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Quality Assurance Project Plan

PCB Method Comparison of
High Resolution and Homolog Analysis

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The plan for this study is available on Ecology's website at
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Quality Assurance Project Plan

PCB Method Comparison of High Resolution and Homolog Analysis

November 2012

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Signatures are not available on the Internet version.
EAP: Environmental Assessment Program

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Abstract

Traditionally, polychlorinated biphenyls (PCBs) in sediment have been analyzed by Aroclor methods when regulatory criteria are to be applied. But limitations of the Aroclor analysis suggest a more informative method is needed. Detection limits above sediment management standards, changes in the analytical signal, and a subjective approach to reading Aroclor chromatograph patterns limit its usefulness. Improvements in alternative methods with lower detection limits and speciation of the most toxic or "dioxin-like" congeners have highlighted the limitations of Aroclor analyses.

Wide differences in toxicity of individual PCB congeners have prompted development of high resolution methods to provide concentrations on a congener-specific basis. But the high resolution analysis comes with a high cost. A less rigorous method than PCB congener analysis is needed to provide lower detection than Aroclors, at a moderate price, and to be useful for screening-level decisions.

The Washington State Department of Ecology will conduct a comparison study of three commonly used PCB analytical methods. A minimum of 10 marine and freshwater sediment samples will be homogenized, split, and analyzed at one laboratory. Each sample split will be analyzed by high resolution PCB congener analysis (EPA 1668C), PCB homolog analysis (EPA 680), and low resolution PCB Aroclor analysis (EPA 8082). Archived samples from various projects around the Pacific Northwest, along with Puget Sound reference sediments, will be used with concentrations ranging from 5 to over 500 ug/Kg, Aroclors.

Results of the three analyses will be compared for significant relationships. PCB homolog totals (EPA 680) will be compared to homolog group totals by the high resolution congener method (EPA 1668C). The expected outcome is a determination of whether homolog totals and homolog group totals from congeners have a strong predictive relationship. If results warrant, Ecology may recommend pursuing an alternative to Aroclors PCB analytical method for screening-level decisions.

Background

PCBs (polychlorinated biphenyls) are stable toxic contaminants which bio-accumulate and bi-magnify in the food chain. Because of their persistence, toxicity, and environmental ubiquity, PCBs are a major concern to resource managers. Included in a class of organic compounds called chlorinated hydrocarbons, PCBs are considered persistent organic pollutants (POPs). One of the most often detected groups of toxic chemicals, PCBs have been banned from manufacture in the United States since the 1970s. Research has indicated PCBs are a likely carcinogen.

PCBs in sediment have traditionally been analyzed by Aroclor methods for comparison to regulatory criteria. Detection limits above risk-based sediment concentrations and sediment background concentrations, changes in the Aroclor analytical signal from degradation and weathering along with the subjective approach to reading Aroclor patterns are just some of the method limitations. Concerns for toxicity of specific congeners have lead to the development of newer high resolution methods to provide detail on concentrations of each congener. But congener analysis comes at a high price. A less rigorous intermediary analytical method is needed to replace Aroclor analysis.

Currently there are three EPA-approved methods available for analysis of PCBs in sediment. They include a (1) high resolution method, (2) PCB homolog method, and (3) low resolution method:

(1) EPA 1668C - HRGC/HRMS (high resolution gas chromatograph/high resolution mass spectrometer) is the high resolution PCB method, determining concentration of all 209 individual congeners;

(2) EPA 680 GC/MS (gas chromatograph/ mass spectrometer) is an intermediary between the high and low resolution methods, reporting total concentration for homolog groups;

(3) SW-846 EPA 8082, GC/ECD (gas chromatograph/electron capture detector) is the low resolution method, reporting concentrations for each Aroclor.

Some modified versions of the GC/MS methods may be offered, but are laboratory-specific. Table 1 compares PCB methods, type of analysis, detection limits, cost, and number of analytes.

Table 1. Comparison of analytical methods for PCBs in sediment.

