SEDQUAL ANALYTICAL TOOL DEVELOPMENT SUPPORT FOR THE ANALYSIS AND INTERPRETATION OF BENTHIC COMMUNITY DATA

STATUS AND RECOMMENDATIONS
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Washington Department of Ecology
Toxics Cleanup Program
Sediment Management Unit

By

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Olympia, Washington

Under contract to

Science Applications International Corporation
Bothell, WA

In conjunction with
Caenum Environmental Associates
Management of Environmental Resources Consulting

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Background

The state's Sediment Management Standards (SMS) rule, Chapter 173-204 WAC, is designed to incorporate best available science into sediment management regulatory decision-making. The Washington State Department of Ecology (Ecology) has developed sediment quality analytical tools and applied the results in a decision framework in the Sediment Quality Information System (SEDQUAL). In January 2003, Ecology contracted with Striplin Environmental Associates (SEA) under subcontract to Scientific Applications International Corporation (SAIC) to provide technical support for developing a benthic invertebrate evaluation module in SEDQUAL. The evaluation module would allow analysis of marine and freshwater benthic community data to support the state's sediment management decisions.

The present effort supports the development of a benthic analytical module that incorporates technical recommendations from peer reviewers and agency staff and numerical and narrative criteria modifications developed during previous Ecology contracts. It also implements the adopted marine benthic sediment quality assessment approach (i.e., shifts in major abundance using site-reference comparisons) through SEDQUAL's structured query language and analytical processes. As an alternative, administrative reference ranges have been included as a method for evaluating the health of marine benthic communities. Further, the benthic module incorporates a preliminary approach for characterizing the health of freshwater benthic communities, based on the current approach used by Ecology's Freshwater Monitoring Unit and other programs.

Implementation Results

The current SMS analytical paradigm and the proposed revisions to the SMS were incorporated into the benthic module for assessing marine sediment quality. In addition, the capabilities to select, calculate, and report a number of marine and freshwater community metrics were incorporated into the module. Within the SEDQUAL system, a taxonomic dictionary was constructed to reflect the current naming, taxonomic coding conventions and metrics, while facilitating expansion of the dictionary and changes in taxonomy.

Recommendations for Further Development

Recommendations for additional analytical capabilities and approaches that could not be incorporated into SEDQUAL under this contract include:

- additional statistical capabilities (ANOVA, *a posteriori* pair-wise testing, temporal comparisons)
- calculation of endpoints reflecting structure and function of the marine and freshwater benthic communities
- inclusion of an analytical paradigm for freshwater sediments
- verification and validation of the analytical approaches and endpoints

1 INTRODUCTION

SEA, in association with SAIC, Caenum Environmental Associates, and Management of Environmental Resources, identified benthic community metrics, analytical approaches, and interpretive guidelines for potential regulation and management of marine and freshwater sediment quality statewide. This work was completed under contract to Ecology and was designed to support the development of analytical and decision tools in SEDQUAL (Ecology 2003b).

This document describes how Ecology has incorporated the technical recommendations, numerical and narrative criteria, and sediment quality assessment approaches into an analytical tool that will be implemented through SEDQUAL. Other regional programs and regulatory agencies have only recently attempted to develop decision frameworks that incorporate elements of sediment chemistry, toxicity, and benthic community structure (triad data) in decision making. Ecology has also chosen to reflect their sediment management policy through the implementation of SEDQUAL. This information system will also provide the mechanism to recognize and incorporate refinements that are inherent in the best available science approach.

1.1 SEDQUAL Background

In 1991, the State of Washington promulgated a state rule, the SMS, which required Washington regulatory agencies to assess marine and freshwater sediment quality using chemical, biological, and other environmental information. Ecology contracted with PTI Environmental Services to modify and enhance PTI's existing SEDQUAL Information System to support development and refinement of the state's numerical chemical and biological confirmatory standards. The system was also designed to evaluate sediment quality based on comparisons of chemical concentrations and laboratory toxicity relative to reference conditions or standards. The original system was designed using FoxBase. Ecology eventually migrated the database component of the system to MS Access during SEDQUAL Release Two. SEDQUAL Release Three migrated the system's database component to Microsoft's SQL Server.

Ecology has chosen to distribute the system to the public at no cost, in addition to being the system's custodial organization. SEDQUAL users submit data to Ecology for addition to the database, and Ecology provides updates to users as system improvements and additional data sets become available. To date, resource and regulatory agencies have used SEDQUAL to store data associated with sediment cleanups, dredging characterization, source control monitoring, sediment research, and ambient monitoring.

Since SEDQUAL's inception, system enhancements have included upgrades to a Windows- and geographic-information–system- (GIS) compatible system and development of a series of analytical and graphical modules for analysis and display of data. As part of the SEDQUAL software, help files are included that outline the data model and several key analysis features. The current version of SEDQUAL can be downloaded from the web at http://www.ecy.wa.gov/programs/tcp/smu/sedqualfirst.htm.

Technical assistance on SEDQUAL may be obtained from Martin Payne, Ecology's SEDQUAL Information System project manager. He can be reached at (360) 407-6920 or by email at mpay461@ecy.wa.gov.

1.2 Report Organization

The remainder of this report describes the best available science that is being used to develop and refine benthic metrics, community indices, and administrative reference ranges, both regionally and nationally. Section 2 describes the analytical approaches that are being proposed to identify potential sediment impacts based on benthic community attributes. Recommendations are also provided regarding metrics and interpretive approaches for possible incorporation into the SMS rule. This section further highlights the suggestions from the technical peer reviewers (MER 2000) about methods to refine the marine reference range values (SEA and Weston 1999). Section 3 describes Phase 1 of the SEDQUAL benthic interpretive module as it has been implemented to date. Finally, Section 4 presents the recommendations for enhancements to the SEDQUAL system that could be implemented during Phase 2 of the project. Phase 2 recommendations include additional freshwater and marine benthic assessment endpoints and analytical techniques that would broaden SEDQUAL's support of state water and sediment management programs, as well as standardize sample collection and handling to ensure data quality.

2 CURRENT PERSPECTIVE ON USING BENTHIC METRICS IN RESOURCE MANAGEMENT DECISIONS

2.1 National Perspective

Historically, benthic community impacts were identified based on comparison of near-field versus far-field differences in a single metric (e.g., total abundance) representing community structure. For example, a metric representing a site potentially impacted by an industrial or municipal outfall was compared to another site at some distance from the point source. Multivariate analytical techniques based on species assemblages were also used to delineate impaired communities. However, interpretations were often confounded by changes in habitat or assemblage characteristics due to natural variations. Historically, few regulatory programs incorporated specific interpretive guidelines in their management decisions.

Methods for assessing benthic impacts across habitat and assemblage boundaries have been refined over the last decade in response to some of the interpretive difficulties. Methods include:

- A discriminant analysis approach used by the U.S. Environment Protection Agency's (EPA) Environmental Monitoring and Assessment in Estuaries program in the Gulf of Mexico (Engle et al. 1994, Engle and Summers 1999) and mid-Atlantic (Paul, J. in prep.) estuaries.

- An index of biotic integrity (IBI) approach (originally applied in freshwater systems) used in Chesapeake Bay (Ranasinghe et al. 1994, Weisberg et al. 1997), the southeast Atlantic (Van Dolah et al. 1999), and the New York-New Jersey Harbor complex (Ranasinghe et al. in review).

- The benthic response index (BRI), which is an abundance-weighted, average species, pollution-tolerance approach used in the southern California Bight (Smith et al. in press).

- Reference ranges used in San Francisco Bay (Thompson et al.1999).

- An index of indicator taxa abundance in California bays and harbors (Hunt et al. 1998).

- River Invertebrate Prediction and Classification Scheme (RIVPACS), a predictive model for evaluating the biological quality of river surface waters, both regionally and nationally (Wright et. al. 1993).

- Puget Sound reference ranges for water depths less than 150 feet (SEA 1996, SEA and Weston 1999).

To date, few agencies have incorporated these methods into regulatory decision frameworks, although several states are evaluating different metrics and approaches. Currently, the State of California is evaluating the use of benthic community metrics for the management of contaminated sediments. The Canadian National Research Council has recently funded MacDonald Environmental Sciences to evaluate the use of benthic community response indices in developing sediment quality guidelines (SQGs). This work will compile electronically available, regional (e.g., Puget Sound Ambient Monitoring Program, EMAP) data sets with derived community metrics and chemistry. As a preliminary step, the originating program's assessment of whether or not a particular sample represents an impacted community will be used. Correlations between chemistry and benthic responses would then be evaluated and preliminary SQGs developed. The analytical approach will be similar to the methods used to develop national SQGs based on bioassay responses that are currently applied by sediment management agencies in various regions of the United States (e.g., Florida Department of Environmental Quality, Minnesota Pollution Control Agency, San Francisco Regional Water Quality Control Board).

2.2 State Perspective

2.2.1 Marine/Estuarine Sediments

For several years, Puget Sound regulatory and resource agencies have been in the forefront in developing realistic assessment frameworks for managing sediment quality. The SMS framework uses a weight-of-evidence approach to indicate impaired sediment quality. Decisions under the SMS integrate ecological responses (benthic community alterations and/or laboratory invertebrate toxicity) to chemical concentrations. Other regional programs (e.g., EMAP) and regulatory agencies have only recently attempted to develop decision frameworks that incorporate elements of triad data.

Benthic community structure provides a critical element in the SMS decision process. Community responses integrate both short- and long-term effects that are not inherent in any other SMS evaluation tool. In addition, collection and evaluation of the benthic invertebrates provide direct assessment of a community-level response and do not suffer from issues of surrogacy or representativeness that laboratory tests must address (i.e., if the sampling design for collecting macroinvertebrates incorporated statistically sound assumptions).

The SMS process is designed to incorporate the best available science in regulatory decisions. Ecology has evaluated different benthic metrics and analytical and interpretive approaches in an effort to identify the most effective use of benthic community data in regulatory decision making. In order to facilitate evaluation of benthic data, Ecology has developed analytical tools and applied the results in a decision framework in the SEDQUAL benthic module.

This project relied extensively on prior work that resulted in the following actions:

- Recommendations made by the National Benthic Experts Workshop (February 1993) panel members (PTI Environmental Services 1993).

- Development and testing of programmatic reference ranges by analyzing a synoptic data set of Puget Sound habitats (SEA 1996).

- Evaluation of the effectiveness of the benthic community metrics concurrent with proposed reference ranges in identifying potentially impacted stations when compared to site-specific reference stations (Weston 1996).

- Refinements to the Puget Sound ranges and selection of endpoints and assessments methods (SEA and Weston 1999).

- Recommendations from the technical peer review of Ecology's proposed benthic assessment methods and endpoints for use in regulatory decisions (MER 2000).

A brief summary of the key elements of past work that formed the basis of the benthic module is described below.

2.2.1.1 Work Conducted to Date

In February 1993, EPA, the Puget Sound Water Quality Authority, and Ecology convened a workshop to discuss issues that complicate the use of benthic communities as indicators of adverse environmental impacts. Specifically, the workshop discussed the technical adequacy of the methods promulgated as part of the SMS to assess and interpret community impacts and developed recommendations for improving interpretive methods. Key recommendations included:

- Use more than one benthic metric to assess impacts. At a minimum, total abundance and total richness should be used in conjunction with major taxa (class Crustacea, class Polychaeta, and phylum Mollusca) abundance.

- Develop and refine an indicator taxa list that would identify both pollution-tolerant and pollution-sensitive taxa.

- Refine the Infaunal Trophic Index (ITI) for Puget Sound.

- Identify benthic community reference conditions indicative of uncontaminated areas in Puget Sound.

- Retain comparisons to reference and use univariate [t-test, analysis of variance (ANOVA)] statistical tests to compare site versus reference.

Following these recommendations, SEA was funded by Ecology to develop programmatic reference ranges to support decision making for Puget Sound sediment management programs. Historical data representing benthic invertebrate communities from four different shallow water (less than 150 feet MLLW) habitat types were compiled. Fourteen benthic metrics were calculated for each of the habitat types (based on grain-size categories ranging from coarse to fine-grained) and were analyzed to develop and test programmatic reference ranges. This work was presented in SEA's 1996 report, *Development of Reference Ranges for Benthic Infauna Assessment Endpoints in Puget Sound*, and concluded the following:

- Programmatic reference ranges are a reasonable substitution for site-specific reference comparisons when no site-specific reference station can be identified. In addition, reference ranges can be used as performance standards for site-specific reference samples.

- Molluscan species richness, total species richness, and derived endpoints [Swartz's dominance index (SDI), ITI, Shannon-Wiener diversity] generally perform well and should be given the greatest weight when evaluating benthic community impacts.

- Taxonomic standardization and use of consistent sampling and handling protocols are necessary to maintain the integrity of the reference range database.

Concurrently, Roy F. Weston, Inc. (Weston) evaluated, in a case study based on the Elliott Bay Action Program data, the effectiveness of these same 14 metrics in identifying potentially impacted stations when compared to site-specific reference stations by using a series of statistical approaches. In this case study, Weston compared the effectiveness of using reference ranges in lieu of site-specific reference data. Weston's results, which were reported in the *Task 3 Evaluation of Analytical Methods and Benthic Community Endpoints for Potential Inclusion in the Sediment Management Standards* (Weston 1996), recommended the following:

- Pollution-tolerant and pollution-sensitive species, along with those taxa that have a disproportionate influence on community structure (i.e., keystone species) should be identified for use in interpreting community responses.

