Evaluation and Interpretation of the Sediment Chemistry and Sediment Toxicity Data for the Upper Columbia River

Final Report

Prepared for:

Washington Department of Ecology
Toxics Cleanup Program
4601 North Monroe Street
Spokane, WA 99205

Prepared – ***May, 2011; Revised May, 2012*** – **by:**

MacDonald Environmental Sciences Ltd.
#24 - 4800 Island Highway North
Nanaimo, British Columbia V9T 1W6

In Association with:

Science Applications International Corporation
18912 North Creek Parkway, Suite 101
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D.D. MacDonald, J.A. Sinclair, M.A. Crawford, H.J. Prencipe, and M.R. Coady
MacDonald Environmental Sciences Ltd.
#24 - 4800 Island Highway North
Nanaimo, British Columbia V9T 1W6

In Association with:

Science Applications International Corporation
18912 North Creek Parkway, Suite 101, Bothell, WA 9801

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List of Acronyms

Al	aluminum
AOI	area of interest
ARAR	applicable or relevant and appropriate requirement
ASTM	American Society for Testing and Materials
AVS	acid volatile sulfide
BERA	baseline ecological risk assessment
C. dilutus	*Chironomus dilutus*
C. dubia	*Ceriodaphnia dubia*
CCC	criterion continuous concentration
Cd	cadmium
CEE	CH2M Hill and Ecology and Environment, Inc.
cm	centimeter
COPC	chemical of potential concern
Cr	chromium
CRM	concentration-response model
CTCR	Confederated Tribes of the Colville Reservation
Cu	copper
-d	-day
DDT	dichlorodiphenyl-trichloroethane
DW	dry weight
ERA	ecological risk assessment
ERM	effects range median
$ESB\text{-}TU_{FCV}$	equilibrium partitioning-based sediment benchmarks toxic unit (final chronic value) for PAHs
Fe	iron
FS	feasability study
f_{OC}	fraction total organic carbon
GIS	geographic information system
H. azteca	*Hyalella azteca*
HHRA	human health risk assessment
HI	high impact
IOT	Incidence of toxicity
km	kilometer
LI	low impact
LRF	Lake Roosevelt Forum
LRM	logistic regression model
LRNRA	Lake Roosevelt National Recreation Area
MESL	MacDonald Environmental Sciences Ltd.
mg	milligram
MI	moderate impact
mm	millimeter
MOT	magnitude of toxicity

MSD	minimum significant difference
n	number of samples
NHC	Northwest Hydraulic Consultants
Ni	nickel
NPS	National Park Service
NRDA	natural resource damage assessment
NRT	Natural Resource Trustee
OC	organic carbon
p	level of significance
PAH	polycyclic aromatic hydrocarbon
Pb	lead
PCDD	polychlorinated dibenzo-*p*-dioxin
PCDF	polychlorinated dibenzofuran
PCB	polychlorinated biphenyl
PEC	probable effect concentration
PEC-Q	probable effect concentration-quotient
PEL	probable effect level
QA	quality assurance
QC	quality control
r^2	coefficient of determination
r_S	Spearman rank correlation coefficient
RI	remedial investigation
RI/FS	remedial investigation/feasability study
RM	river mile
SRCA	Spearman's rank correlation analysis
SD	standard deviation
SEM	simultaneously extracted metal
SEM-AVS	simultaneously extracted metal minus acid volatile sulfide
SLERA	screening-level ecological risk assessment
SQG	sediment quality guideline
SQS	sediment quality standard
SVOC	semi-volatile organic compounds
TAL	target analyte list
TCL	target compound list
TCAI	Teck Cominco American Incorporated
Teck	Teck Cominco American Incorporated
TEC	threshold effect concentration
TOC	total organic carbon
TPST	threshold for predicting sediment toxicity
$TPST_{HI}$	threshold for predicting sediment toxicity high impact
$TPST_{LI}$	threshold for predicting sediment toxicity low impact
TU	toxic unit
UCR	Upper Columbia River
UCR NRTC	Upper Columbia River Natural Resource Trustee Council

USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
Zn	zinc

Glossary of Terms

A priori – Designated in advance.

Acid Volatile Sulphide (AVS)– An analyte used to predict the toxicity of divalent metals (including copper, cadmium, nickel, lead and zinc) in sediments.

Adverse effects – Any abnormal, harmful, or undesirable effects on an organism that causes anatomical or functional damage, irreversible physical changes, or increases the susceptibility to other biological, chemical, or environmental stresses.