Method	Detector	Detection Limits	Cost	Analytes	Comments
EPA 1668C	High Resolution GC/MS	0.002 – 0.050 ug/Kg	$750 - 1150	All 209 Congeners, All Co-planars	Highest resolution available, some co-elution
EPA 680	GC/MS	0.2 ug/Kg	$400 - 600	Homolog Group Totals	No Congeners or Co-planars identified
SW-846 EPA 8082	GC/ECD – Dual column confirmation	2 - 5 ug/Kg	$225 - 350	Aroclors – 9 common	Not all congeners, but all Co-planars included

PCB Structure and Analyses

PCBs are a group of man-made organic compounds with no known natural source. A total of 209 individual PCB compounds called congeners exist as solids or in carrier oil-based liquid, without taste or smell. PCBs were originally manufactured and sold as a good electric insulator and heat-transfer fluid as well as having stability and resistance to degradation under high temperature. PCBs have also been used in lubricants, sealants, paints, rubber, ink, and insecticides. Each individual congener is assigned a name based on the number and location of chlorine atom attachment to two linked benzene rings (biphenyl). Congeners are divided into different groups referred to as homologs or isomers, based on the total number of chlorine atoms (1 to 10) attached to the biphenyl ring (Figure 1, fully chlorinated).
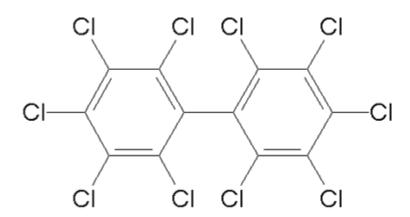

Figure 1. PCB molecular structure.

PCB Congeners

PCB congener analysis by method EPA 1668C – HRGC/HRMS is the state-of-the-art high resolution method. Congener analysis would be the obvious choice over Aroclors if not for samples costing at least twice as much as other methods. Detection limits are orders of magnitude lower than homolog or Aroclor analyses. EPA 1668C resolves all 209 individual congeners that have a wide range of toxicity. Congener analysis allows an accurate prediction of sample toxicity by resolving that small proportion of the most toxic PCB congeners. Analysis of PCB congeners is relatively new and allows a perspective into the risks associated with exposure. The World Health Organization (WHO) has developed toxic equivalent factors (TEFs) for the 12 most toxic PCB congeners (also known as "dioxin-like" or co-planar congeners) that can be compared to the toxicity of dioxin (2,3,7,8-TCDD). Method detection limits are in the sub-parts per trillion (ng/Kg, dw) range for sediments.

PCB Homologs

PCB homolog analysis by method EPA 680 GC/MS is less rigorous than congener analysis. Homolog analysis may hold promise for lower cost than high resolution analysis and be applicable to sediment screening levels. Detection limits are lower than Aroclors and quality control is performed at a higher level. Homologs are groups of PCB congeners with equal number of chlorine atom attachment to the biphenyl molecule. PCB congeners with the same number of chlorine atoms are in the same homolog group. For example tetrachlorobiphenyls are PCB congeners all having four chlorine substitutes in any arrangement (Figure 1). There are 10 different PCB homolog groups possible from mono- through deca- chlorobiphenyls. This method reports a PCB total for each homolog group, without resolving individual congeners. Method detection limits are in the low parts per billion (ug/Kg, dw) range for sediment.

PCB Aroclors

PCB totals by Aroclor analysis are determined by method EPA 8082 GC/ECD. Aroclor is a trade name for the commercial mixtures of PCBs made by the Monsanto Company. Each Aroclor is a mixture of PCB congeners, from a total possible of 62, based on specific application needs. Information is not available for individual or the 12 "dioxin-like" congeners. Traditionally Aroclors have been the regulatory choice for PCB analysis because of the reasonable detection limits offered cost effectively, but they are not able to reach human health assessment levels that drive the cleanup standards.

PCB Aroclor concentrations are determined by matching gas chromatograph patterns (fingerprints) to a similar pattern indicative of known Aroclors. There are nine commonly known Aroclor mixtures. Weathering and biotic degradation can be problematic by changing the Aroclor signal from its original shape. If too much sample degradation has occurred, Aroclor analysis can give erroneous results. Homolog or congener analysis is likely a better choice for samples with high degradation potential. Method detection limits for Aroclor analyses are in the low parts per billion (ug/Kg, dw) range for sediments. Below is a list of the common Aroclors.