- Total richness, major taxa abundance (polychaete, crustacean, and molluscan abundance), Shannon-Weiner diversity, and the SDI should be relied upon for SMS decisions because of the ability of these metrics to discern moderate impacts and consistency with the rule.

- All impacts should be based on site metrics being less than reference metrics, with the exception of polychaete abundance, which should be greater than reference. For abundance measures, the interpretive endpoint should be a value based on (i.e., less than) 50 percent of the reference value. For richness and derived metrics, the interpretive endpoint should be based on a statistically significant difference (i.e., less than) from reference.

- Proposed 1996 reference ranges need further evaluation to address the inclusion of some values that appear more representative of stressed or impacted communities, potential geographical variability in reference conditions, and potential differences or similarities among habitat classifications.

- Proposed reference ranges could be applied where a reference site was either not available or failed SMS performance criteria.

In 1999, the recommendations resulting from these separate efforts were consolidated in the report, *Puget Sound Reference Value Project Task 3: Development of Benthic Effects Sediment Quality Standards* (SEA and Weston 1999). Final recommendations were based on additional refinements and testing of selected benthic metrics and included:

- Base benthic community evaluations primarily on the SDI and enhanced polychaete abundance. Molluscan richness and abundance, crustacean abundance, and total richness should be used to confirm the magnitude of the impact.
- Use numerical comparisons to reference ranges (a non-statistical approach) as the method for identifying impacts[1] until a method of distributing reference data sets was available.
- Define a minor adverse impact [Sediment Quality Standard (SQS) "hit" or failure] by a single exceedance of either the SDI or enhanced polychaete abundance decision criterion. (A single failure of molluscan richness or abundance, crustacean abundance, or total richness should not trigger an SQS level hit.)
- Define a moderate to severe impact [Cleanup Screening Level (CSL) hit] by a failure of both the SDI and enhanced polychaete abundance, or either the SDI or enhanced polychaete abundance coupled with a failure of molluscan richness or abundance, crustacean abundance, or total richness test criterion. If the SDI is less than or equal to 5.0, this should also be considered sufficient to trigger a CSL failure.
- Solicit input from Ecology's sediment management program staff, potentially affected parties, and regional benthic experts regarding the scientific validity, defensibility, and regulatory implementability of these recommendations.

[1] Use of statistical pairwise comparisons (t-test or *post hoc* tests following an ANOVA) was also considered a valuable tool in evaluating changes in benthic community structure. A pair-wise test between a single potentially impacted station and its matching Puget Sound reference data set tended to have a high degree of statistical power to identify differences. However, from a programmatic perspective, management of the distribution of the reference data sets to potentially liable parties or project proponents that have been required to perform biological testing under the SMS rule seemed unwieldy prior to implementation of the benthic module in SEDQUAL. Therefore, use of the t-test (or other statistical pair-wise testing) for reference area comparisons was not included in the recommendations at the time. The current development of the benthic module now provides a mechanism for distributing and updating reference data sets and addresses the original concern of maintaining data integrity.

- Conduct an evaluation of the sensitivity and efficiency of the recommended endpoints based on reference range comparisons.
- Evaluate the effect of the taxonomic changes as to the magnitude of the impact on the reference ranges for benthic endpoints based on richness. If significant, the reference ranges should be recalculated.
- Reevaluate the habitat definitions as the reference database is expanded to address preliminary evidence that habitat categories could be combined or refined.
- Evaluate the potential for geographical variability in endpoint values as the reference database is expanded.
- Develop and evaluate an approach to incorporate indicator taxa.
- Continue to collect data within Puget Sound in potential reference areas and habitat types not represented in the current reference database (e.g., deep-water depositional areas).

In April 2000, Ecology contracted with five benthic experts: Dr. Richard Swartz, EPA, retired; Dr. Robert Smith, consultant; Dr. Jeff Hyland, NOAA, Charleston Laboratory; Dr. Jennifer Ruesink, University of Washington, Department of Zoology; and Dr. Jack Word, MEC Analytical. They were asked to review the basis that the two key documents (SEA 1996, SEA and Weston 1999) considered in developing the proposed changes to the benthic community evaluations to be conducted under the SMS rule. The experts were asked to address the scientific validity (including ecological relevance), defensibility, and implementability of the recommendations.

In response to their charge, the experts were able to reach a consensus regarding use of reference threshold values to define impaired benthic communities; this proposal has their full support. However, the experts raised issues related to the details of the reference ranges, including compilation of the reference data, representation of natural conditions given removal of outliers, and the reliability of the endpoints based on an apparently elevated false positive rate for a number of key endpoints.

A summary of their comments is provided below:

- The majority of the reviewers supported development of habitat-specific reference ranges. However, there were a number of differing opinions as to how to calculate the reference ranges (or limits) associated with them (e.g., percentiles, tolerance limits). Experts also felt strongly that reference ranges should be developed for deeper habitat categories (i.e., fined-grained, deep water habitats).

- With respect to the calculation of reference ranges, the majority of the reviewers felt that the original data set should be used in its entirety (i.e., including outliers), unless there was sufficient evidence that the anomalous values were due to factors other than natural variability. One reviewer strongly recommended that the issue of pseudo-replication be addressed prior to calculating reference ranges.[2]

- The reviewers suggested that additional analysis is needed to confirm the possibility of geographic variability in habitats and endpoints. They strongly recommended use of biological variables to determine if there are geographic differences rather than basing the analysis on physical habitat parameters.

- They also felt that the probability of incorrectly classifying a station was fairly high, particularly for false positives (saying something is impacted when it is not), but could be addressed through additional refinements to the reference ranges and/or endpoints used.

- The general thought was that taxonomic discrepancies would not affect the use of the reference ranges; however, standardization of nomenclature and sampling protocol were viewed as critical.

- All reviewers agreed that multiple benthic endpoints are needed to evaluate community-level impacts. However, some reviewers questioned the proposed endpoints, and were not supportive of limiting the number of endpoints without an evaluation of the correlation among endpoints or other testing. While all of the 14 endpoints originally evaluated were considered appropriate for characterizing benthic community responses, reviewers particularly recommended inclusion of. measures of dominance and evenness in the adopted approach.

- Another reviewer did not agree with the use of 5.0 as the threshold for the SDI in defining impacted communities, and recommended use of statistical difference from reference.

- Most reviewers supported use of a reference-range approach and felt that the overall procedures were acceptable, but were concerned that the current reference ranges would result in a high error rate (particularly false positives). The experts recommended that Ecology consider inclusion of outliers and the use of percentiles or tolerance limits and other methods to maximize the difference between the proportion of contaminated stations above the limit and proportion of uncontaminated stations below the limit, as part of future refinements to the reference ranges.

- Overall, the experts did not support giving any benthic metric greater weight than another in regulatory decision making. Rather, they supported a weight-of-evidence approach.

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[2] The 1999 reference ranges were modified by removing statistical outliers or samples with anomalous community structure. In addition, each grab sample was treated as an independent sample when calculating reference range statistics.

2.2.1.2 Response to Agency and Expert Input

In response to the input received from various sediment management programs and experts regarding SEA and Weston's 1999 recommendations, the following modifications were made to the benthic reference ranges and analytical approaches incorporated into the Phase 1 support for SEDQUAL analytical module development:

- All marine reference samples were included in the reference database, with the exception of a few stations that were represented by anomalous community assemblages due to known factors (e.g., due to historical outfall effects). No outliers were excluded.

- Individual grab samples were combined at the station level within unique surveys or investigations. Station means were calculated prior to computing marine reference range statistics to address the issue of pseudo-replication and variability.

- Percentiles (i.e., 10^{th} and 90^{th}) were used to represent marine reference ranges rather than ± 1 standard deviation to address the different distributional properties of the individual endpoints and be consistent with other programmatic characterizations of benthic community endpoint.

- A weight-of-evidence approach was developed for inclusion of more benthic metrics, rather than relying on only a few metrics for both freshwater and marine assessments.

- Additional endpoints (total abundance, major taxa richness and abundance, Shannon-Weiner diversity and Pielou's evenness[3]) were included as assessment endpoints for developing the marine benthic weight-of-evidence assessment approach in response to peer review comments and to be consistent with national benthic community assessment approaches.

- Evaluation of SDI was based on a statistical comparison to reference conditions or reference ranges, rather than a single threshold value (i.e., 5.0).

2.2.2 Freshwater Sediments

The SMS rule does not currently stipulate freshwater benthic sediment quality standards or assessment methods. As part of criteria and protocol development, Ecology reviewed available North American freshwater benthic community metrics for potential use in assessing Washington State sediments (Ecology 1991). A summary of the findings included:

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[3] Additional endpoints based on pollution tolerance, pollution sensitivity, and trophic structure (i.e., the ITI) are also recommended, but could not be implemented as part of Phase 1.

- Primary metrics used by nearly every agency to assess surface water quality for stream and rivers include taxa richness, EPT richness (i.e., total taxa of the orders Ephemeroptera, Plecoptera and Trichoptera), and a regionally developed biological index such as the Hilsenhoff family level biotic index.

- Secondary metrics used by approximately half of the agencies contacted included Shannon-Weiner diversity, functional feeding classifications (e.g., shredders, filterers, etc.), and dominance and similarity.

- Multivariate statistics are not typically used because macroinvertebrate samples collected for most biological monitoring programs are not replicated or are processed using a semi-quantitative approach (i.e., they are subsampled).

- Rapid bioassessment protocols developed by EPA are used by all agencies for field sampling and processing (e.g., sorting, taxonomic identifications).

The document further recommended the following:

- Various metrics available for assessing the benthic invertebrate community should be used despite the variability in the composition and distribution of the benthos from factors such as seasonality, temperature, and hydrodynamics.

- In determining which benthic metrics should be used in a regulatory context, a set of community measures should be defined that will cover all conditions but still maintain some flexibility so that new biological interpretation methods can be included for individual cases.

In the state's review of assessment methods, other assessment techniques were identified, including an ecosystem approach. This is an approach in which resource management objectives are expressed by a set of biological variables that correspond with aquatic system variables (e.g., oxygen and temperature variables, conventional parameters) for evaluating the health of the ecosystem (Turak et. al. 1999). One method that has been employed in Washington State is the RIVPACS model (River Invertebrate Prediction and Classification System), which predicts the health of a river system based on habitat-specific differences relative to physical, chemical, and biological reference conditions. RIVPACS predicts the expected macroinvertebrate fauna, if no environmental stressors are present, using a small suite of environmental characteristics for a site. Site-specific collections of benthic invertebrates are conducted, and then the observed versus expected community structure forms the basis on which a site can be assessed.

3 DEVELOPMENT OF THE PHASE 1 BENTHIC TOOL FOR THE SEDQUAL DATABASE

Benthic data were included in the original SEDQUAL database, and the file structure for inputting data into the system was standardized across all data types to facilitate data entry. Benthic data in SEDQUAL were used to develop apparent effects thresholds; however, no analytical tools were available to evaluate benthic data according to the SMS regulatory paradigm. A tool to analyze benthic invertebrate community data was planned as part of the original SEDQUAL in the early 1990s, but was not completed at that time because regulatory decisions were being made primarily from sediment chemical and/or toxicological data. In addition, project managers were experiencing difficulties in identifying suitable reference areas for regulatory comparisons.

In the last several years it has become apparent to developers of SQGs that benthic community structure (what species are present, how many individuals, and how are they distributed among the different taxa) may be a more sensitive indicator of the health of the community than sediment chemical or laboratory toxicological information. As a result, the endpoints and interpretive guidelines under the SMS have been refined based on the work described in Section 2. Ecology decided to complete the development of a benthic tool for SEDQUAL to facilitate use of benthic community responses in sediment management decisions.

3.1 SEDQUAL General Structure and Capabilities

The SEDQUAL information system comprises a set of software products consisting of four main components: 1) a database component that stores the data and documents information, 2) an integrated GIS component that spatially represents database information, 3) an comparison/analysis interface component that helps the SEDQUAL user interact with and use the database/GIS system, and 4) an online technical reference component that provides useful information on how to use the system and enter data. SEDQUAL contains sophisticated analytical functions and data summarization routines that help the user obtain needed information. In addition, SEDQUAL contains a technical reference, and all components can be downloaded from the Ecology web site (*www.ecy.wa.gov/programs/tcp/smu/sedqualfirst.htm*).

3.1.1 Data Types

There are currently six data types with templates for entering data into SEDQUAL:

- Sediment chemistry data
- Sediment bioassay with associated control and reference data
- Tissue chemistry data
- Bioaccumulation data
- Benthic community data
- Histopathology data.

These data entry templates are a set of ASCII, comma-delimited text files that can be edited using a text editor or spreadsheets available from the Windows operating system. These spreadsheet files with their data values can then be imported into SEDQUAL using SEDQUAL's data entry utility.

There are four hierarchical data entry files that are shared in common among the six data types:

- A **Reference File** provides general information about a survey's sponsoring organization, the name of the reference documents, authors, key words, and publication date. The reference template is an Excel, comma-delimited (.csv) file with seven fields.

- The **Survey File** is an Excel, comma-delimited (.csv) file that provides general information about the sampling event, such as the survey name, the agency that performed the sampling, and when it was performed. It is the main template to which other templates are linked. The survey template has 13 fields.

