established because there were no *biological effects* stations with chemical concentrations above the highest concentration among *no-effects* stations (also known as the *greater than* or *indefinite* AET). These chemicals are recommended for routine analysis in Puget Sound sediments. Specific criteria may be established for these chemicals before adoption of the sediment quality standards.

[b] The low molecular weight polycyclic aromatic hydrocarbon (LPAH) criteria are applicable to the sum of the following LPAH compounds: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene.

[c] The high molecular weight polycyclic aromatic hydrocarbon (HPAH) criteria are applicable to the sum of the following HPAH compounds: fluoranthene, pyrene, benz(a)anthracene, chrysene, total benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene.

[d] The total benzofluoranthenes criterion represent the sum of the B, J, and K isomers.

TABLE A-2. HUMAN TOXICITY CLASSIFICATIONS

Drinking Water Standards

Guideline for Drinking Water Quality ($\mu g/L$)	Drinking Water Toxicity Rating
<1.0	Very high
>1 to 10	High
>10 to 10^2	Medium
>10^2 to 10^3	Low
>10^3	Very low

Chronic Toxicity

Guideline for Chronic Oral Toxicity (mg/kg/day)	Chronic Toxicity Rating
$\leq 10^{-3}$	Very high
>10^{-3} to 10^{-2}	High
>10^{-2} to 10^{-1}	Medium
>10^{-1} to 10	Low
>10	Very low

Acute Toxicity

Acute Oral LD_{50} or LD_{LO} (mg/kg-body weight)	Acute Toxicity
≤50	Very high
>50 to ≤500	High
>500 to ≤5,000	Medium
>5,000 to ≤15,000	Low
>15,000	Very low

TABLE A-2. (Continued)

Carcinogenicity (Adjustment Factor)

Weight of Evidence	Weight of Evidence: EPA Rating	Weight of Evidence: Adjustment Factor
Known human carcinogen	A	1.0
Probable human carcinogen	B1 or B2	0.8
Possible human carcinogen	C	0.5
Not classified as to human carcinogenicity	D	Mark an "X" in matrix
Evidence of noncarcinogenicity	E	0
No rating available	None available	Mark an "X" in matrix

Carcinogenicity (Potency Rating)

EPA CAG Carcinogenic Potency Factor (mg/kg/day)^{1}	Adjusted Potency Factor[a]	Carcinogenic Potency Rating
>10^{2}	>10^{2}	Very high
>10 to 10^{-2}	>10 to 10^{2}	High
>1 to 10	>1 to 10	Medium
>10^{-2} to 1	>10^{-2} to 1	Low
>10^{-2}	>10^{-2}	Very low

[a] Adjusted potency factor = weight of evidence adjustment factor × EPA CAG potency factor.

Data source: IRIS.

This could be the case if a chemical had relatively high acute lethality, but affected a sensitive endpoint (e.g., reproductive toxicity) at a relatively low dose.

Drinking Water Standards

An aquatic contaminant may be regulated under more than one EPA drinking water standard or advisory. EPA standards and advisories should be selected in the following order of preference as designated by WARM (SAIC and Parametrix 1989): maximum contaminant level goal, recommended maximum contaminant level, and long term health advisory. As indicated in WARM (SAIC and Parametrix 1989), recommended contaminant levels and maximum contaminant level goals can be obtained from 40 CFR 141 and 40 CFR 142, and long-term health advisories can be obtained from EPA's Office of Drinking Water Health Advisories or from EPA's integrated risk information system (IRIS).

Chronic Toxicity

EPA has developed several types of chronic toxicity criteria that should be used in the following order of preference: oral acceptable intake levels for chronic exposure, reference doses, no observed effect levels, and lowest observed effect levels. These criteria can be found in IRIS.

Acute Toxicity

Acute toxicity can be evaluated from LD_{50} and LD_{Lo} data. Due to the high degree of variability in LD_{50} data from one species of laboratory animal to another, data from rats should be used first. Where these are not available, data from mice should be used. LD_{50} data should be given preference over LD_{Lo} data, as the latter is not a statistical measure and can be a record of a study with a single animal. While data resulting from human fatalities were used in the WARM scheme (SAIC and Parametrix 1989), these data usually do not include accurate information on exposure and should not be used unless the LD data in humans is lower than that seen in rats or mice. Acute toxicity data can be obtained from the National Library of Medicines databases including the Hazardous Substances Database and the Registry of the Effects of Toxic Substances.