- PCB-1016
- PCB-1221
- PCB-1232
- PCB-1242
- PCB-1248
- PCB-1254
- PCB-1260
- PCB-1262
- PCB-1268

Project Description

Description

The Environmental Assessment Program (EAP) of the Washington State Department of Ecology (Ecology) will carry out the study. No sampling will be conducted. Sediment for analysis will be provided by the Toxics Cleanup Program and the Shorelands and Environmental Assistance Program. Archived marine and freshwater sediment samples from Washington and Oregon will be selected from projects with generally known PCB concentrations ranging from 5 to over 500 ug/Kg, Aroclors. Also included in samples is a standard reference material (SRM) from Puget Sound sediment developed by EPA.

Samples will be analyzed by a laboratory contracted by Manchester Environmental Laboratory (MEL). The contract lab must have the ability to conduct all three of the requested PCB analyses. A minimum of ten samples will be analyzed. The final number will depend on the cost of the laboratory contract and data review.

Sediment samples will be analyzed by the contract laboratory for PCBs using high resolution (congeners), homolog, and Aroclor methods. Samples will be homogenized and split for analysis at the laboratory. No ancillary analysis will be requested. For split sample comparison normalization should not be needed assuming proper homogenization.

Data from this study will provide information on whether relationships exist between high resolution PCB congener analysis and PCB homolog analysis, such that either alone or with modifications to analytical procedures PCB homolog analysis could replace Aroclor analysis traditionally used for sediment cleanup comparisons.

Goal and Objectives

The goal of the study is to determine if PCB homolog analysis can provide needed information at a lower cost than high resolution congener analysis and provide lower detection limits than Aroclors. The objectives are to:

- Analyze a minimum of 10 sediment samples as three-way splits to be analyzed for PCB congeners, homologs, and Aroclors.

- Compare PCB homolog totals to congener totals in homolog groups for correlations, and determine if strong relationships exist.

- Assess if PCB homolog analysis provides better information as a screening level method to replace Aroclor analysis in sediments.

Organization and Schedule

Table 2 lists the people involved in this project. All are employees of Ecology. Table 3 presents the proposed schedule for this project.

Table 2. Organization of project staff and responsibilities.

Staff (all are EAP except client)	Title	Responsibilities
Laura Inouye Shorelands and Environmental Assistance Program Phone: 360-407-6165	EAP Client	Clarifies scope of the project. Provides internal review of the QAPP and approves the final QAPP. Reviews and approves the final report.
Chance Asher Toxics Cleanup Program Phone: 360-407-6914	EAP Client	Clarifies scope of the project. Provides internal review of the QAPP and approves the final QAPP. Reviews and approves the final report.
Randy Coots Toxics Studies Unit SCS Phone: 360-407-6690	Project Manager/ Principal Investigator	Writes the QAPP. Oversees transportation of samples to the laboratory. Conducts QA review of data, and analyzes and interprets data. Writes the draft report and final report.
Dale Norton Toxics Studies Unit SCS Phone: 360-407-6765	Unit Supervisor for the Project Manager	Provides internal review of the QAPP, approves the budget, and approves the final QAPP.
Will Kendra SCS Phone: 360-407-6698	Section Manager for the Project Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP.
Joel Bird Manchester Environmental Laboratory Phone: 360-871-8801	Director	Approves the final QAPP.
William R. Kammin Phone: 360-407-6964	Ecology Quality Assurance Officer	Reviews and approves the draft QAPP and final QAPP.

EAP: Environmental Assessment Program
SCS: Statewide Coordination Section
QAPP: Quality Assurance Project Plan

Table 3. Proposed schedule for completing laboratory work and reports.

Laboratory work	Due date
Laboratory analyses completed	January 2013
Final report	
Author lead	Randy Coots
Schedule	
Draft due to supervisor	March 2013
Draft due to client/peer reviewer	April 2013
Final (all reviews done) due to publications coordinator	May 2013
Final report due on web	June 2013

Quality Objectives

Quality objectives for this study are to:
- Analyze marine and freshwater samples representative of typical field conditions found during sediment investigations for cleanup programs
- Obtain analytical results that minimize uncertainty and are comparable between methods.