- The **Station File** provides basic information about the stations, such as their locations and names. The station template is an Excel, comma-delimited (.csv) file with 12 fields.

- The **Sample File** provides general information about the samples collected, such as what gear was used to collect the sample and at what depth below the sediment/water surface. The sample template is an Excel, comma-delimited (.csv) file with 14 fields.

There are additional file types for data entry currently available in SEDQUAL that are specific to the above six data types. All of these files are Excel, comma-delimited (.csv) files.

The interrelationship among these files allows a user to search SEDQUAL for data by sponsoring organization, by survey, by station, or by sample. The GIS component allows the user to highlight an area and search for all data from sampling locations within that area and plot new station locations derived from SEDQUAL comparisons to GIS.

3.1.2 Analytical Capabilities

Analytical tools currently available in SEDQUAL fall into two groups. The first group includes the data selection or grouping tools. These include the ability to select stations for analysis based on survey, station and/or sample, and through the use of the built-in GIS. The second group includes statistical tools that examine sediment chemical and bioassay data to determine whether a sample exceeds the numerical and/or narrative SMS criteria. Sediment chemistry data can be compared to both the SQS or to the CSL. Bioassay data from test stations can be compared to the batch-specific control station and to the grain-size-matched reference station. SEDQUAL also has built-in abilities to do limited data transformations and tests for normality and homogeneity of variances. SEDQUAL users may create any chemical or bioassay performance criteria to compare with site data.

3.2 Benthic Tool

The basic benthic community analytical tool developed in Phase 1 consists of a taxonomic dictionary, a module for selecting station test groups, and two data analytical pathways for statistically testing benthic community data (Figure 3-1). The first pathway corresponds to the SMS rule decision process. Within this path, the abundances of major taxa groups (polychaetes, molluscs, and crustaceans) are numerically and statistically compared, using a pairwise test, to data from a corresponding reference station. The ability to examine benthic community data in relation to a new set of draft SMS benthic endpoints (see Table 3-1) and numeric thresholds was also incorporated into this part of the tool. The second pathway to be developed in a future Phase 2 will encompass a broader range of analytical tools, including the ability to conduct ANOVA tests. Both pathways will utilize the same taxonomic dictionary and methods for the selection of test and comparison groups.

3.2.1 Taxonomic Dictionary

The taxonomic dictionary contains the list of all species that potentially reside in the marine and freshwater sediments in Washington. The dictionary contains 21 fields (columns) and 5,504 records (rows). The list of field names and attributes is presented in Table 3-2. Other benthic database systems rely on the taxonomically based National Oceanographic Data Center (NODC) codes that are maintained by NOAA or by the Integrated Taxonomic Information System (ITIS) taxonomic serial codes that are maintained by group of six federal agencies. The ITIS system is gradually replacing the NODC system; however, there are a number of inconsistencies between the two that preclude complete conversion of NODC to ITIS codes. As a result, the SEDQUAL database system will use the scientific name as the key field for inputting new data. ITIS and NODC codes will also be maintained along with up to four synonyms for each taxon.

3.2.2 Endpoint Calculations

Currently, SEDQUAL supports the calculation and/or reporting of the endpoints listed in Table 3-3. Additional endpoints will be added as part of future enhancements to the benthic tool. See Section 4.0 for further discussion of proposed enhancements to the analytical module.

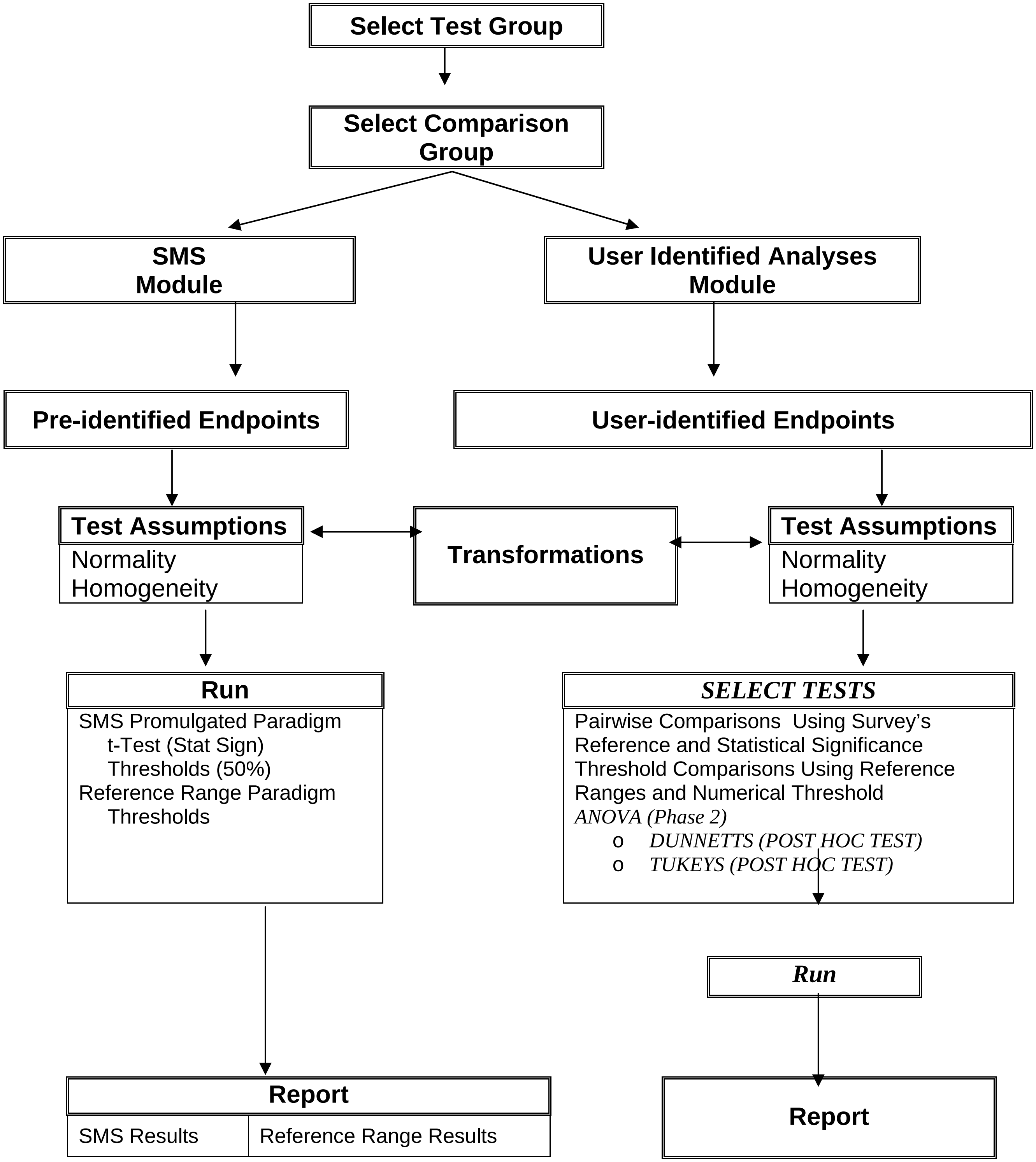

Figure 3-1. The Conceptual Design of the SEDQUAL Benthic Tool. The figure presents the elements of the tool that have been incorporated into this update of SEDQUAL, with italicized, all-caps text representing those elements that will be implemented in Phase 2.

Table 3-1. Primary and Secondary Benthic Community Endpoints for Incorporation into the Revised/proposed SMS Rule. (Primary endpoints were the most sensitive of the two groups.)

Primary Endpoints	Secondary Endpoints
Swartz's Dominance Index (SDI) Enhanced polychaete abundance	Total Taxa Richness Total Abundance Molluscan Abundance Molluscan Taxa Richness Crustacean Taxa Richness Crustacean Abundance Polychaete Richness Shannon-Weiner Diversity Pielou's Evenness

Table 3-2. Names, Data Types, and Lengths for Fields in the SEDQUAL Taxonomic Dictionary.

Field Name	Field Name Abbreviation	Data Type	Length
Taxonomic Identifier	TAXON_ID_NR	Integer	4
ITIS Code	TSN_CD	Variable character	8
NODC Code	NODC	Variable character	12
First Synonym	SYNONYM_NM	Variable character	110
Second Synonym	SYNONYM_NM2	Variable character	110
Third Synonym	SYNONYM_NM3	Variable character	110
Fourth Synonym	SYNONYM_NM4	Variable character	110
Phylum	PHYLUM_NM	Variable character	30
Subphylum	SUBPHYLUM_NM	Variable character	30
Class	CLASS_NM	Variable character	30
Order	ORDER_NM	Variable character	30
Family	FAMILY_NM	Variable character	30
Genus	GENUS_NM	Variable character	30
Species	SPECIES_NM	Variable character	30
Subspecies	SUBSPECIES_NM	Variable character	30
Subspecies source name	SUBSRC_NM	Variable character	20
Subspecies source date	SUBSCR_DT	Small date time	4
Valid scientific name	SCI_NM	Variable character	110
Comments	CMNT_DS	Variable character	255
Standing of name in ITIS	ITIS_STANDING	Variable character	50
Date of name in ITIS	ITIS_STANDING_DATE	Small date time	4

Table 3-3: Endpoint Calculations Currently Available in SEDQUAL.

Endpoint	Medium	Endpoint Derivation
Total Abundance	Both	Sum of all individuals
Total Number of Taxa	Both	Count all unique taxa
Polychaeta Abundance	Marine	Sum of all Polychaeta
Mollusca Abundance	Both	Sum of all Mollusca
Arthropoda Abundance	Both	Sum of all Arthropoda
Crustacean Abundance	Both	Sum of all Crustacean
Amphipoda Abundance	Both	Sum of all Amphipoda
Echinodermata Abundance	Marine	Sum of all Echinodermata
Oligochaeta Abundance	Both	Sum of all Oligochaeta
Nematode Abundance	Both	Sum of all nematode
Polychaeta Species Richness	Marine	Count all Polychaeta taxa
Oligochaeta Species Richness	Both	Count all Oligochaeta taxa
Amphipoda Species Richness	Both	Count all Amphipoda taxa
Mollusca Species Richness	Both	Count all Mollusca taxa
Echinodermata Species Richness	Marine	Count all Echinodermata taxa
Crustacean Species Richness	Both	Count all Crustacean taxa
Arthropoda Species Richness	Both	Count all Arthropoda taxa
Nematode Species Richness	Both	Count all Nematode taxa
Swartz's Dominance Index	Marine	Formula
Shannon-Weiner Diversity (H')	Both	Formula (3 different log bases)
Pielou's Evenness (J')	Both	Formula
Ephemeroptera Abundance	Freshwater	Sum of all Ephemeroptera
Plecoptera Abundance	Freshwater	Sum of all Plecoptera
Trichoptera Abundance	Freshwater	Sum of all Trichoptera
Chironomid Abundance	Freshwater	Sum of all Chironomids
EPT Abundance	Freshwater	Sum of all EPT taxa
Percent Ephemeroptera	Freshwater	Abundance Ephemeroptera/total abundance
Percent Plecoptera	Freshwater	Abundance Plecoptera/total abundance
Percent Trichoptera	Freshwater	Abundance Tricoptera/total abundance
Percent Chironomids	Freshwater	Abundance Chironomids/total abundance
Percent EPT	Freshwater	Abundance EPT/total abundance
Top 3 Dominant Taxa	Both	Abundance of top 3 most abundant taxa
Ephemeroptera Richness	Freshwater	Count all Ephemeroptera taxa
EPT Richness	Freshwater	Count all EPT taxa
Chironomid Richness	Freshwater	Count all Chironomid taxa
Plecoptera Richness	Freshwater	Count all Plecoptera taxa
Tricoptera Richness	Freshwater	Count all Tricoptera taxa

3.2.3 Test Group Selection

A test group can consist of a group of surveys, stations, or samples that may be of interest to a SEDQUAL user. Groups can be selected by a survey identifier; by the custom selection of surveys, stations, or samples; or by the use of the SEDQUAL GIS interface.

A survey, by definition, is a group of stations that are sampled or samples that are collected at roughly the same time. In a typical survey, field-collected sediment samples may be analyzed for chemical concentrations, toxicological responses, and benthic community structure. Each survey in the SEDQUAL database has a unique identifier. When the database is queried for a particular survey, data from all stations and samples within that survey are brought forth for analysis.

The second method for selecting test groups is by choosing specific surveys, stations, or samples that are of interest to the user. This powerful tool allows the user to review and analyze data from a broader geographic area than by simply selecting a specific survey.

The third method of selecting test groups is by the use of the SEDQUAL GIS interface. This built-in GIS interface provides basic spatial analysis features at no cost. The user selects a map from which to select stations located within a drainage basin or other geographic study area. The built-in GIS interface also allows users to interface with external GIS programs that a user must purchase separately. Users can quickly and easily perform database query and analysis functions using the selected stations. Similarly, a user can quickly view and map station locations associated with any query or analysis result produced by the system.

3.2.4 Reference Assignment

A reference is a station or group of stations that can be selected by the user based on the environmental or habitat conditions of interest. The typical comparison group in an environmental survey consists of stations that are indicative of the ambient or background communities in rivers, streams, and marine basins. These “reference areas or stations” represent the benthic community from unimpacted areas, and are usually located away from potential sources of organic enrichment and chemical contamination. In addition to a comparison selected to identify reference stations or conditions, user-created groups can be compiled to reflect any number of environmental conditions. Examples of these other comparison groups could be stations selected that have similar sediment grain sizes, organic carbon content, or water depths.