Carcinogenicity

The ranking for carcinogenicity is based on two EPA values: weight of evidence and carcinogenic potency. The weight of evidence is a characterization of the likelihood that a material is a carcinogen in humans. In this ranking, values from Table A-2 are used to adjust the carcinogenic potency factors. Higher values are assigned based on the weight of evidence (e.g. known human carcinogens are assigned a value of 1, while chemicals for which the evidence of carcinogenicity is limited to findings from studies in laboratory animals are assigned either 0.8 or 0.5).

Table A-2 also includes rankings for CPFs. CPFs are the 95th percentile upper-bound estimate of the slope of the dose-response curve for carcinogenic effects. In risk assessment, CPFs are multiplied by an exposure amount to calculate the amount of risk associated with exposure (U.S. EPA 1989). Thus, more potent carcinogens have higher CPFs.

The categorization of a chemical for carcinogenicity is generated by multiplying the weight of the evidence score by the carcinogenic potency score. In this way, the degree of evidence and the potency can be considered in one score.

CPFs and weight of evidence categorizations are included in IRIS files for carcinogens.

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APPENDIX B

Comparison of SEDQUAL Chemistry Data To Selected Chemical Indices

COMPARISON OF SEDQUAL CHEMISTRY DATA TO SELECTED CHEMICAL INDICES

Chemical data in the SEDQUAL database were evaluated to provide a preliminary assessment of the scale for the toxicity algorithm proposed for the ecological hazard assessment, and to better understand the nature and severity of chemical contamination in Puget Sound. All stations containing chemical data (a total of 1,054) were compared to interim sediment standards, Puget Sound Dredged Disposal Analysis (PSDDA) screening levels, and PSDDA maximum level (ML) (equivalent to PSDDA Site Condition 2 for chemical criteria). For all stations where at least one chemical exceeded these indices, the following information was determined:

- Specific chemicals that exceeded sediment quality standards
- Severity of exceedance by individual chemicals (i.e., enrichment ratios, represented by the ratio of observed concentration to interim sediment quality standard).

The number of stations that had at least one chemical that exceeded these different indices is summarized in Table B-1.

For all stations where at least one station exceeded sediment standards, the following were determined:

- Sum of enrichment ratios for all chemicals exceeding sediment standards (by station)
- Rank order of all chemicals that exceeded sediment standards, in order of number of stations where exceedance was observed
- Rank order of all stations where exceedances were observed, in order of sum of enrichment ratios.

The rank order of all chemicals that exceeded sediment standards is summarized in Table B-2. The rank order of the sum of enrichment ratios is presented in Table B-3.

TABLE B-1. NUMBER OF STATIONS EXCEEDING SELECTED INDICES

Index	Number of Stations[a]	Percent of Total Stations
Total number of stations evaluated	1,054	--
Stations exceeding interim sediment standards	419	40
Stations exceeding PSDDA SL	832	79
Stations exceeding PSDDA ML	159	15
Stations exceeding PSDDA Site Condition 3[b]	101	10

[a] Where at least one chemical exceeded index for the purpose of this evaluation.

[b] PSDDA Site Condition 3 is defined here in terms of chemical criteria only.

TABLE B-2. RANK ORDER OF CHEMICALS EXCEEDING INTERIM SEDIMENT QUALITY STANDARDS

Chemical	Number of Stations Exceeding Interim Sediment Quality Standards	Number of Stations Exceeding PSDDA ML
Mercury	172	18
PCB	161	21
Chrysene	77	26
Fluoranthene	72	41
Indeno(1,2,3 cd)pyrene	71	5
Benzo(g,i,h)perylene	69	5
Phenanthrene	67	49
HPAH	65	20
Butylbenzylphthalate	65	0
Zinc	59	11
Fluorene	59	10
Benzo(a)pyrene	59	12
Acenaphthene	56	11
Arsenic	50	5
Benzo(a)anthracene	47	25
Total benzofluoranthene (b+k)	46	22
Phenol	45	11
4-Methylphenol	40	24
LPAH	37	52
Di-n-octylphthalate	36	0
Dibenzofuran	36	26
Cadmium	34	9
2,4-dimethylphenol	31	26
Lead	31	16
Hexachlorobenzene	26	2
Dibenzo(a,h)anthracene	25	12
1,4-Dichlorobenzene	24	3
Copper	24	14
Benzyl alcohol	23	17
Naphthalene	23	31
Hexachlorobutadiene	22	7
Anthracene	17	53
Antimony	16	8
Bis-2-ethylhexylphthalate	16	0
Pyrene	15	37
Di-n-butylphthalate	15	--
1,2,4-Trichlorobenzene	15	6
Benzoic Acid	13	11
Pentachlorophenol	10	4
2-Methylphenol	10	6