Objectives will be achieved through careful planning and execution of analysis, and through quality control (QC) procedures presented in this plan. The plan was developed with direction found in *Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies* (Lombard and Kirchmer, 2004).

The laboratory contracted by MEL is expected to meet QC requirements selected for the project. QC procedures used during laboratory analyses will provide data for determining the accuracy of the monitoring results.

Table 4 shows measurement quality objectives (MQOs) for the methods selected for sample analysis. Analytical precision and bias will be evaluated and controlled by use of laboratory check standards, duplicates, and labeled compounds analyzed along with study samples (MEL, 2008).

Precision is a measure of the ability to consistently reproduce results. Precision will be evaluated by analysis of check standards, duplicates, and labeled compounds. Results of laboratory duplicate (split) analyses will be used to estimate laboratory precision.

Bias is the systematic error due to contamination, sample preparation, calibration, or the analytical process. Most sources of bias are minimized by adherence to established protocols for the collection, preservation, transportation, storage, and analysis of samples. Check standards (also known as laboratory control standards) contain a known amount of an analyte and indicate bias due to sample preparation or calibration.

Labeled PCB congeners will be added to congener and homolog samples prior to extraction. They have similar characteristics but do not interfere with resolution of target compounds. The percent recovery of labeled compounds is used to estimate the recovery of target compounds in samples.

The lowest concentrations of interest in Table 4 are levels below the lowest expected results from the archived sediment samples with known levels of PCBs. MEL and their contractors have reported similar results for sediment analysis from other studies.

Data outside MQOs will be evaluated for appropriate corrective action by the contract laboratory and MEL. The project manager will be contacted by laboratory quality assurance personnel to discuss how to handle the data. The final decision to accept, to accept with qualification, or to re-analyze the samples in question will be the responsibility of the project manager.

Table 4. Measurement quality objectives.

Analyte	Lab Control Samples (% Recovery)	Duplicate Samples (RPD)	Recoveries (% Recovery)	Lowest Concentration of Interest
PCB Congeners	25 – 150%	≤50%	25 – 150%[1]	2 ug/Kg, dry
PCB Homologs	25 – 150%	≤50%	25 – 150%[1]	2 ug/Kg, dry
PCB Aroclors	25 – 150%	≤50%	25 – 150%[2]	2 ug/Kg, dry

1 = Labeled compounds
2 = Surrogates

Comparability

Comparability of study results will be ensured by using standard operating procedures and adhering to established data quality criteria consistent with standard practices for analyzing PCBs in sediment. Detection limits will be equal to or better than analyses of sediment from other studies using the methods described here. Care will be given to ensure proper homogenization of study samples prior to splitting for specific analyses.

Representativeness

The study design was developed to obtain representative data on three different PCB methods. Samples are to be split three ways and selected to represent a range of PCB levels in sediment. Representativeness will be ensured by using appropriate sample handling and splitting procedures, and homogenization techniques.

Completeness

Completeness can be defined as the need to generate enough valid data to allow decisions to be made for which the study was designed. The goal of completeness is to analyze 100% of the archive samples described in the sampling plan.

Measurement Procedures

Analytical parameters, sample numbers, methods, and reporting limits for the study are presented below in Table 5. Method selection was based on study objectives to determine if results from PCB homolog analysis are able to provide the information needs of sediment cleanup managers. High resolution PCB congener analysis, PCB homolog analysis, and PCB Aroclors will be analyzed from each sediment sample.

Project samples will be analyzed by a laboratory selected and contracted by MEL capable of each of the three PCB methods. Laboratories contracted by MEL must be on the Ecology list of accredited laboratories (http://www.ecy.wa.gov/programs/eap/labs/lab-accreditation.html). Contract laboratories must use the three methods specified.

Table 5. Laboratory parameters, number of samples, expected range of results, reporting limits, and analytical methods.