3.2.4.1 Within-survey Reference Group

Most surveys collect reference samples for comparison with the survey test samples. These samples can be collected from one or a number of stations depending on the study design of the survey. The type of benthic community found in an area is highly dependent on sediment grain size. As a result, a survey with stations from a broad range of grain sizes should have reference samples that represent the benthic community from that range of grain sizes. SEDQUAL has the capability of selecting one or more samples from within a specific survey that could be indicative of reference conditions or some other environmental or habitat condition of interest. Data from these samples can then be used to conduct statistical testing against within-survey test samples.

3.2.4.2 Across-survey Reference Group

In some cases, the benthic community at a reference station may turn out to be unsuitable for comparison to the survey test stations. In other cases, a user may want to increase the statistical power of an analytical test by using data from multiple reference stations. In either of these cases, the SEDQUAL database can be examined to determine whether reference stations from other surveys may be suitable for use. Additionally, the user can create a reference group from other surveys that reflect certain environmental or habitat conditions that are of interest. If additional stations are identified, then these can be selected for inclusion in an analysis.

3.2.4.3 Administrative Reference Group

An administrative reference group consists of data from a group of stations in which sediment chemical and biological tests have been conducted. The stations are typically from numerous surveys with broad geographic and temporal ranges. The marine administrative reference group proposed for use by Ecology was created from data accumulated as part of the development of reference ranges for Puget Sound (SEA and Weston 1999). This group of stations was separated into habitat categories based on the sediment grain size, none of which contained any chemical of concern equal to or greater than the SQS of the SMS rule. At this time the reference ranges and the administrative reference group consists of stations at water depths less than 150 feet.

3.2.5 Analytical Modules

The analytical modules within the SEDQUAL database are represented in **Figure 3-1** as twin analytical pathways. The two modules are the SMS Module and the User Identified Analyses Module. The User Identified Analyses Module will be enhanced in Phase 2 and is discussed in greater detail in Section 4.0

3.2.5.1 Test Assumptions

Prior to using parametric statistical tests to determine if a test station has an impacted benthic community, the distribution of the data must be examined. The data are tested for normality and homogeneity of variance. The use of Student's t-test on non-normal data can lead to the rejection of the hypothesis being tested when it is in fact true (Type I error). The Bioassay Module in SEDQUAL has the capability of testing data sets for normality and homogeneity of variance, and the benthic community module uses those same methods.

SEDQUAL uses the Shapiro-Wilk W-statistic to test for normality [Shapiro and Wilk (1965), as cited in Michelsen and Shaw (1996), Corps and EPA (1994)].

Levine's test is used to examine the homogeneity of variance of test and reference samples. The U.S. Army Corps of Engineers, Waterway Experiment Station, reviewed two methods for determining the homogeneity of variance. They reviewed Cochran's test to evaluate equality of variance and the Levene test [as cited in Michelsen and Shaw (1996)], and determined that Cochran's test might have very high Type I error rates when the data set has a non-normal distribution. To be consistent with the state's Dredged Material Management Program, SEDQUAL uses Levene's test in both the bioassay and benthic community modules.

The transformation of benthic community data prior to statistical testing is an issue that is still unresolved. Benthic community abundance data tend to be log-normally distributed, while richness and derived metrics or indices data are usually normally distributed. The decision to transform data should be on a case-by-case basis. However, if the decision is to transform the data, then the abundance data should be log-transformed. The SEDQUAL bioassay module has the ability to log-transform the abundance data, and that methodology has been carried into the benthic community module.

3.2.5.2 Current SMS Analytical Paradigm

Under the current SMS rule, for a station to be identified as impacted, the abundance of any one major taxon (specifically polychaetes, molluscs, or crustaceans) at the test station must be statistically less than the reference station abundance using the Student's t-test. In addition, the abundance at the test station must be at least 50 percent less than the corresponding abundance at the reference station. This paradigm has been incorporated into the benthic tool.

3.2.5.3 Proposed SMS Analytical Paradigm

The revisions to the SMS benthic interpretation paradigm focus on the use of the Puget Sound reference ranges for selected benthic community endpoints (see **Table 3-3**) for four habitat types. Endpoints that were consistently effective in identifying impaired conditions (SEA and Weston 1999) are considered primary endpoints and are used individually to interpret benthic community responses. Those endpoints that were less effective (secondary endpoints) or were recommended by peer reviewers or used in other regional programs are evaluated collectively to interpret the community response.

The decision process is similar to the current SMS process in that three benthic community metrics will be used to determine if a community is impaired. Endpoints can be either statistically compared to a site-specific reference or numerically compared to habitat-specific reference thresholds. In this revision, the SDI, enhanced polychaete abundance, and the secondary endpoints (collectively) will be used to make a decision. Each individual endpoint will be compared to its reference condition [site-specific reference or numeric reference threshold (see discussion below)]. The SDI and enhanced polychaete abundance will represent the first two endpoints used in the decision. The results of the comparison of the secondary endpoints will be compiled in a weight-of-evidence approach to represent the third part of the decision. An SQS level hit is based on the failure of one of the three individual (i.e., enhanced polychaete abundance or SDI) or composite (secondary endpoints, evaluated collectively) endpoints to be either statistically similar to the site-specific reference data set or fall within the numerical reference range. In the case of the enhanced polychaete endpoint, a hit occurs when the test value is statistically greater than the site-specific reference, or the test value is numerically greater than the habitat-specific Puget Sound reference threshold value. A CSL hit is based on two or more of the endpoints being statistically less than reference (or greater than in the case of polychaete abundance) or outside of the habitat-specific reference range.

3.2.5.3.1 Reference Range Thresholds

The reference ranges describe the attributes of a typical reference community. As such, the lower range has been defined as the 10th percentile and the upper range as the 90th percentile of the reference range data set. The lower reference range represents that value below which test station endpoints are likely to be statistically and significantly lower than reference, and the upper reference range is that value above which test station endpoints are statistically higher than reference. However, there is no consensus that an exceedance of the upper threshold represents an impact, with the exception of the abundance of polychaetes. Polychaetes respond rapidly to increases in organic carbon with large increases in abundance (Pearson and Rosenberg 1978). As a result, for polychaete abundance, the upper reference range is used as a primary endpoint to identify potential impacts. Reference range values are summarized in Table 3-4.

3.2.6 Reporting Capabilities

The reporting capabilities within SEDQUAL include being able to export data in Excel format (.csv format) or print out benthic community data by sample, station, or survey groups. Mean values for the benthic endpoints can also be summarized by sample, station or by survey groups. The data can also be reported as to whether test stations comply with the Washington State SMS regulatory criteria, draft SMS benthic endpoints (see Table 3-1), or user-specified benthic sediment quality value groups/endpoints. Data can be exported to a GIS program where stations exceeding SMS criteria can be mapped and examined for trends.

Table 3-4: 2003 Reference Value Ranges for Puget Sound Habitats[a].

Benthic Endpoint	Habitat Category <150 ft.							
	N	0-20% Fines	N	20-50% Fines	N	50-80% Fines	N	80-100% Fines
Total Abundance	57	278.1-764.9	19	334.1-726.8	22	120.3-736.3	30	171.6-511.6
Total Taxa	57	44.5-98.0	19	51.5-87.4	22	22.5-66.6	30	22.5-51.2
Crustacean Abundance	57	40.1-286.0	19	26.9-221.6	22	6.9-268.5	30	12.8-216.2
Crustacean Taxa	57	7.8-21.2	19	6.7-17.8	22	3.4-12.2	30	3.2-7.2
Amphipoda Abundance	57	6.9-62.0	19	3.7-132.3	22	1.2-37.5	30	1.0-55.5
Amphipoda Taxa	57	3.6-12.0	19	2.3-10.2	22	0.9-6.8	30	0.9-3.9
Polychaeta Abundance	57	65.2-418.8	19	145.1-479.5	22	54.2-280.8	30	32.8-173.9
Polychaeta Taxa	57	19.6-54.5	19	26.5-53.1	22	11.9-35.4	30	9.2-28.3
Mollusca Abundance	57	38.3-195.7	19	50.7-277.9	22	37.1-277.4	30	17.0-136.7
Mollusca Taxa	57	11.2-21.4	19	9.9-17.8	22	5.9-18.0	30	5.3-14.1
Shannon-Wiener Diversity (H')	57	1.0-1.6	19	1.1-1.5	22	1.0-1.5	28	0.8-1.2
Pielou's Evenness (J')	57	0.6-0.8	19	0.6-0.8	22	0.6-0.9	28	0.6-0.8
Infaunal Trophic Index (ITI)	57	67.0-85.5	19	67-86.1	22	61.6-80.6	28	61.5-87.5
Swartz's Dominance Index (SDI)	57	5.2-24.5	19	7.8-19.3	22	5.6-18.7	28	3.9-10.1

a: Thresholds are based on the 10^{th} and 90^{th} percentile of reference data. All values are presented in per 0.1 m^2.

4 RECOMMENDATIONS FOR FURTHER SEDQUAL DEVELOPMENT

During the development of the benthic module, a series of enhancements were identified as being beyond the scope of work for the current project. These enhancements are carried forward and are discussed further in the following sections as proposals for Phase 2 work. Proposals for both marine and freshwater assessments include use of additional metrics and indices as well as analytical techniques and evaluation approaches, to meet Ecology objectives.

4.1 Marine Benthic Community Evaluations

Other sediment and water quality management programs have identified a series of metrics that would be useful for analyzing benthic community data. In addition, several indices or analytical approaches have been successful in identifying impaired communities in other areas of the country and may be applicable for use in Puget Sound.

4.1.1 Individual Metrics

Metrics recommended as future enhancements to SEDQUAL include the following:

- Miscellaneous taxa abundance
- Miscellaneous taxa richness.

Indices that are recommended for inclusion in SEDQUAL include:

- Puget Sound Infaunal Trophic Index (Word 1990).

These indices will require additional development and testing for Puget Sound and freshwater habitats concurrent with SEDQUAL redevelopment efforts (e.g., supplement the taxonomic dictionary to include species behavioral and functional attributes)[4].

4.1.2 Community Response Indices

Several multimetric indices (benthic response index and benthic index of biotic integrity) were reviewed for consideration for future incorporation in SEDQUAL. A brief description of each index and its potential utility for regulatory purposes is discussed below.

[4] A table of draft biological attributes (e.g., trophic guilds, life history strategies) for specific species (Merritt and Cummins 1996, Wisseman 1998, Word 1990) is included as Appendix 2. This table will assist Ecology in the "early-stage" development and/or review of a multimetric index regarding the SMS decision framework (i.e., a weight-of-evidence approach).

4.1.2.1 Benthic Response Index

The Benthic Response Index (BRI) was developed in southern California in 1997 (Bergen et al. 1997). It was developed to assess the sequential or successional gradients in benthic communities that result from natural environmental stresses and from anthropogenic activity. The BRI is calculated in a two-step process:

1. Use ordination analysis to define a pollution gradient.
2. Determine the pollution tolerance of each species based on its distribution of abundance along the gradient.

Once the pollution gradient and the pollution tolerance of each species are determined, the index is calculated as the abundance-weighted-average pollution tolerance of species in a sample. The BRI ranges from 0 to 100, with low values found in samples representative of reference conditions and high values in samples from stations with some benthic community impact. Four levels of biological response were identified. First, a threshold value was identified for the reference condition, and then three levels of biological response were established based on deviations from the reference condition. The threshold values for each of the following three levels were based on BRI values above which species or groups of species were lost:

1. Loss of Biodiversity: The BRI value above which 25 percent of the species in the reference sample were lost.
2. Loss in Community Function: The BRI value above which major taxonomic groups were lost (i.e., phylum Echinodermata, class Crustacea).
3. Defaunation: The BRI value above which 90 percent of the species in the reference samples were lost.

The BRI appears to be sensitive in identifying changes in benthic community structure and function in southern California. However its utility in Puget Sound is untested. The BRI was developed using samples collected from areas with very clear pollution gradients from both chemical contamination and organic enrichment on the southern California shelf. Large sewage outfalls depositing solids from municipal effluent into the strong long shore currents caused these pollution gradients. For the most part, Puget Sound does not have the same large treatment plants or the persistent long shore currents, and, as a result, clear gradients of chemical contamination and organic enrichment do not exist.

Two questions arise when considering BRI use in Puget Sound. First, can temporal benthic community data from Puget Sound be used to develop and define a pollution gradient for use in ordination analysis? Without clear gradients in contamination, historical Puget Sound data from the urban embayments would have to be used to define the pollution gradient. Second, can the pollution-tolerance scores for the southern California species be used for the same organisms if found in Puget Sound? There is concern among Puget Sound benthic community experts that pollution-tolerance scores for species in Puget Sound may be different than those in southern California. If pollution-tolerance scores specific to Puget Sound need to be developed, significant expenditures in time and money would be needed.

It is the consensus among the SEDQUAL workgroup that the development of a Puget Sound BRI would not be cost-effective at this time due to funding constraints and because other existing benthic community indices function as well as the BRI. If funding becomes available in the future, the use of the California (species) BRI should be investigated to determine its applicability in Puget Sound.