TABLE B-2. (Continued)

Chemical	Number of Stations Exceeding Interim Sediment Quality Standards	Number of Stations Exceeding PSDDA ML
2-Methylnaphthalene	10	26
1,2-Dichlorobenzene	7	--
Acenaphthylene	6	20
Chromium	6	--
Diethylphthalate	4	--
Dimethylphthalate	3	--
N-nitrosodiphenylamine	3	3
Silver	1	1

TABLE B-3. STATIONS IN PUGET SOUND THAT EXCEED INTERIM SEDIMENT QUALITY

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
EPAPS88	6	765.66	16
TPPS3AB	WP-11-2	717.13	17
TPPS3AB	WP-11-1	540.51	16
EHCHEM	EH-08-V1	527.06	15
TPPS3AB	EB-35-2	398.15	18
CBMSQS	RS-18	392.49	12
CBMSQS	HY-46	374.48	21
EPAPS88	10	356.95	14
CBMSQS	RS-17	331.84	8
EBCHEM	SS-09	298.41	14
CBMSQS	RS-21	285.96	11
TPPS3AB	WP-14	226.13	6
EHCHEM	EH-08-B1	198.21	17
TPPS3AB	WP-10-2	185.63	13
EPAPS88	12	184.46	11
TPPS3AB	EB-39-2	183.64	12
EVCHEM	EW-07	168.32	8
TPPS3AB	EB-36-1	163.52	8
EBCHEM	WW-02	160.74	3
TPPS3AB	EB-31-2	154.59	15
CBMSQS	SP-14	147.33	2
TPPS3AB	EB-37-2	144.11	13
TPPS3AB	EB-33-1	128.68	10
TPPS3AB	EB-35-1	120.1	11
EVCHEM	EW-04	112.46	7
EBCHEM	SS-08	110.54	16
EBCHEM	AB-01	107.19	15
EPAPS88	7	97.54	23
TPPS3AB	WP-07-2	97.12	12
EVCHEM	EW-14	91.49	15
EBCHEM	NH-08	89.47	17
EBCHEM	PS-05	87.36	16
EBCHEM	WW-04	86.65	14
TPPS3AB	WP-07-1	84.55	10
EPAPS88	3	79.11	9
TPPS3AB	WP-02-2	78.16	12
EBCHEM	SS-03	73.1	16
EBCHEM	NH-03	72.53	17
GAMPONIA	LTHE03	69.01	7

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
CBMSQS	HY-22	68.36	12
TPPS3AB	WP-08-2	68.27	12
CBMSQS	HY-41	62.3	7
EBCHEM	NH-06	58.34	18
TPPS3AB	EB-34-2	57.53	11
GAMPONIA	LTID04	56.28	6
EHCHEM	EH-15	56.24	16
EBCHEM	NH-04	53.87	17
CBMSQS	RS-19	52.67	9
EBCHEM	EW-02	51.32	8
EVCHEM	EW-10	46.86	3
TPPS3AB	EB-33-2	45.17	4
EPA8283	42	43.98	4
TPPS3AB	EB-34-1	43.65	5
EVCHEM	EW-13	40.17	2
EBCHEM	WW-14	39.46	9
TPPS3AB	EB-39-1	38.84	9
CBMSQS	HY-45	37.89	4
GAMPONIA	LTHE01	37.55	5
CBMSQS	HY-40	36.01	6
CBMSQS	HY-42	35.24	4
TPPS3AB	WP-13-2	34.86	8
TPPS3AB	WP-10-1	34.53	9
EPAPS88	5	34.37	14
DUWAM84	U137	33.94	4
DUWRIV2	DR-10	33.69	2
EBCHEM	EW-14	32.99	13
CBMSQS	RS-13	32.68	14
EBCHEM	WW-12	32.39	12
CBMSQS	HY-39	31.93	5
EHCHEM	EH-19	31.76	11
TPPS3AB	WP-15-2	30.76	9
GAMPONIA	LTHC03	29.85	4
EBCHEM	KG-06	29.77	6
PSDDA1	EBS02	28.93	7
TPPS3AB	EB-38-2	27.7	6
EHCHEM	EH-04	27.6	11
EVCHEM	NG-11	27.28	12
EPA8283	4	26.04	4
EHCHEM	EH-10	24.77	9