Amphipod – A crustacean of the order Amphipoda. Amphipod and *Hyalella azteca* are used interchangeably throughout the report.

Anthropogenic – Effects, processes, objects, or materials derived from human activities, as opposed to those occurring in natural environments without human influences.

Aquatic ecosystem – All the living and nonliving material interacting within an aquatic system.

Aquatic invertebrates – Animals without backbones that utilize habitats in freshwater, estuarine, or marine systems.

Aquatic organisms – The species that utilize habitats within aquatic ecosystems (e.g., microorganisms, aquatic plants, invertebrates, fish, amphibians, and reptiles).

Area of Interest – A portion of the study area that is targeted for investigation.

Areal extent – The magnitude of an area meeting a set of conditions.

Benthic invertebrate community – The assemblage of aquatic invertebrates that utilize the bottom substrate (e.g., sediment) within an aquatic ecosystem.

Benthic – The lowest level of a body of water, such as an ocean or a lake, inhabited by organisms that live in close relationship with (if not physically attached to) the bed sediments, called benthos or benthic organisms.

Bioaccumulation – The net accumulation of a substance by an organism as a result of uptake from all environmental sources.

Biomass – The total mass of living biological material in a given area or of a biological community or group.

Cladoceran – A branchiopod crustacean of the order Cladocera, which includes the water fleas. The term Cladoceran and *Ceriodaphnia dubia* are used interchangeably throughout the report.

Chemicals of potential concern – The toxic or bioaccumulative substances that occur in environmental media at levels that could adversely affect ecological receptors.

Concentration-response models – Models a relationship which describes the change in effect on a receptor caused by differing levels of exposure to a stressor (usually a chemical) after a certain exposure time.

Contaminated sediment – Sediment that contains chemical substances at concentrations that could harm microbial, benthic invertebrate, plant, fish, avian or mammalian communities.

Detection limit – The lowest concentration of a substance that can be differentiated from zero with a 99% certainty.

Ecosystem – All the living (e.g., plants, animals, and humans) and nonliving (rocks, sediments, soil, water, and air) material interacting within a specified location in time and space.

Embayment – an indentation of a shoreline larger than a cove but smaller than a gulf.

Endpoint – A measured response of a receptor to a stressor. An endpoint can be measured in a toxicity test or a field survey.

Exposure – Co-occurrence of or contact between a stressor (e.g., chemical substance) and an ecological component a receptor (e.g., aquatic organism).

Geographic Information Systems – GIS is a system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data.

Highly impacted – Sediment samples with >10% reduction in survival, growth, biomass, or reproduction relative to the lower limit of the reference envelope.

Heterotrophic (other nourishing) – Organisms that utilize, transform, and decompose the materials that are synthesized by autotrophic organisms (i.e., by consuming or decomposing autotrophic and other heterotrophic organisms).

Impaired benthic invertebrate community – An assemblage of benthic invertebrates that has characteristics (i.e., mIBI score, abundance of selected taxa, etc.) that are generally inconsistent with those that have been observed at uncontaminated reference sites.

Injury – A measurable adverse change, either long or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a discharge of oil or release of a hazardous substance, or exposure to a product of reactions resulting from the discharge to oil or release of a hazardous substance.

Lacustrine – Of or relating to lakes. Lacustrine habitats are typically characterized by the absence of trees, shrubs, or emergent vegetation.

Longitudinal variation – Variation in an area running lengthwise.

Mean PEC-Q – Mean Probable Effects Concentration Quotient. The Mean PEC-Q is calculated with the Mean PEC-Q for metals, total PAHs and total PCBs (USEPA 2000). See Appendix 4.4 for additional information.

Metric – A variable that is measured to provide information on the status of an indicator of environmental quality conditions (e.g., the concentration of cadmium in sediment).

Midge – An insect of the order diptera, frequently used for assessing the toxicity of freshwater sediments. Midge and *Chironomus dilutus* are used interchangeably throughout the report.

Moderately impacted – Sediment samples with survival, growth, biomass, or reproduction <10% below the lower limit of the reference envelope.

Negative control sample – A sample this is essentially free of contaminants and is used routinely to assess the acceptability of a toxicity test.

Not toxic – Sediment samples with survival, growth, biomass, or reproduction is greater than or equal to the minimum value of the reference envelope.

Organic carbon – The pool of carbon bound in organic compounds that is present in aqueous solution, soils, and/or sediment.

Organic compounds – Any member of a large class of gaseous, liquid, or solid chemical compounds whose molecules contain carbon.