4.1.2.2 Marine Benthic Index of Biotic Integrity

An IBI, originally developed for assessing freshwater fish communities, was adapted for evaluating benthic invertebrate communities in several East Coast estuaries (Chesapeake Bay, southeast Atlantic, and the New York-New Jersey Harbor complex). Most recently, this index was modified for use in the Mid-Atlantic Integrated Assessment (MAIA) Program (Llanso, R in prep.). This marine benthic IBI (B-IBI) uses various metrics indicating community structure and function that are able to distinguish among degraded and non-degraded conditions for five major habitat types. Threshold values used to score site responses were derived from the range of values for each metric measured at a number of reference sites. The final index integrates the scores based on various measures of abundance, diversity, species composition, life history, and trophic structure. The MAIA B-IBI uses the scores associated with total abundance, total richness, Shannon-Wiener diversity, percent dominance, percent abundance of pollution-tolerant taxa abundance, percent abundance of pollution-sensitive taxa, abundance of selected major taxa groups, Tanypodinae/Chironomidae abundance ratios, and percent abundance of deep deposit feeders for deriving the composite index. This multimetric index was shown to correctly classify sites as degraded or not (82 percent of the time, on average), and performed best in higher salinity habitats.

This type of approach may have great utility for assessing the health of marine benthic communities in Puget Sound. An advantage to using a composite index is that multiple metrics indicating diverse community structure and function are incorporated into the decision process. In addition, the final B-IBI score is easily interpreted and can accommodate the different outcomes (SQS versus CSL exceedances) used in SMS decisions. An example of a possible scoring approach (derived from existing reference range data) is provided in Appendix 1.

4.2 Freshwater Benthic Community Evaluations

Ecology has established guidance on freshwater numerical criteria for use in sediment management decisions. Since 1997, Ecology has used sediment toxicity testing, in addition to chemical data, to characterize sediment quality trends and to provide a management process for the cleanup of contaminated freshwater sediments. However, Ecology recognizes that benthic community assessments are also useful in determining the impact of contaminants that may not be fully characterized by chemical and toxicity data.

Freshwater benthic invertebrates (e.g., mayflies, caddisflies, beetles, midges, oligochaetes) are important elements of ecological surveys of streams and lakes because they tend to live in, on, or near sediments. In addition, these organisms have, with the exception of most molluscs, life cycles that are intermediate to fish (years) and algae (weeks) and are relatively sessile compared to larger organisms. The combination of these characteristics provides the mechanism for measuring shifts in benthic invertebrate community structure in response to natural and anthropogenic environmental conditions that physically or chemically alter the sediment habitats and distinguish the extent and magnitude of a biological effect. Therefore, these factors make benthic invertebrates well suited for use in assessing site-specific sediment quality, conducting comparisons of sediment quality at multiple sites, and integrating effects over time.

Ecology is evaluating freshwater benthic community assessment endpoints and interpretation processes concurrent with developing guidance regarding sample collection and processing protocols for inclusion in the SMS. The following sections highlight the approach of using benthic community assessments in a regulatory context and propose benthic metrics for making sediment quality determinations for streams and lakes. Appendix 3 summarizes the sampling protocol necessary to ensure data quality so that quantitative data representing community structure and function can be easily incorporated in sediment management decisions.

4.2.1 Proposed Evaluation Framework

The decision framework for assessing freshwater sediment quality should be based on a statistical comparison of site conditions to a site-specific reference. Comparison to reference ranges developed for specific ecoregions are also appropriate, where they are available. Physical habitat attributes or classifications will be used to interpret whether detected differences between test and reference sites are due to natural and/or anthropogenic conditions that physically or chemically alter bottom substrates. Thus, the decision of whether or not the benthic community is healthy will use calculated biometrics and physical habitat characteristics such as grain size.

This is consistent with other studies that have identified the distribution of benthic species and shifts in assemblage structure as corresponding with sediment properties (Rempel et al. 1999). However, it is also recognized that shifts in community makeup will also occur in response to other environmental factors, such as organic loading, dissolved oxygen, stream flow and turbulence, and bed roughness, which result in alterations in feeding strategies, attachment methods, and reproductive strategies (Culp et al. 1983). Morphology and feeding behavior data are currently being studied and documented (Merritt and Cummins 1996, Thorp and Covich 1991). Although morphology and feeding behavior are useful information for evaluating the extent and level of the physically/chemically altered sediments, these data are not as important as obtaining good quality information on species-level identifications that is greatly needed for state monitoring programs (Ecology 1996).

4.2.2 Data Analysis and Interpretation

It is recommended that evaluation of the freshwater benthic invertebrate data be conducted using the benthic analytical module included in SEDQUAL. The module consists of analytical and graphical tools that support statistical analyses required by current regulatory programs (pair-wise comparisons to reference conditions), in addition to other tests to evaluate whether or not statistical assumptions are being met. Data violating assumptions are flagged to allow the user to choose various transformations to improve the statistical properties of the data set before proceeding with data analysis. The benthic module allows the user to define what dataset results are to be compared to, as well as what data are to be used to represent reference conditions [comparison and reference groups can be defined within an ecological survey, across an ecoregion (e.g., Puget Sound Lowlands), or by the programmatic data set]. For details of these data analysis tools, refer to Section 3.0 of this paper.

The Students t-test is recommended for interpreting differences in benthic community metrics between a test sample and a matching freshwater reference condition. Use of the t-test to conduct a pair-wise test between the questionable benthos sample and programmatic reference (Ecology 2003a) is also recommended as an evaluation approach. This approach allows for greater use of the benthic biometrics in sediment management decisions because it addresses the difficulties experienced by many regulated parties or investigators in identifying appropriate reference sites.

4.2.3 Proposed Metrics

Several studies have identified the complex interactions between physical factors and sedimentary properties. The interaction of physical processes (e.g., near-bed shear velocity, Reynolds number, turbulence behavior) and sediment properties (e.g., grain size, sorting) makes it difficult to evaluate if changes to the benthic community structure are from either physical or chemical effects. For example, grain-size composition determines the heterogeneity in surface bed roughness, which in turn creates fine-scale flow patterns that influence the deposition and distribution of organic matter. These microhabitats can then be colonized by macroinvertebrate species with specific morphological or physiological attributes that make them successful in specific microhabitats. These types of interactions tend to create more complex environments that are difficult to characterize by a single community metric. When other factors, such as contaminants or other forms of disturbance are introduced, a single metric measuring a community-level response is even less predictive.

In this general model of benthic macroinvertebrate responses to chemical or organic alterations of sediment, selection of a combination of metrics is recommended for use to identify the sediment quality of a habitat. The following metrics describe different responses, including community composition, diversity, dominance, feeding behaviors, and sensitivity or tolerance of the community, to various abiotic factors. Historical studies indicate that each of these endpoints has adequate or good ability in identifying potentially impacted communities for both fine- and coarse-grained habitats, such as assemblage shifts from intolerant to tolerant taxonomic groups.

- ***Composition/Abundance Measures***
  - Percent Chironomidae (Chironomid abundance as a percent of total abundance)
  - Percent Ephemeroptera, Plecoptera, Trichoptera or EPT (EPT abundance as a percent of total abundance)
  - Percent Oligochaetes (Oligochaete abundance as a percent of total abundance)

- ***Diversity***
  - Trichoptera richness (number of taxa in the order Trichoptera)
  - Plecoptera richness (number of taxa in the order Plecoptera)
  - Ephemeroptera richness (number of taxa in the order Ephemeroptera)
  - Chironomid richness (number of taxa in the family Chironomidae)
  - Total taxa richness (total number of unique taxa)

- ***Trophic Strategy***
  - Percent predators (abundance of x, y, and z species as a percentage of total abundance)
  - Percent filterers (abundance of a, b, and c species as a percentage of total abundance)
  - Percent clingers (abundance of h, j, and l species as a percentage of total abundance)
  - Percent scrapers (abundance of m, n, and o species as a percentage of total abundance)

- ***Tolerance/Sensitivity***
  - Tolerant richness (number of tolerant taxa as a percentage of total abundance)
  - Intolerant richness (number of taxa representing sensitive groups)
  - Percent intolerant (number of individuals representing sensitive taxa as a percentage of total abundance)
  - Percent tolerant (number of individuals from tolerant taxa as a percentage of total abundance)
  - Percent long-lived richness (number of unique long-lived taxa)

- ***Dominance***
  - Percent top three abundant (number of individuals representing the top three most abundant taxa as a percentage of total abundance).

For the purpose of developing confirmatory freshwater sediment biological tests for the SMS rule use, it is recommended that endpoints that are currently used by Ecology's Freshwater Monitoring Unit be incorporated, and decisions follow the interpretive framework in the rule (i.e., pairwise comparisons between site and reference conditions).

4.2.4 Proposed Analytical Paradigm for Freshwater Sediments

In order to incorporate all of the information typically collected as part of freshwater monitoring programs into a regulatory decision, two weight-of-evidence approaches are presented below that could be used in interpreting the data. The preferred paradigm relies on the use of five community responses to determine if a community has been adversely affected by anthropogenic activity. However, this paradigm is complex and several SEDQUAL programming issues have to be resolved before it can be implemented. The second paradigm uses three community responses (a simplified weight-of-evidence approach) to identify a potentially impacted community. This simplified approach can be implemented immediately without additional programming.

Both paradigms are discussed in greater detail below, and regardless of which approach is included in SEDQUAL, it is strongly recommended that a field evaluation be conducted on the performance of the freshwater macroinvertebrate metrics concurrent with SEDQUAL development. This evaluation should also include reliability testing against a regional data set of synoptic chemistry, bioassay, and fauna data to determine numeric break points, false negative/positive rates, and overall reliability in making correct predictions regarding potential adverse sediment impacts. Results will also be used to provide recommendations on refining SMS narrative goals and freshwater apparent effects threshold (AETs) values.

4.2.4.1 Preferred Analytical Paradigm for Freshwater Sediments

This approach would rely on the five community response types (i.e., changes in composition, diversity, tolerance, trophic strategy, dominance) to make the final determination. Initially, each individual metric would be calculated for a sample and statistically compared to reference conditions. Results from the statistical testing would be grouped into respective community response types, as described above, to be used to indicate a potentially deleterious response. Thus, the second step of the decision process would be that within each response type, the results of the statistical comparisons for each contributing metric would be compiled. If two or more metrics in the response group (with the exception of dominance when one is sufficient) result in a statistically significant difference, it will constitute a potential impairment. Finally, a weight-of-evidence approach would be applied to the entire group results. If two of the five aggregated community groups indicate a potential impairment, then the response would be considered an SQS exceedance. If three or more aggregated community groups were impaired, this would comprise a CSL exceedance.

The weight-of-evidence approach will provide an initial evaluation process within SEDQUAL until Phase 2 recommendations about incorporating a multimetric index (e.g., the IBI) can be programmed and tested (see earlier discussion). Use of a weight-of-evidence approach allows regulators to use metrics based on direct response to stressors, as well as general behavioral and evolutionary information (e.g., Ephemeroptera species adjust their life-cycles to avoid periods of pollution stress, and chironomids ability to survive in anoxic environments is due to the presence of hemoglobin).

4.2.4.2 Simplified Alternative of Analytical Paradigm for Freshwater Sediments

While the five-part community response approach described previously parallels with other regional monitoring programs interpretive analyses, the required programming sequence to execute such a complex logic statement is currently out-of-scope regarding SEDQUAL's structured query language. Therefore, as an interim step, until the recommendation above can be implemented, it is suggested that a trimmed-down version of the preferred freshwater weight-of-evidence approach be used for making biological regulatory assessments. It is recognized that, depending upon the timing of Phase 2 recommendations, the process described in Section 4.2.4.1 may not be implemented and this less preferred alternative would last until full implementation of Phase 2 (e.g., augmenting the taxonomic dictionary with species functional and behavioral attributes, see Appendix 2).

This variation would rely on evaluating three response types (i.e., changes in composition, diversity, and dominance) when making a decision about rivers and/or lakes sediment quality. If one of the three aggregated community response types indicates a potential impairment (i.e., results of the compiled statistical site-specific reference comparisons; details provided in Section 4.2.4.1), this would be considered an SQS exceedance. If two or more aggregated responses were impaired, this would comprise a CSL exceedance.

4.2.5 Evaluation of Benthic Index of Biotic Integrity for Freshwater Systems

Ecology's Freshwater Monitoring Unit monitors the health of Washington's freshwater ecosystems (i.e., the biological quality of surface waters under the Clean Water Act) using a B-IBI index approach (Ecology 2003a). The index is based on a composite score that indicates whether a community's health is good, fair, or poor. The community's score is derived from individual community metric values that are ranked based on their response relative to reference conditions. Because communities vary by habitat type and watershed, individual metrics and composite index values representing reference conditions can also vary. There are currently calibrated B-IBI values for the following ecoregions: Puget Lowlands, Cascade Watersheds, and Columbia River Basin. For additional information regarding the development approach and calibration of the multimetric index, refer to Ecology's (2003a) report, Multi-Metric Index Development for Biological Monitoring in Washington State Streams.

Ecology personnel use the overall score computed from a specific ecoregion to classify the health and stability of the benthic community (Table 4-1). Scores for individual metrics used to compile the composite score are provided in Appendix 4.

Table 4-1. Water Quality Classification by Ecoregion Using B-IBI Values

Classification	Puget Lowlands	Cascade Watersheds	Columbia River Basin
Good	>30	>28	>33
Fair	20-30	23-28	23-33
Poor	<20	<23	<23

These ranges could be used as break points for developing numeric freshwater sediment quality standards or AETs. Other suggestions include developing tolerance limits or administrative reference ranges using the data set. However, this might be difficult because the synoptic chemical data consist of conventional and physio-chemical information only.