Parameter	Sample Number	Expected Range of Results	Reporting Limits	Sample Cleanup Method	Analytical Method
PCB Congeners	10[1]	5 - 500 ug/Kg	0.20 – 0.50 ug/Kg[2], dry	EPA 1668C	EPA 1668C HRGC/HRMS[3]
PCB Homologs	10	5 - 500 ug/Kg	2 ug/Kg, dry	EPA 680	EPA680 GC/MS[4]
PCB Aroclors	10	5 - 500 ug/Kg	10 ug/Kg, dry	EPA 3541	SW-846 EPA 8082 GC/ECD[5]

1 = 10 is the minimum number of samples for analysis.
2 = Congener specific.
3 = Environmental Protection Agency (1999).
4 = Environmental Protection Agency (1995).
5 = Environmental Protection Agency (2008).

Sediment samples analyzed for the study will be archived samples from other studies with a generally known PCB concentration.

Budget

The laboratory costs estimated for this project total $18,911. Table 6 presents these estimates.

Table 6. Project analytical cost estimate.

PCB Method	Number of Samples	Number of QA Samples	Cost per Sample	MEL Contracting[1]	Total Cost ($)
EPA 1668C - HRGC/HRMS	10	1	750	188	$10,320
EPA 680 GC/MS	10	1	400	100	$5,500
SW-846 EPA 8082, GC/ECD	10	1	225	56	$3,091
Total laboratory cost					$18,911

1 = MEL contracting services are charged at 25%.

Quality Control Procedures

Laboratory

PCB analyses will be conducted by a contract laboratory selected by MEL. For analytical consistency the laboratory selected to run the samples will have the ability to conduct all three PCB methods. The contract laboratory will make available all routinely run control samples for sample batches. Laboratory control samples for this project are presented below in Table 7.

Table 7. Laboratory quality control samples.

Analysis	PCB Method	Method Blank	Check Standard	Labeled Compounds
PCB Congeners	EPA 1668C	1/batch	1/batch	All samples
PCB Homologs	EPA 680	1/batch	1/batch	All samples
PCB Aroclors	SW-846 EPA 8082	1/batch	1/batch	-

Data Management Procedures

Case narratives, included in the data package from MEL, will discuss any problems encountered with the analyses, corrective action taken, changes to the requested analytical method, and a glossary for data qualifiers. Laboratory QC results will also be included in the data package. This will include results for check standards, labeled compounds, laboratory duplicates and blanks. The information will be used to evaluate data quality, determine if the MQOs were met, and act as acceptance criteria for project data.

Laboratory results for project samples will not be entered into Ecology's Environmental Information Management (EIM) system. Results from the parent samples have already been reported elsewhere or are already in EIM.

In PCB congener analysis not all of the 209 congeners in a sample are above reporting limits. A number of possible options exist for censored data from not using non-detected data to using ¼, ½, or the full detection limit for the purpose of calculating totals. For this study if a congener is not detected in a sample it will not be included in the totals. Qualified PCB congener values that are laboratory estimates ("J" or "NJ" flags) will be used at full value in PCB totals.

Statistical Analysis

Laboratory data will be analyzed using statistical techniques for paired data sets. PCB homolog group totals from both congener and homolog analyses will be compared.

The strength of relationship between PCB homolog group totals from congener and homolog methods will be quantified by linear regression. To test for differences in the total data sets if data are normally distributed or can be transformed to a near normal distribution a Student's paired t-test will be applied. If a normal distribution cannot be achieved a nonparametric Wilcoxon signed-rank test for related samples may be applied to look for significant differences between methods. The null hypothesis is that there are no significant differences between the PCB homolog totals from the two methods. A significance level of 5% will be used to test for differences ($p<0.05$). Coefficients measuring the degree of correlation between data sets will be reported ($p=0.05$ and r^2 values).

Final Report

A draft and final report of the study findings will be completed by the principal investigator. The report will include, at a minimum, the following:

- The study background and description of the reason the study was conducted.
- Description of laboratory methods.
- Discussion of data quality and the significance of any problems encountered.
- Summary tables of the chemical data.
- Complete set of chemical data and MEL quality assurance review in the Appendix.
- Discussion of the statistical methods used and outcome of analysis.
- Conclusions drawn based on the study results.
- Recommendations for PCB method use based on study outcomes.

Public access to the final report for the study will be available through Ecology's Internet homepage (www.ecy.wa.gov).