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
TPPS3AB	WP-15-1	24.54	8
TPPS3AB	EB-31-1	24.22	6
TPPS3AB	WP-04-2	23.9	10
CBMSQS	HY-47	23.87	4
CBMSQS	HY-36	22.44	5
EBCHEM	WW-09	22.21	12
TPPS3AB	WP-05-2	21.47	9
GAMPONIA	LTIB07	21.38	1
EBCHEM	EW-07	21.34	4
EBCHEM	EW-05-1	21.32	6
TPPS3AB	EB-37-1	21.09	9
EVCHEM	NG-09	21.08	3
DUWRIV2	DR-27	20.93	5
DUWAM84	U136	20.69	2
EBCHEM	EW-12	20.67	5
DUWRIV1	DR-08	20.46	4
TPPS3AB	EB-30-2	20.02	8
EBCHEM	EW-09	19.43	3
EBCHEM	WW-19	19.4	10
CBMSQS	RS-24	19.24	4
CBMSQS	HY-35	19.08	4
EBCHEM	EW-08	18.67	3
EBCHEM	EW-04	18.36	10
EBCHEM	EW-05-2	18.07	5
CBMSQS	HY-48	17.79	6
EBCHEM	NS-07	17.73	10
EVCHEM	NG-05	17.71	2
EBCHEM	DR-08	17.44	3
EBCHEM	NS-06	17.24	1
TPPS3AB	WP-05-1	17.14	2
GAMPONIA	LTHE02	16.81	2
EBCHEM	NS-08	16.39	9
EBCHEM	DR-10	15.83	1
CBMSQS	HY-43	15.65	3
EHCHEM	EH-05	14.96	10
TPPS3AB	WP-06-2	14.83	7
TPPS3AB	WP-12-1	14.8	3
EVCHEM	EW-11	14.78	3
CBMSQS	HY-37	14.74	4
TPPS3AB	WP-16-2	14.63	5

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
CBMSQS	HY-33	14.43	5
CBMSQS	HY-21	14.42	3
CBBLAIR	B18	14.04	6
TPPS3AB	EB-38-1	13.77	7
EBCHEM	SS-07	13.72	3
EBCHEM	NH-01	13.65	9
EBCHEM	DR-12	13.43	3
TPPS3AB	EB-36-2	13.34	4
EBCHEM	NH-07	13.27	3
EBCHEM	EW-06	13.23	8
GAMPONIA	LTJD05	13.1	1
EVCHEM	EW-15	12.93	3
EBCHEM	SS-04	12.87	5
DUWRIV2	DR-25	12.85	4
EVCHEM	EW-01	12.77	2
CBMSQS	RS-16	12.71	4
DUWRIV2	DR-23	12.49	2
TPPS3AB	WP-09-2	12.4	5
CBMSQS	BL-16	12.31	1
DUWRIV2	DR-28	12.08	2
DUWRIV2	DR-29	11.95	2
DUWRIV2	DR-36	11.85	2
EBCHEM	DR-25	11.76	5
EHCHEM	EH-11	11.72	7
GAMPONIA	LTHD03	11.71	2
EBCHEM	WW-18	11.7	6
EBCHEM	SS-06	11.63	7
CBMSQS	CI-12	11.56	8
EBCHEM	SS-10	11.56	5
PSDDA1	BBP04	11.43	1
CBMSQS	HY-38	11.41	3
EBCHEM	WW-15	11.33	1
TPPS3AB	WP-02-1	10.97	8
CBMSQS	MD-13	10.88	3
EIGHTBAY	SC-07	10.88	5
TPPS3AB	EB-30-1	10.81	5
TPPS3AB	WP-12-2	10.23	2
EBCHEM	NS-04	10.22	6
CBMSQS	SP-13	10.04	4
EVCHEM	NG-14	9.94	4