4.3 Other Analytical Approaches

Additional analytical approaches are planned for inclusion in SEDQUAL to support analytical needs of other sediment management programs and investigations. One major enhancement will be the ability to perform multi-sample comparisons using ANOVA techniques. Another proposed enhancement will be the ability to compare benthic metrics to reference threshold values.

4.3.1 Threshold Comparisons

Another option for evaluating benthic metrics could be comparisons to characteristic reference values. Within SEDQUAL, a user could select numeric comparisons, then either a single station mean or an aggregated station mean could be compared to the Puget Sound reference range threshold applicable to the endpoint or endpoints selected.

Another option for reference thresholds could be the development of performance criteria for either evaluating the use of within-survey reference stations or identifying candidate reference stations from clean habitats within Puget Sound.

4.3.2 Analysis of Variance

A multiple sample comparison would be done using an ANOVA, with *a posteriori* pairwise testing, to identify which group or groups were different from the others. Tukey's should be used in the case when all groups are compared to all other groups. Dunnett's should be used when all groups are compared to just one other group (e.g., representing reference or baseline). Types of comparisons are as follows:

- Multiple single station means (i.e., no aggregation other than at the station level) versus matching (i.e., within-survey) reference mean. Each group is a single station with replicated data. Dunnett's would be used for the *a posteriori* pairwise test.

- Multiple single station means versus matching (by habitat type) Puget Sound reference mean (i.e., use the matching reference data set either from the individual survey or from the Puget Sound reference data set). Each group is a single station with replicated data, except for the habitat-specific Puget Sound reference data sets (i.e., those stations used to create the reference ranges; membership is therefore pre-defined by Ecology), which is composed of multiple stations, not all of which are replicated. Dunnett's would generally be used for the *a posteriori* pairwise test because only one reference station or reference data set is assumed to be used in this comparison.

- Aggregated (by area, time, survey, etc) station mean versus other aggregated (representing some other area, time, or survey) station means, which is similar to pairwise, but includes more than two groups. Tukey's would be used as the *a posteriori* test.

4.4 Summary of Phase 2 Recommendations

The following represents a summary of outstanding recommendations from the experts' review and prior project work (SEA 1996, SEA and Weston 1999), in addition to recommendations formulated as part of the benthic module development. The recommendations should be used to formulate the basic scope of work for the Phase 2 benthic module development.

SEDQUAL Benthic Comparison Module

- Conduct an evaluation of the sensitivity and efficiency of all the recommended metrics that form the basis of the revised SMS paradigm.
- Conduct field validation of the recommended revisions to the SMS paradigm.
- Incorporate a simple interpretive approach for evaluating freshwater community metrics. Ultimately, the benthic tool should incorporate the results of current work by Ecology's Freshwater Monitoring Unit to develop geographically specific, multimetric indices that use additional information regarding community responses based on evolutionary traits, behavior, or other community response types.
- Develop and evaluate an approach to incorporate indicator/keystone taxa (e.g., pollution-tolerant, pollution-sensitive).
- Develop multiple-comparison capabilities within SEDQUAL (i.e., ANOVA).
- Include additional freshwater and marine community metrics and indices to support other sediment and water quality program needs.
- Expand taxonomic dictionary to include fields indicating functional or behavioral groups to support the calculation of composite indices.
- Expand benthic module capabilities to calculate composite indices (i.e., B-IBI) or those based on functional or behavioral groups (e.g., ITI).

Modifications to Benthic Community Reference Ranges

- Evaluate the effect of the taxonomic changes as to the magnitude of the impact on the reference ranges for benthic endpoints based on richness[5]. If significant, the reference ranges should be recalculated.
- Reevaluate the habitat definitions as the reference database is expanded. There is some evidence that habitat categories could be combined or refined.
- Evaluate the potential for geographical variability in endpoint values as the reference database is expanded.
- Develop deep water (>400 feet), fine-grained (>80 percent fines) references ranges based on currently available data.

Monitoring and Protocol Development

- Continue to collect data within Puget Sound in potential reference areas and habitat types not represented in the current reference database to support development of additional reference ranges.
- Continue to collect a freshwater reference sample for comparison with test samples because there are no promulgated numeric sediment quality criteria and administrative reference ranges.
- Adopt the guidance on protocols for biological monitoring in rivers and streams (Ecology 2001) and on taxonomic standardization for freshwater macroinvertebrates (Ecology 1996) by other state programs to ensure that high quality and relevant data for regulatory decision making is obtained and included in the SEDQUAL database.

[5] Taxonomic resolution will not affect abundance measures.

5 REFERENCES

Bergen, M., S.B. Weiusberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and R.G. Velarde. 1997. Assessment of Benthic Infauna on the Mainland Shelf of Southern California. SCCWRP Report. Costa Mesa, CA.

Britton, L.J., and Greeson, P.E. (eds.) 1988. *In*: Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples. U.S. Geological Survey Open-File Report 88-190. U.S. Geological Survey, Boulder, CO. 685 pp.

Corps and EPA. 1994. Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. Testing Manual. Draft Report. U.S. Environmental Protection Agency, Office of Science and Technology, and the U.S. Army Corps of Engineers, Washington, DC.

Culp, J.M., S.J. Walde, and R.W. Davies. 1983. Relative importance of substrate particle size and detritus to stream benthic macroinvertebrate microdistribution. *Can. J. Fish. Aquat*. 40:1568-1574.

Ecology. 2003a. Multi-Metric Index Development for Biological Monitoring in Washington State Steams. Pub. No. 03-03-035. Washington Department of Ecology, Olympia, WA.

Ecology. 2003b. SEDQUAL Sediment Quality Information and Management System (Release 4.4). Washington Department of Ecology, Olympia, WA.

Ecology. 2001. Benthic Macroinvertebrate Biological Monitoring Protocols for Rivers and Streams (Revised). Pub. No. 01-03-028. Washington Department of Ecology, Olympia, WA.

Ecology. 1996. Taxonomic Laboratory Protocol for Stream Macroinvertebrates Collected by the Washington State Department of Ecology. Final Report. Pub. No. 96-323. Washington Department of Ecology, Olympia, WA.

Ecology. 1991. A Review of Interpretation Methods for Freshwater Benthic Invertebrate Survey Data Used by Selected State and Federal Agencies. Prepared for the Washington Department of Ecology, Sediment Management Unit, Olympia, WA. R.D. Kathman and R.O. Brinkhurst, Young-Morgan and Associates, Franklin, TN. 69 pp.

Engle, V.D., and J.K. Summers. 1999. Refinement, validation, and application of a benthic condition index for northern Gulf of Mexico estuaries. *Estuaries* 22:624-635.

Engle, V.D., J.K. Summers, and G.G. Gaston. 1994. A benthic index of environmental condition of Gulf of Mexico estuaries. *Estuaries* 17:372-384.

EPA. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish. U.S. Environmental Protection Agency, Office of Water Monitoring Water Quality, Washington, DC.

Flannagan, J. 1970. Efficiencies of various grabs and cores in sampling freshwater benthos. *J. Fish. Res. Board Can*. 27:11691-1700.

Hunt, J.W., B.S. Anderson, B. Phillips, J. Newman, R. Tjeerdema, K. Taberski, C. Wilson, M. Stephenson, H. Puckett, R. Fairey, and J. Oakden. 1998. Sediment Quality and Biological Effects in San Francisco Bay. State Water Resources Control Board, Sacramento, CA.

Llanso, R. (In preparation). An Index of Benthic Condition for Mid-Atlantic Estuaries.

Mackay, R.J. 1979. Life history patterns of some species of Trichoptera: Hydropsychidae in southern Ontario. *Can. J. of Zool*. 57:963-975.

MER. 2000. Peer Review of Ecology's Proposed Benthic Assessment Methods and Endpoints for Use in Regulatory Decisions. MER Consulting, Seattle, WA. 76 pp. + attachment.

Merritt, R.W., and K.W. Cummins. 1996. *An Introduction to the Aquatic Insects of North America.* 3rd ed. Kendall/Hunt Publishing Company, Dubuque, IA. 862 pp.

Michelsen, T., and T.C. Shaw. 1996. Statistical Evaluation of Bioassay Results. PSDDA Clarification Paper; SMS Technical Information Memorandum *In*: Sediment Management Program Biennial Report, Puget Sound Dredged Disposal Analysis Program, U.S. Environmental Protection Agency and U.S. Army Corps of Engineers, Seattle, WA.

Murdoch, A., and S.D. MacKnight. 1994. *Handbook of Techniques for Aquatic Sediment Sampling*. Lewis Publishers, Chelsea, MI.

Paul, J. (In preparation). Development and Application of a Benthic Index of Estuarine Conditions for the Virginian Biogeographic Province.

Pearson, T.H., and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. and Mar. Biol. Annu. Rev.* 16:229-311.

PTI Environmental Services. 1993. Recommendations for Assessing Adverse Benthic Effects in Puget Sound. Prepared for Washington Department of Ecology, Olympia, WA. PTI Environmental Services, Inc, Bellevue, WA. 21 pp. + appendices

Ranasinghe, J.A., S.B. Weisberg, D.M. Dauer, L.C. Schaffner, R.J. Diaz, and J.B. Frithsen. 1994. Chesapeake Bay Benthic Assemblage Restoration Goals. CBP/TRS/107/94. Prepared for U.S. Environmental Protection Agency and the Maryland Department of Natural Resources, Chesapeake Bay Research and Monitoring Division, Columbia, MD. Versar, Inc., Columbia, MD.

Ranasinghe, J.A., S.B. Weisberg, J.S. O'Connor, and D.A. Adams. (In review). A benthic index of biotic integrity (B-IBI) for the New York/New Jersey Harbor. *J. of Aquat. Ecosyst. Stress Recovery*.

Rempel, L.L., J.S. Richardson, and M.C. Healey. 1999. Flow refugia for benthic macroinvertebrates during flooding of a large river. *J. N. Amer. Bentho. Soc.* 18:34-48.

Smith, R.W., M. Bergen, S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, J.K. Stull, and R.G. Velarde. (In press). A benthic response index for assessing infaunal communities on the mainland shelf of Southern California. Submitted to *Ecological Applications*.

SEA. 1996. Development of Reference Value Ranges for Benthic Infauna Assessment Endpoints in Puget Sound. Prepared for Washington Department of Ecology, Olympia, WA. Striplin Environmental Associates, Inc., Olympia, WA. 45 pp + appendices.

SEA and Weston. 1999. Puget Sound Reference Value Project, Task 3: Development of Benthic Effects Sediment Quality Standards. Prepared for Washington Department of Ecology, Olympia, WA. Striplin Environmental Associates, Inc., and Roy F. Weston, Inc., Olympia, WA. 49 pp. + appendices.

Thorp, J.H., and A.P. Covich. 1991. *Ecology and Classification of North American Freshwater Invertebrates*. Academic Press, Toronto, Canada.

Turak, E., L.K. Flack, R.H. Norris, J. Simpson, and N. Waddell. 1999. Assessment of river condition on large spatial scales using predictive models. *Freshwater Biol*. 41(2):283-298.

Thompson, B., S. Lowe, M. Kellogg, and H. Peterson. 1999. Macrobenthic Assemblages of the San Francisco Bay-Delta. Technical Report of the Regional Monitoring Program, San Francisco Estuary Institute, Richmond, CA.

Van Dolah, R.F., J.L. Hyland, A.F. Holland, J.S. Rosen, and T.R. Snoots. 1999. A benthic index of biological integrity for assessing habitat quality in estuaries of the southeastern United States. *Mar. Environ. Res*. 48:1-15.

Weisberg, S.B., J.A. Ranasinghe, D.M. Dauer, L.C. Schaffner, R.J. Diaz , and J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries* 20:149-158.

Weston. 1996. Evaluation of Analytical Methods and Benthic Community Endpoints for Potential Inclusion in the Sediment Management Standards. Prepared for the Washington Department of Ecology, Olympia, WA. Roy F. Weston, Inc., Seattle, WA. 45 pp. + appendices.

Wisseman, R.W. 1998. Taxonomy and Biological Notes. Aquatic Biology Associates, Inc., Corvallis, OR

Word, J.Q. 1990. The Infaunal Trophic Index, A Functional Approach to Benthic Community Analyses. Ph.D. Dissertation. University of Washington, Seattle, WA. 235 pp. + appendices

Wright, J.F., M.T. Furse, and P.D. Armitage. 1993. RIVPACS: A technique for evaluating the biological quality of rivers in the UK. *Eur. Water Poll. Contr.* 3(4):15-25.

APPENDIX 1:

PROPOSED SCORING CRITERIA FOR DEVELOPMENT OF A PUGET SOUND BENTHIC IBI

Table 1-1. Scoring Categories for Fined-grained (greater than 80% fines) Marine Sediments.