Data Verification

Data verification is a process conducted by people producing data. Verification of laboratory data is normally performed by a MEL unit supervisor or an analyst experienced with the method. It involves a detailed examination of the data package, using professional judgment to determine whether the measurement quality objectives (MQOs) have been met.

Final acceptance of the project data is the responsibility of the principal investigator. The complete data package, along with MEL's written report, will be assessed for completeness and reasonableness. Based on these assessments, the data will either be accepted, accepted with qualifications, or rejected and re-analysis considered.

Data verification involves examining the data for errors, omissions, and compliance with QC acceptance criteria. MEL's SOPs for data reduction, review, and reporting will meet the needs of the project. Data packages will be assessed by MEL's QA Coordinator using Laboratory Program (CLP) Functional Guidelines for Organic Data Review (MEL, 2008).

MEL staff will provide a written report of their data review which will include a discussion of whether (1) MQOs were met; (2) proper analytical methods and protocols, including storage conditions and holding times, were followed; (3) calibrations and controls were within limits; and (4) data were consistent, correct, and complete, without errors or omissions.

Data Quality (Usability) Assessment

After the project data have been reviewed and verified, the principal investigator will determine if the data are of sufficient quality to make determinations and decisions for which the study was conducted. The data from the laboratory's QC procedures, as well as results from laboratory duplicates, will provide information to determine if MQOs (Table 4) have been met. Laboratory and quality assurance staff familiar with assessment of data quality may be consulted. The project final report will discuss data quality and whether the project objectives were met. If limitations in the data are identified, they will be noted.

Some analytes may be reported near the detection capability of the selected methods. MQOs are difficult to achieve for these results. MEL's SOP for data qualification and best professional judgment will be used in the final determination of whether to accept, reject, or accept the results with qualification. The assessment will be based on a review of laboratory QC results. This will include assessment of laboratory precision, accuracy, matrix interferences, and the success of laboratory QC samples meeting control limits.

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Appendix. Glossary, Acronyms, and Abbreviations

Glossary

Aroclor: Aroclor is a trade name for the commercial mixtures of polychlorinated biphenyls (PCBs) made by the Monsanto Company. Analysis for Aroclors is by EPA method 8082 GC/ECD. There are nine commonly known Aroclor mixtures. Each Aroclor is a mixture of a number of PCB compounds called congeners based on specific application needs. PCB Aroclor concentrations are determined by matching gas chromatograph patterns (fingerprints) to a similar pattern indicative of known Aroclors. Method detection limits for Aroclors are in the low parts per billion (ug/Kg, dw) range in sediments.

Congener: PCBs are a group of 209 individual compounds known as congeners. Individual congeners have a wide range of toxicity. When PCBs are analyzed as congeners that small proportion of the most toxic PCB congeners are resolved. Analysis of PCB congeners is relatively new. The World Health Organization (WHO) has developed toxic equivalent factors (TEFs) for the 12 most toxic PCB congeners (also known as "dioxin-like" or co-planar congeners) that can be compared to the toxicity of dioxin (2,3,7,8-TCDD). Method detection limits are in the sub-parts per trillion (ng/Kg, dw) range for sediments.

Homolog: Homologs are groups of PCB congeners with equal number of chlorine atom attachment to the biphenyl molecule. For example, tetrachlorobiphenyls are PCB congeners all having four chlorine substitutes in any arrangement. There are 10 different PCB homolog groups possible from mono- through deca- chlorobiphenyls. Homolog method detection limits are in the low parts per billion (ug/Kg, dw) range for sediment.

Parameter: A physical chemical or biological property whose values determine environmental characteristics or behavior.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report.

e.g.	For example
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
i.e.	In other words
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
NTR	National Toxics Rule
PCB	Polychlorinated biphenyl
QA	Quality assurance
RPD	Relative percent difference
SOP	Standard operating procedures
WAC	Washington Administrative Code

Units of Measurement

dw	dry weight
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
mg	milligram, a unit of mass equal to 1/1000 of a gram
mg/Kg	milligrams per kilogram (parts per million)
ng/Kg	nanograms per kilogram (parts per trillion)
ug/Kg	micrograms per kilogram (parts per billion)