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
TPPS3AB	WP-08-1	9.93	4
EBCHEM	EW-11	9.81	4
TPPS3AB	EB-32-2	9.76	2
EBCHEM	WW-05	9.72	2
EBCHEM	KG-10	9.69	1
DUWAM84	U133	9.67	4
EPAPS88	11	9.49	6
DUWRIV2	DR-14	9.44	4
DUWAM84	U121	9.28	6
DUWRIV2	DR-34	9.17	1
CBMSQS	CI-13	9.07	4
CBMSQS	CI-11	9.05	5
EBCHEM	NH-05	8.98	6
EBCHEM	SS-05-2	8.86	3
DUWRIV2	DR-26	8.71	4
EIGHTBAY	SC-14	8.48	2
MALINS	10039	8.44	2
PSDDA1	EBP05	8.37	4
EBCHEM	WW-08	8.04	4
DUWRIV2	DR-33	8	1
CBMSQS	HY-24	7.99	4
EIGHTBAY	SC-20	7.9	3
EBCHEM	WW-17	7.83	4
CBMSQS	SI-14	7.78	4
TPPS3AB	WP-03-2	7.77	4
TPPS3AB	WP-01-1	7.62	5
EVERETT1	EV-20	7.55	3
EBCHEM	DR-06	7.52	2
CBMSQS	CI-15	7.5	5
EHCHEM	EH-18	7.49	3
EIGHTBAY	EL-10	7.41	4
EBCHEM	WW-20	7.33	5
EIGHTBAY	EV-04	7.32	3
DUWRIV2	DR-38	7.17	1
EPAPS88	2	7.14	4
EHCHEM	EH-07	7	5
EIGHTBAY	SC-06	6.99	2
MALINS	10030	6.98	4
CBMSQS	HY-27	6.93	3
TPPS3AB	WP-09-1	6.9	3

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
EBCHEM	WW-16	6.9	3
EIGHTBAY	EL-20	6.85	3
EBCHEM	DR-07	6.83	1
PSDDA1	EBP01	6.83	1
EIGHTBAY	EL-09	6.78	3
PSDDA1	EBZ01	6.69	2
CBMSQS	HY-16	6.39	2
EVCHEM	NG-10	6.27	3
EVCHEM	ES-03	6.12	3
CBMSQS	HY-28	6.05	1
CBMSQS	CB-11	6.03	2
CBMSQS	CI-16	6.02	4
EBCHEM	KG-01	5.86	4
EBCHEM	EW-03	5.83	2
DUWRIV2	DR-35	5.74	2
PSDDA1	EBP08	5.73	2
DUWRIV2	DR-11	5.71	2
EHCHEM	RB-02	5.66	3
CBMSQS	HY-23	5.64	3
EBCHEM	NS-03	5.62	2
EBCHEM	EW-10	5.61	3
EPA8283	39	5.55	3
EBCHEM	EW-01	5.52	2
CBMSQS	BL-26	5.41	3
EBCHEM	SS-05-1	5.4	2
EVCHEM	EW-12	5.37	1
EBCHEM	MG-04	5.31	1
EPAPS88	14	5.26	2
EBCHEM	DR-16	5.2	4
EBCHEM	WW-06-2	5.13	4
EIGHTBAY	SC-19	5.12	1
CBMSQS	HY-20	5.1	2
DUWRIV2	DR-30	5.08	1
EBCHEM	WW-11	5.02	3
EBCHEM	KG-05	5.01	2
CBMSQS	HY-25	4.96	3
CBMSQS	CI-18	4.92	3
DUWAM84	U115	4.88	2
EHCHEM	EH-17	4.86	4
EIGHTBAY	SC-08	4.85	2