		Score		
Metric	**Predicted Response**	**1** **<10th percentile of reference**	**3** **10th to 50th percentile**	**5** **> 50th percentile of reference**
		Biometric Range		
Total Abundance	Decrease indicates degradation	<172	172 to 320	>320
Total Richness	Decrease indicates degradation	<22	22 to 32	>32
Arthropoda Abundance	Decrease indicates degradation	<13	13 to 54	>54
Arthropoda Richness	Decrease indicates degradation	<3	3 to 5	>5
Polychaeta Abundance	Increase indicates degradation	>174 or <33	33 to 83	83 to 173
Polychaeta Richness	Decrease indicates degradation	<9	9 to 15	>15
Mollusca Abundance	Decrease indicates degradation	<17	17 to 65	>65
Mollusca Richness	Decrease indicates degradation	<5	5 to 9	>9
Swartz's Dominance Index	Decrease indicates degradation	<3.9	3.9 to 6.8	>6.8
Pielou's Diversity	Decrease indicates degradation	<0.8	0.8 to 1.1	>1.1
ITI	Decrease indicates degradation	<61.5	61.5 to 78.5	>78.5

Table 1-2. Scoring Categories for Mixed-grained (50 to 80% fine) Marine Sediments.

		Score		
Biometric	**Predicted Response**	**1 <10th percentile of reference**	**3 10th to 50th percentile**	**5 > 50th percentile of reference**
		Biometric Range		
Total Abundance	Decrease indicates degradation	<120	120 to 383	>383
Total Richness	Decrease indicates degradation	<22	22 to 52	>52
Arthropoda Abundance	Decrease indicates degradation	<7	7 to 56	>56
Arthropoda Richness	Decrease indicates degradation	<3	3 to 8	>8
Polychaeta Abundance	Increase indicates degradation	>281 or < 54	54 to 161	161 to 281
Polychaeta Richness	Decrease indicates degradation	<12	12 to 28	>28
Mollusca Abundance	Decrease indicates degradation	<37	37 to 72	>72
Mollusca Richness	Decrease indicates degradation	<6	6 to 14	>14
Swartz's Dominance Index	Decrease indicates degradation	<5.6	5.6 to 8.5	>8.5
Pielou's Diversity	Decrease indicates degradation	<1.00	1.00 to 1.1	>1.1
ITI	Decrease indicates degradation	<61.6	61.6 to 71.2	>71.2

Table 1-3. Scoring Categories for Mixed-grained (20 to 50% fine) Marine Sediments.

		Score		
Biometric	**Predicted Response**	**1 <10th percentile of reference**	**3 10th to 50th percentile**	**5 > 50th percentile of reference**
		Biometric Range		
Total Abundance	Decrease indicates degradation	< 334	334 to 534	>534
Total Richness	Decrease indicates degradation	< 52	52 to 67	>67
Arthropoda Abundance	Decrease indicates degradation	< 27	27 to 122	>122
Arthropoda Richness	Decrease indicates degradation	< 7	7 to 11	>11
Polychaeta Abundance	Increase indicates degradation	>480 or < 145	145 to 210	210 to 480
Polychaeta Richness	Decrease indicates degradation	< 26	26 to 38	>38
Mollusca Abundance	Decrease indicates degradation	< 51	51 to 75	>75
Mollusca Richness	Decrease indicates degradation	<10	10 to 13	>13
Swartz's Dominance Index	Decrease indicates degradation	<7.8	7.8 to 14.6	>14.6
Pielou's Diversity	Decrease indicates degradation	<1.1	1.1 to 1.4	>1.4
ITI[a]	Decrease indicates degradation	<67.0	67.0 to 71.0	>71.0

Table 1-4. Scoring Categories for Coarse-grained (less than 20% fine) Marine Sediments.

		Score		
Biometric	**Predicted Response**	**1 <10th percentile of reference**	**3 10th to 50th percentile**	**5 > 50th percentile of reference**
		Biometric Range		
Total Abundance	Decrease indicates degradation	<278	278 to 513	>513
Total Richness	Decrease indicates degradation	<44	44 to 68	>68
Arthropoda Abundance	Decrease indicates degradation	<40	40 to 134	>134
Arthropoda Richness	Decrease indicates degradation	<8	8 to 13	>13
Polychaeta Abundance	Increase indicates degradation	>418 or <65	65 to 168	168 to 418
Polychaeta Richness	Decrease indicates degradation	<20	20 to 34	>34
Mollusca Abundance	Decrease indicates degradation	<38	38 to 67	>67
Mollusca Richness	Decrease indicates degradation	<11	11 to 16	>16
Swartz's Dominance Index	Decrease indicates degradation	<5.2	5.2 to 14.7	>14.7
Pielou's Diversity	Decrease indicates degradation	<1.0	1.0 to 1.3	>1.3
ITI	Decrease indicates degradation	<67	67 to 74	>74

APPENDIX 2:

FUNCTIONAL GROUPINGS FOR CALCULATION OF PHASE 2 FRESHWATER AND MARINE METRICS

Table 2-1. Functional Feeding Groups for Washington Freshwater Taxa: Predators.

Predators	
Berosus sp.	Helobdella stagnalis
Dytiscidae	Helobdella sp.
Dytiscus sp.	Hirudinea
Gyrinidae	Corydalidae
Gyrinus sp.	Corydalus sp.
Hydrobius sp.	Megaloptera
Hydrophilidae	Neohermes sp.
Laccobius sp.	Orohermes sp.
Oreodytes sp.	Sialidae
Tropisternus sp.	Sialis sp.
Athericidae	Aeshnidae
Atherix sp.	Coenagrionidae
Cardiocladius sp.	Cordulegaster sp.
Ceratopogoninae sp.	Cordulegastridae
Chaoborus sp.	Gomphidae
Chelifera sp.	Lestidae
Chrysops sp.	Libellulidae
Clinocera sp.	Calineuria californica
Conchapelopia sp.	Claassenia sabulosa
Cryptochironomus sp.	Cascadoperla trictura
Dicranota sp.	Chloroperlidae
Dolichopodidae	Cultus sp.
Empididae	Diura sp.
Forcipomyiinae sp.	Doroneuria sp.
Glutops sp.	Frisonia picticeps
Hemerodromia sp.	Hesperoperla pacifica
Hexatoma sp.	Haploperla sp.
Labrundinia sp.	Isogenoides sp.
Larsia sp.	Isoperla sp.
Limnophila sp.	Kathroperla perdita
Limnophora sp.	Kogotus sp.
Macropelopia sp.	Megarcys sp.
Muscidae	Osobenus yakimae
Natarsia sp.	Perlinodes aureus
Oreogeton sp.	Picteiella expansa
Parachironomus sp.	Paraperla sp.
Paramerina sp.	Perlidae
Pedicia sp.	Perlodidae
Pelecorhynchidae	Plumiperla sp.
Tabanidae	Rickera sorpta
Tabanus sp.	Setvena sp.
Tanypodinae	Skwala sp.
Thienemannimyia Gr.	Suwallia sp.
Thienemannimyia Gr.	Sweltsa grp.
Wiedemannia sp.	Triznaka sp.
Xenochironomus sp.	Utaperla sp.
Zavrelimyia sp.	Glossiphonia sp.
Drunella spinifera	Rhyacophila Ecosa grp. – ecosa
Glossiphoniidae	Rhyacophila Grandis grp. – grandis
Arctopsyche grandis	hyacophila Hyalinata grp.
Arctopsyche sp.	Rhyacophila Lieftincki grp. – arnaudi
Himalopsyche phryganea	Rhyacophila malkini
Himalopsyche sp.	Rhyacophila Nevadensis grp.
Nyctiophylax sp.	Rhyacophila Oreta grp.
Parapsyche almota	Rhyacophila Rotunda grp.
Parapsyche elsis	Rhyacophila Sibirica grp.
Parapsyche sp.	Rhyacophila Sibirica grp. – blarina
Polycentropodidae sp.	Rhyacophila Sibirica grp. – narvae
Polycentropus sp.	Rhyacophila Sibirica grp. – pellisa
Piscicola salmositica	Rhyacophila Sibirica grp. – valuma
Placobdella montifera	Rhyacophila Vagrita grp.

Predators	
Rhyacophila Alberta grp.	Rhyacophila Vemna grp.
Rhyacophila Angelita grp.	Rhyacophila Vofixa grp.
Rhyacophila Betteni grp.	Rhyacophila Iranda Gr.
Rhyacophila Brunnea grp.	Rhyacophila sp.
Rhyacophila Coloradensis grp.	Rhyacophilidae

Table 2-2. Functional Feeding Groups for Washington Freshwater Taxa: Scrapers.

Scrapers	
Acneus sp.	Phaenopsectra sp.
Cylloepus sp.	Philorus sp.
Eubrianax edwardsi	Cinygma sp.
Microcylloepus sp.	Cinygmula sp.
Optioservus sp.	Epeorus grandis
Psephenidae	Epeorus sp.
Psephenus sp.	Heptagenia sp.
Agathon sp.	Heptagenia/Nixe sp.
Bibiocephala sp.	Nixe sp.
Blepharicera sp.	Rithrogena hageni
Blephariceridae	Rithrogena robusta
Deuterophlebia sp.	Rhithrogena sp.
Deuterophlebiidae	Stenonema sp.
Eukiefferiella Brehmi Gr.	Ancylidae
Maruina sp.	Anagapetus sp.
Ferrissia rivularis	Apatania sp.
Ferrissia sp.	Dicosmoecus gilvipes
Fluminicola sp.	Goera archaon
Gastropoda	Glossosoma sp.
Gyraulus sp.	Glossosomatidae
Hydrobiidae	Goeridae
Juga sp.	Helicopsyche borealis
Planorbidae	Helicopsyche sp.
Pleuroceridae	Helicopsychidae
Valvatidae	Leucotrichia pictipes
Petrophila sp.	Leucotrichia sp.
Potamopyrgus antipodarum	Neophylax occidentis
Allocosmoecus partitus	Neophylax rickeri
Agapetus sp.	Neophylax splendens
Neophylax sp.	Protoptila sp.
Neothremma sp.	Psychomyia sp.
Neotrichia sp.	Psychomyiidae
Oligophlebodes sp.	Tinodes sp.
Pedomoecus sierra	Zumatrichia sp.

Table 2-3. Functional Feeding Groups for Washington Freshwater Taxa: Filterers.

Filterers	
Prosimulium sp.	Margaritiferidae
Rheotanytarsus sp.	Pelecypoda
Simuliidae	Unionidae
Simulium sp.	Cheumatopsyche sp.
Tanytarsus sp.	Chimarra sp.
Twinnia sp.	Dolophilodes sp.
Isonychia sp.	Hydropsyche sp.
Corbicula fluminea	Hydropsychidae
Corbicula sp.	Philopotamidae
Margaritifera falcata	Wormaldia sp.
Margaritifera sp.	

Table 2-4. Functional Feeding Groups for Washington Freshwater Taxa: Clingers.

Clingers	
Elmidae	Rhyacophila Angelita grp.
Cleptelmis sp.	Rhyacophila Ecosa grp. - ecosa
Heterlimnius sp.	Rhyacophila Grandis grp. - grandis
Lara sp.	Rhyacophila Sibirica grp. - pellisa
Narpus sp.	Rhyacophila Sibirica grp. - valuma
Optioservus sp.	Rhyacophila Sibirica grp. - blarina
Zaitzevia sp.	Rhyacophila Vemna grp.
Agathon sp.	Rhyacophila Betteni grp.
Clinocera sp.	Rhyacophila Brunnea grp.
Simulium sp.	Rhyacophila Coloradensis grp.
Antocha sp.	Rhyacophila Hyalinata grp.
Rhyacophila sp.	Rhyacophila Nevadensis grp.
Rhyacophila bifila	Rhyacophila Oreta grp.
Rhyacophila vaccua	Rhyacophila Rotunda grp.
Rhyacophila Sibirica grp. - narvae	Rhyacophila Vagrita grp.
Rhyacophila Lieftincki grp. - arnaudi	Rhyacophila Verrula grp.
Rhyacophila malkini	Rhyacophila Vofixa grp.
Rhyacophila Alberta grp.	

Table 2-5. Taxa Within Functional Feeding Groups for the Puget Sound Infaunal Trophic Index (ITI) (Word 1990): Group I.

Group I: Water Column/Suspended Detrital Feeders (SS)	
Ampelisca spp.	Spio setosa
Amphiodia spp.	Streblospio benedicti
Byblis spp.	Tritella pilimana
Caprella spp.	Acila spp.
Chaetopterus spp.	Clinocardium spp.
Cucumaria spp.	Corophium insidiosum
Erichthonius spp.	Crenella spp.
Haploops spp.	Deutella californica
Mayerella spp.	Dulichia monacantha
Metacaprella spp.	Dulichia porrecta
Nereis dioversicolor	Florimetis opesa
Nereis zonata	Macoma balthica
Ophiopholis spp.	Macoma elimata
Ophiothrix spp.	Macoma incongrui
Phragmatepoma spp.	Macoma inquinata
Platynereis spp.	Macoma nasuta
Praxillura maculata	Megacrenella spp.
Sabella spp.	Scalpellum californicum
Sabellaria spp.	Scalpellum sanctipretrense
Serpula spp.	Tagelus californianus
Aora typical	Tellina salmonea
Bathyporeia typical	Transenella spp.
Diastylis spp.	Urechis caupo
Lyonsia spp.	Mesochaetopterus spp.
Owenia fusiformis	Phyllochaetopterus spp.
Paraprionospio pinnata	Onuphidae
Spiophanes bombyx	

Table 2-6. Taxa Within Functional Feeding Groups for the Puget Sound Infaunal Trophic Index (ITI) (Word 1990): Group II.

Group II: Interface/Surface Detrital Feeders (ST)	
Ampharetinae	Lumbrineris spp.
Amphitrite spp.	Melita spp.
Brisaster spp.	Monoculodes spp.
Brissopsis spp.	Oedocerotidae
Corophium salmonis	Ophiura spp.
Corophium volutator	Phoxocephalidae
Echinocardium spp.	Synchelidium spp.
Hobsonia florida	Tanidacea
Listriolobus pelodes	Westwoodilla caecula
Magelona spp.	Amphicteis spp.
Mediomastus spp.	Aporiionospio pygmaea
Myriochele spp.	Axiothella rubrocincta
Nephtys spp.	Boccardia pugettensis
Photis spp.	Eusyllinae
Polycirrus spp.	Exogoninae
Polydora ligni	Glycera spp.
Protomedia spp.	Golfingia spp.
Scoloplus spp.	Lanassa venusta
Spiochaetopterus spp.	Leptosynapta spp.
Terebellidae (not Amphtritinae polycirrinae)	Myriowenia spp.
Thelepus crispus	Macoma brota
Trichobranchidae	Pectinaria californiensis
Trochochaetidae	Pectinaria gouldii
Adontorhina cylia	Polydora ligni
Axinopsida serricata	Prionospio malmgreni
Cumingia spp.	Prionospio steenstrupi
Hiatella arctica	Pseudopolydora kempi
Macoma tenta	Pygospio elegans
Mysella bidentata	Scolelepis spp.
Mysella tumida	Caudina arenicola
Psephedia lordi	Hemicordata
Tellina spp.	Heteromastus filiformis
Arenicolidae	Praxillella spp.
Bathymedon spp.	Hippomedon spp.
Cirratulidae	Molpadia spp.
Euphilomedes spp.	Scalibregmidae

Table 2-7. Taxa Within Functional Feeding Groups for the Puget Sound Infaunal Trophic Index (ITI) (Word 1990): Group III.

Group III: Interface/Surface Deposit Feeders	
Travisia spp	Lysianasidae
Petaloproctus spp..	Alia permodesta
Macoma alaskana	Nassarius mendicus
Macoma carlottensis	Nassarius perpinguis
Parvilucina tenuisculpta	Scoloplos spp.
Thyasira flexuosa	Nuculana spp.
Bittium spp.	Yoldia spp.
Leitoscoloplos pugettensis	Clymenella spp
Scoletoma luti	

Table 2-8. Taxa Within Functional Feeding Groups for the Puget Sound Infaunal Trophic Index (ITI) (Word 1990): Group IV.

Group IV: Subsurface/Anaerobic Deposit Feeders	
Capitella capitata	Ophelina acuminata
Armandia bioculata	Oligochaeta
Armandia brevis	Solemya spp.
Dorvilleidae	Stenothoidae

Table 2-9. Tolerant Freshwater Taxa Used by Ecology to Identify Potentially Impacted Waterbodies.

Tolerant Taxa	
Dryopidae	Ptychoptera sp.
Helichus sp.	Stratiomyidae
Dytiscidae	Odontomyia sp.
Dytiscus sp.	Syrphidae
Oreodytes sp.	Tabanidae
Cleptelmis sp.	Chrysops sp.
Dubiraphia sp.	Tabanus sp.
Lara avara	Limonia sp.
Microcylloepus sp.	Baetis tricaudatus
Optioservus sp.	Callibaetis sp.
Stenelmis sp.	Centroptilum sp.
Zaitzevia sp.	Caenidae
Gyrinidae	Caenis sp.
Gyrinus sp.	Stenonema sp.
Haliplidae	Choroterpes sp.
Brychius sp.	Leptophlebia sp.
Haliplus sp.	Paraleptophlebia bicornuta
Peltodytes sp.	Siphlonurus sp.
Berosus sp.	Tricorythidae
Eubrianax edwardsi	Tricorythodes sp.
Psephenus sp.	T. minutus
Hemerodromia sp.	Ancylidae
Athericidae	Ferrissia sp.
Atherix sp.	Ferrissia rivularis
Chironomus	Fluminicola sp.
Cladopelma sp.	Lymnaeidae
Cryptochironomus sp.	Fossaria sp.
Cryptotendipes sp.	Physidae
Dicrotendipes sp.	Physella sp.
Diplocladius sp.	Planorbidae
Endochironomus sp.	Gyraulus sp.
Eukiefferiella Brehmi Gr.	Juga sp.
Eukiefferiella Pseudomontana Gr.	Potamopyrgus antipodarum
Glyptotendipes sp.	Oligochaeta
Labrundinia sp.	Lumbriculidae
Limnophyes sp.	Naididae
Natarsia sp.	Helicopsychidae
Parachironomus sp.	Helicopsyche sp.
Paratendipes sp.	Helicopsyche borealis
Procladius sp.	Cheumatopsyche sp.
Psectrocladius sp.	Hydroptila sp.
Stictochironomus sp.	Leucotrichia sp.
Zavrelimyia sp.	Leucotrichia pictipes
Culicidae	Neotrichia sp.
Dixella sp.	Ochrotrichia sp.
Dolichopodidae	Oxyethira sp.
Ephydridae	Nectopsyche sp.
Muscidae	Oecetis sp.
Limnophora sp.	Triaenodes sp.
Psychoda sp.	Hesperophylax sp.
Limnephilus sp.	

Table 2-10. Intolerant Freshwater Taxa Used by Ecology to Identify Potentially Impacted Waterbodies.

Intolerant Taxa	
Blephariceridae	Yoraperla mariana
Agathon sp.	Doroneuria sp.
Bibiocephala sp.	Cascadoperia trictura
BlephKricera sp.	Cultus sp.
Philorus sp.	Diura sp.
Cricotopus (Nostococladius) sp.	Frisonai picticeps
Heterotrissocladius sp.	Kogotus sp.
Krenosmittia sp.	Megarcys sp.
Xenochironomus sp.	Osobenus yakimae
Deuterophlebiidae	Pictetiella expansa
Deuterophlebia sp.	Rickera sorpta
Oreogeton sp.	Setvena sp.
Pelecorhynchidae	Pteronarcys princeps
Glutops sp.	Apatania sp.
Tanyderidae	Pedomoecus sierra
Protanyderus sp.	Anagapetus sp.
Thaumaleidae	P. elsis
Hesperoconopa sp.	P. almota
Rhabdomastix sp.	Palaeagapetus sp.
Baetis bicaudatus	A. partitus
Caudatella sp.	C. centralis
Caudatella hystrix	Cryptochia sp.
Caudatella cascadia	Desmona sp.
Caudatella edmundsi	Desmona bethula
Caudatella heterocaudata	Dicosmoecus atripes
Drunella doddsi	Ecclisocosmoecus scylla
Drunelaa spinifera	Ecclisomyia sp.
Cinygma sp.	Halesochila taylori
Epeonus grandis	Homophylax sp.
Kathroperla perdita	Philocasca sp.
Paraperla sp.	Pseudostenophylax sp.
Leuctridae	Dolophilodes sp.
Despaxia sp.	Yphria sp.
Leuctra sp.	Himalopsyche phryganea
Megaleuctra sp.	Rhyacophila Alberta grp.
Moselia infuscata	Rhyacophila Iranda grp.
Paraleuctra sp.	Rhyacophia Oreta grp.
Perlomyia sp.	Rhyacophila Rotunda grp.
Visoka cataractae	Rhyacophila Vagrita grp.
Zapada columbiana	Rhycophila Verrula grp.
Zapada frigida	Rhyacophila Vofixa grp.
Sierraperla sp.	Neophylax occidentis
Soliperla sp.	Neothremma sp.
Yoraperla sp.	Oligophlebodes sp.
Yoraperla brevis	

APPENDIX 3:

DRAFT FRESHWATER MACROINVERTEBRATE SAMPLING PROTOCOLS

SAMPLING PROTOCOL STANDARDIZATION SUMMARY

Sampling Protocols

Timing

Sampling should occur at a time of year when the majority of benthic fauna are at or near maturity and few species are in early stages between molts (e.g., pupae). This will reduce problematic taxonomic identifications that are caused by small size and lack of adult morphological features that preclude identification to genus or species. In temperate climates such as the Puget Sound region, the period of maximum benthic community maturity and richness typically occurs from early to late fall depending upon water temperature (Mackay 1979). Another period of maximum maturation also occurs in the benthic assemblage that characterizes spring high-flow conditions, although fewer species are present. Characterization of both types of communities should be required because of the importance of water temperature in freshwater benthic invertebrate development. Therefore, minimum and maximum water temperatures need to be measured in conjunction with community characteristics so that data interpretation can account for habitat variables that affect community differences within the survey.

Sampling Devices

The type of sampler used to collect quantitative samples depends upon the habitat type being sampled. Factors that affect selection of sampling gear include:

- Substrate grain size (coarse versus fine-grained)
- Access
- Water depth [wadeable (<1 m) versus non-wadeable (>1 m)]
- Stream velocity (quiescent versus measurable flow).

Disturbance/removal sampling techniques are the most appropriate method for sampling wadeable, coarse-grained habitats. In this habitat type, Hess and Surber samplers (e.g., 0.09-m^2, 500-µm mesh), stovepipe corers, D-frame kicknets (0.19-m^2, 500-µm mesh) and box samplers are collection devices that can be used. For coarse substrate in deeper waters, a diver-operated dome sampler is required. This sampler consists of a battery-operated pump that empties material into a Nitex bag with 425-µm mesh openings. Artificial substrates, such as rock-filled barbecue baskets, can also be used in sampling coarse substrates in non-wadeable sites (Britton and Greeson 1988). This sampler consists of a basket filled with uniform indigenous rocks from the site that is placed on the bottom and stabilized by floats or buoys. The basket is allowed to colonize for 6-weeks (i.e., unless historical data suggest that a shorter/longer colonization period is more appropriate) after which organisms that have settled onto the artificial substrate are dislodged and placed into a net with 425-µm mesh openings.

Grab samplers are appropriate for collecting benthic invertebrate samples from fined-grained substrates (e.g., pools or sloughs). For example, an Ekman grab is particularly useful in wadeable habitats with sand or silt substrates; whereas a Ponar grab is suitable for habitats that are of fine-gravel sediments (e.g., outwash habitats). In non-wadeable fine-grained habitats, weighted grab samplers that can be used from boats with a power winch are the appropriate sampling gear. Petersen, van Veen, Shipek, and Ponar grab samplers are a few of the recommended grabs for collecting benthos samples from deep waters.

For further details on collecting and sampling of macrobenthic samples, refer to *Benthic Macroinvertebrate Biological Monitoring Protocols for Rivers and Streams* (Ecology 2001), *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish* (EPA 1999), *Efficiencies of Various Grabs and Cores in Sampling Freshwater Benthos* (Flannagan 1970), and *Manual of Aquatic Sediment Sampling* (Murdoch and MacKnight 1994).

APPENDIX 4:

WASHINGTON STATE DEPARTMENT OF ECOLOGY B-IBI SCORES FOR INDIVIDUAL METRICS FOR THREE FRESHWATER HABITATS (2003a)

Table 4-1. Individual Metrics Used in the Puget Lowlands IBI.

		Scoring Criteria		
Category	**Metric**	**1**	**3**	**5**
Richness	Ephemeroptera Richness	<4	4-6	>6
Richness	Plecoptera Richness	<3	3-5	>5
Richness	Total richness	<24	2433	>33
Richness	Trichoptera Richness	<4	4-6	>6
Tolerance	Intolerant richness (bi)	<2	2	>2
Tolerance	% top 3 abundant	>70	54-70	<54
Tolerance	% Tolerant (TV7)	>19	11-19	<11
Trophic/Habit	% Clingers	<26	26-47	>47
Trophic/Habit	% Predators	<11	11-19	>19
Voltinism	Long-Lived Richness	<3	3-5	>5

Table 4-2. Individual Metrics Used in the Cascades IBI.

		Scoring Criteria		
Category	**Metric**	**1**	**3**	**5**
Composition	% Ephemeroptera	<35	35-57	>57
Richness	Clinger Richness	<12	12-16	>16
Richness	Plecoptera Richness	<5	5-9	>9
Richness	Total richness	<37	37-52	>52
Richness	Trichoptera Richness	<9	9-12	>12
Tolerance	Intolerant richness (bi)	<6	6-9	>9
Tolerance	Hilsenhoff biotic integrity	>3.8	2.8-3.8	<2.8
Tolerance	% Tolerant (bi)	>23	12-23	<12
Trophic/Habit	% Clingers	<36	36-54	>54
Trophic/Habit	% Filterers	>28	15-28	<15

Table 4-3. Individual Metrics Used in the Columbia Basin IBI.

		Scoring Criteria		
Category	**Metric**	**1**	**3**	**5**
Richness	Ephemeroptera Richness	<4	4-6	>6
Richness	Long-lived Richness	>5	5-7	>7
Richness	Plecoptera Richness	<4	4-5	>5
Richness	Total richness	<25	25-36	>36
Richness	Trichoptera Richness	<5	5-7	>7
Tolerance	% top 3 dominant	>67	54-67	<54
Tolerance	Hilsenhoff biotic integrity	>5.0	4.0-5.0	<4.0
Tolerance	Intolerant richness (bi)	<2	2	>2
Composition	% Ephemeroptera	<16	16-30	>30
Trophic/Habit	% Filterers	44	23-44	<23