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
CBMSQS	MD-11	4.82	3
EHCHEM	EH-06	4.56	2
EVCHEM	SR-05	4.53	2
MALINS	10016	4.53	2
TPPS3AB	WP-16-1	4.51	3
EIGHTBAY	SM-01	4.47	1
PTGARQC	ANCAP-10	4.45	2
EIGHTBAY	BH-03	4.44	2
TPPS3AB	WP-13-1	4.42	1
CBMSQS	SI-11	4.3	3
DUWAM84	U134	4.28	3
DUWRIV2	DR-13	4.27	2
EBCHEM	WW-10	4.27	3
EIGHTBAY	EL-17	4.24	2
EIGHTBAY	EL-22	4.24	2
CBMSQS	RS-20	4.2	3
EBCHEM	DR-13	4.17	1
EIGHTBAY	BH-04	4.15	1
CBMSQS	HY-29	4.08	1
EVCHEM	SD-03	4.05	3
EBCHEM	DR-05	4	1
EBCHEM	NH-11	4	1
GAMPONIA	LTHD04	3.97	2
CBMSQS	HY-31	3.95	1
MALINS	10041	3.95	2
CBMSQS	SP-15	3.88	1
CBBLAIR	B04	3.86	3
CBMSQS	HY-51	3.86	2
EVCHEM	NG-15	3.86	3
EPAPS88	1	3.76	2
CBMSQS	HY-32	3.68	1
TPPS3AB	WP-01-2	3.68	2
CBMSQS	HY-26	3.66	2
DUWAM84	U120	3.62	2
CBMSQS	SP-16	3.61	2
EVCHEM	NG-04	3.58	1
EBCHEM	KG-09	3.57	2
CBMSQS	BL-29	3.54	3
DUWRIV2	DR-31	3.5	1
GAMPONIA	LTID05	3.43	2

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
EBCHEM	SS-12	3.41	1
EVCHEM	NG-08	3.39	2
EPA8283	37	3.35	2
CBMSQS	BL-23	3.34	2
EBCHEM	KG-11	3.33	1
GAMPONIA	LTKD04	3.32	2
MALINS	10015	3.26	2
EBCHEM	EW-16	3.23	2
EBCHEM	DR-15	3.2	2
EBCHEM	SS-11	3.17	1
PSDDA1	EBP07	3.15	2
EVCHEM	NG-13	3.03	2
EVCHEM	OG-01	3.01	2
DUWAM84	U122	2.98	2
EPA8283	12-1	2.93	1
EBCHEM	DR-03	2.92	1
OAKHRBR	OH-C	2.92	2
	10050	2.91	2
PSDDA1	EBP10	2.9	2
EBCHEM	WW-06-1	2.87	2
CBMSQS	CI-20	2.86	1
DUWAM84	U107	2.86	1
EBCHEM	NH-10	2.83	1
EHCHEM	WP-01	2.83	1
EVCHEM	OG-04	2.81	2
EBCHEM	WW-01	2.75	1
PSDDA1	EBP09	2.74	2
MALINS	10044	2.71	2
EHCHEM	EH-01	2.65	1
EVCHEM	NG-07	2.62	1
MALINS	10031	2.6	2
EBCHEM	DR-11	2.58	1
EBCHEM	DR-14	2.58	1
CBMSQS	BL-22	2.55	1
EBCHEM	WW-13	2.53	2
CBMSQS	HY-13	2.52	2
DUWRIV2	DR-22	2.5	1
EBCHEM	NH-02	2.48	2
EBCHEM	NS-02	2.47	2
EHCHEM	BH-01	2.45	1

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
CBMSQS	MD-11	4.82	3
EHCHEM	EH-06	4.56	2
EVCHEM	SR-05	4.53	2
MALINS	10016	4.53	2
TPPS3AB	WP-16-1	4.51	3
EIGHTBAY	SM-01	4.47	1
PTGARQC	ANCAP-10	4.45	2
EIGHTBAY	BH-03	4.44	2
TPPS3AB	WP-13-1	4.42	1
CBMSQS	SI-11	4.3	3
DUWAM84	U134	4.28	3
DUWRIV2	DR-13	4.27	2
EBCHEM	WW-10	4.27	3
EIGHTBAY	EL-17	4.24	2
EIGHTBAY	EL-22	4.24	2
CBMSQS	RS-20	4.2	3
EBCHEM	DR-13	4.17	1
EIGHTBAY	BH-04	4.15	1
CBMSQS	HY-29	4.08	1
EVCHEM	SD-03	4.05	3
EBCHEM	DR-05	4	1
EBCHEM	NH-11	4	1
GAMPONIA	LTHD04	3.97	2
CBMSQS	HY-31	3.95	1
MALINS	10041	3.95	2
CBMSQS	SP-15	3.88	1
CBBLAIR	B04	3.86	3
CBMSQS	HY-51	3.86	2
EVCHEM	NG-15	3.86	3
EPAPS88	1	3.76	2
CBMSQS	HY-32	3.68	1
TPPS3AB	WP-01-2	3.68	2
CBMSQS	HY-26	3.66	2
DUWAM84	U120	3.62	2
CBMSQS	SP-16	3.61	2
EVCHEM	NG-04	3.58	1
EBCHEM	KG-09	3.57	2
CBMSQS	BL-29	3.54	3
DUWRIV2	DR-31	3.5	1
GAMPONIA	LTID05	3.43	2

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
EBCHEM	SS-12	3.41	1
EVCHEM	NG-08	3.39	2
EPA8283	37	3.35	2
CBMSQS	BL-23	3.34	2
EBCHEM	KG-11	3.33	1
GAMPONIA	LTKD04	3.32	2
MALINS	10015	3.26	2
EBCHEM	EW-16	3.23	2
EBCHEM	DR-15	3.2	2
EBCHEM	SS-11	3.17	1
PSDDA1	EBP07	3.15	2
EVCHEM	NG-13	3.03	2
EVCHEM	OG-01	3.01	2
DUWAM84	U122	2.98	2
EPA8283	12-1	2.93	1
EBCHEM	DR-03	2.92	1
OAKHRBR	OH-C	2.92	2
	10050	2.91	2
PSDDA1	EBP10	2.9	2
EBCHEM	WW-06-1	2.87	2
CBMSQS	CI-20	2.86	1
DUWAM84	U107	2.86	1
EBCHEM	NH-10	2.83	1
EHCHEM	WP-01	2.83	1
EVCHEM	OG-04	2.81	2
EBCHEM	WW-01	2.75	1
PSDDA1	EBP09	2.74	2
MALINS	10044	2.71	2
EHCHEM	EH-01	2.65	1
EVCHEM	NG-07	2.62	1
MALINS	10031	2.6	2
EBCHEM	DR-11	2.58	1
EBCHEM	DR-14	2.58	1
CBMSQS	BL-22	2.55	1
EBCHEM	WW-13	2.53	2
CBMSQS	HY-13	2.52	2
DUWRIV2	DR-22	2.5	1
EBCHEM	NH-02	2.48	2
EBCHEM	NS-02	2.47	2
EHCHEM	BH-01	2.45	1

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
EBCHEM	DR-17	2.42	1
EBCHEM	EW-15	2.4	2
CBMSQS	BL-30	2.39	1
EIGHTBAY	BH-07	2.37	1
GAMPONIA	LTKD03	2.34	2
CBMSQS	BL-20	2.33	2
EBCHEM	DR-04	2.33	1
CBMSQS	HY-12	2.31	2
MALINS	10043	2.29	2
EBCHEM	EW-13	2.25	1
EBCHEM	AB-04	2.24	1
CBMSQS	BL-14	2.24	2
EBCHEM	MG-01	2.24	1
EBCHEM	MG-02	2.24	1
EBCHEM	MG-03	2.24	1
CBMSQS	CI-22	2.23	2
EBCHEM	AB-02	2.2	2
CBMSQS	BL-18	2.17	1
EBCHEM	DR-01	2.17	1
EHCHEM	RB-01	2.17	1
EHCHEM	RB-04	2.14	1
EBCHEM	NH-09	2.08	1
DUWRIV2	DR-39	2.07	1
EBCHEM	KG-02	2.07	1
EHCHEM	RB-03	2.07	1
DUWAM84	U123	2.05	1
EHCHEM	RB-07	2.03	1
EVERETT1	EV-21	2.02	1
DUWAM84	U113	2.02	1
DUWAM84	U124	2.02	1
EBCHEM	NS-05	2	1
DUWAM84	U135	2	1
EIGHTBAY	BH-05	1.98	1
88PSRECN	DY-6	1.93	1
CBBLAIR	B11	1.9	1
PTGARQC	SWIN-6	1.88	1
DUWAM84	U102	1.83	1
PSDDA1	EBP04	1.8	1
GAMPONIA	LTIC05	1.78	1
88PSRECN	DY-4	1.76	1

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
EIGHTBAY	SC-18	1.76	1
EPA8283	15-1	1.75	1
CBMSQS	HY-11	1.75	1
EIGHTBAY	SC-17	1.71	1
DUWRIV1	DR-01	1.66	1
EVCHEM	OG-03	1.64	1
CBMSQS	RS-15	1.64	1
EPA8283	12-2	1.63	1
MALINS	10036	1.63	1
EHCHEM	RB-06	1.62	1
88PSRECN	DY-5	1.61	1
DUWRIV2	DR-18	1.58	1
EIGHTBAY	BH-12	1.56	1
EHCHEM	EH-16	1.55	1
CBMSQS	HY-17	1.51	1
OAKHRBR	OH-C3	1.51	1
DUWAM84	U131	1.51	1
MALINS	CS-62	1.49	1
PSDDA1	EBS01	1.49	1
EVCHEM	OG-02	1.49	1
CBMSQS	RS-22	1.49	1
EPA8283	43	1.49	1
EVCHEM	SR-04	1.46	1
EHCHEM	EH-02	1.45	1
EHCHEM	EH-12	1.45	1
EVCHEM	NG-03	1.45	1
MALINS	10042	1.45	1
EIGHTBAY	BH-24	1.44	1
DUWAM84	U128	1.44	1
EHCHEM	BH-02	1.43	1
TPPS3AB	WP-06-1	1.43	1
MALINS	10045	1.43	1
CBMSQS	HY-15	1.41	1
MALINS	PS-00	1.41	1
CBMSQS	CB-14	1.4	1
CBMSQS	HY-18	1.4	1
PSDDA1	BBB01	1.37	1
DUWAM84	U127	1.37	1
EHCHEM	EH-14	1.36	1
EBCHEM	NS-01	1.36	1

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
EVCHEM	OG-05	1.36	1
CBMSQS	BL-32	1.35	1
EVCHEM	SS-03	1.34	1
EIGHTBAY	CS-01	1.33	1
DUWRIV2	DR-19	1.33	1
DUWAM84	U101	1.33	1
EIGHTBAY	BH-11	1.32	1
EIGHTBAY	BH-23	1.32	1
CBMSQS	CB-12	1.32	1
EPA8283	44	1.32	1
CBMSQS	HY-49	1.3	1
PSDDA1	EBB03	1.29	1
TPPS3AB	EB-32-1	1.29	1
DUWAM85	LSCT02	1.29	1
CBBLAIR	B03	1.28	1
CBMSQS	HY-50	1.28	1
CBMSQS	MI-12	1.28	1
CBMSQS	CI-14	1.27	1
MALINS	PM-06	1.24	1
CBMSQS	BL-24	1.23	1
CBMSQS	HY-19	1.23	1
DUWAM85	LSCL01	1.22	1
CBBLAIR	B02	1.2	1
	EP-20	1.2	1
PSDDA1	EBB02	1.17	1
DUWAM85	LSAT01	1.17	1
PSDDA1	EBP06	1.15	1
	EP-19	1.15	1
GAMPONIA	LTHB01	1.15	1
CBMSQS	CI-17	1.14	1
DUWAM84	U125	1.14	1
EIGHTBAY	SM-20	1.13	1
DUWAM85	LSBQ01	1.12	1
CBMSQS	SI-12	1.11	1
CBMSQS	HY-34	1.1	1
DUWRIV2	DR-32	1.08	1
EIGHTBAY	EL-23	1.08	1
BNWS006F	A1	1.07	1
CBMSQS	CB-13	1.07	1
EBCHEM	KG-04	1.07	1

TABLE B-3. (Continued)

Survey	Station	Sum of Exceedance Ratios	Number of Chemicals Exceeding Standards
EVCHEM	OG-06	1.07	1
CBMSQS	SP-12	1.07	1
PTGARQC	ANNAG-12	1.06	1
88PSRECN	DY-1	1.06	1
EPA8283	15-2	1.05	1
EPA8283	6A	1.05	1
88PSRECN	QM-1	1.02	1