PEC-Q$_{METALS}$ – Probable Effects Concentration Quotient for Metals, consisting of either the sum or average of the PEC-Qs for arsenic, cadmium, chromium, copper, nickel, lead and zinc. See Appendix 4.4 for additional information.

PEC-Q$_{EXT\ METALS}$ – Probable Effects Concentration Quotient Extended Metals, consisting of either the sum or average of the PEC-Qs for antimony, arsenic, cadmium, chromium, copper, iron, nickel, lead, manganese and zinc. See Appendix 4.4 for additional information.

Pore water – The water that occupies the spaces between sediment particles.

Positive control sample – A sample with a known concentration of contaminant that is used routinely to assess the acceptability of a toxicity test.

Predictive ability – A measure of the ability of a threshold for predicting sediment toxicity to correctly classify a sediment sample as toxic or not toxic, based on data independent of those used to derive the threshold. High predictive ability is indicated by an incidence of toxicity of <20% below the threshold, an incidence of toxicity of >50% above the threshold, and an overall correct classification rate of >80%.

Probable effect level (PEL; Concentration) – Concentration of a chemical in sediment above which adverse biological effects are likely to occur.

Quality Assurance Project Plan – The document that outlines, defines and provides guidance for the operation of a laboratory. This document generally contains, but is not limited to, information pertaining to: laboratory personnel, sampling procedures and sample rejection criteria, sample handling and chain of custody routines, the equipment employed by the laboratory, analytical methods, data reduction, validation and reporting, calibration and quality control procedures, equipment maintenance, routine procedure for precision and accuracy, method validation, verification and corrective actions, health and safety policy and training.

Reach –A river or stream segment of a specific length.

Receptor – A plant or animal that may be exposed to a stressor.

Reference sample – A reference sediment sample is collected near an area of concern and is used to assess sediment conditions exclusive of materials of interest (ASTM 2011b).

Reference envelope - A statistical representation of data from reference locations that is used to evaluate toxicity data for test sites.

Reliability – A measure of the ability of a threshold for predicting sediment toxicity to correctly classify a sediment sample as toxic or not toxic, based on the data that were used to derive the threshold. A threshold is considered reliable if the incidence of toxicity is <20% below the threshold, the incidence of toxicity is >50% above the threshold, and the overall correct classification rate is >80%.

Remedial action objectives – Descriptions of the narrative intent of any remedial actions that are undertaken to mitigate risks to the ecological receptors that are exposed to contaminants of concern.

Remedial investigation – A soil, ground water, surface water and/or air investigation to determine the nature and extent of contamination at a site, to assess risks to human health, and to evaluate risks to ecological receptors.

Risk – The probability or likelihood an adverse effect will occur.

Riverine – Of or relating to a river.

Sediment – Particulate material that usually lies below the ponds, lakes, stream, and rivers.

Sediment-associated contaminants – Contaminants that are present in sediments, including whole sediments and/or pore water.

Sediment chemistry data – Information on the concentrations of chemical substances in whole sediments and/or pore water.

Sediment-dwelling organisms – The organisms that live in, on, or near bottom sediments, including both epibenthic and infaunal species.

Sediment quality guidelines – Chemical benchmark that is intended to define the concentration of sediment-associated contaminants that is associated with a high or a low probability of observing harmful biological effects or unacceptable levels of bioaccumulation, depending on its purpose and narrative intent.

Simultaneously extracted metals (SEM) – Divalent metals - commonly cadmium, copper, lead, mercury, nickel, and zinc - that are solubilized during acidification (0.5m HCl for 1 hour). Information on SEM concentrations is used with data on acid volatile sulfides in sediments to evaluate the potential for toxicity to benthic invertebrates. See Appendix 4.4 for additional information.

Slag – A waste matter separated from metals during the smelting or refining of ore.

Slag-dominated sediment samples – Sediment samples where indicator metal to reference metal ratios were equal to or greater than the expected ratio for sediments containing an initial approximation of at least 5% slag (also referred to as slag-affected sediment samples).

Slag-influenced sediment samples – Sediment samples where the indicator metal to reference metal ratios were higher than the ratios observed in reference sediments, but less than the expected ratio in sediments containing an initial approximation of at least 5%

slag. Such sediments may, or may not, be impacted by smelter effluent or other hazardous substances (also referred to as potentially slag-affected sediment samples).

Study area – For the purpose of this report, the study area is defined as the areal extent of contamination by hazardous substances within the United States in or adjacent to the Upper Columbia River, including the Franklin D. Roosevelt Lake, from the border between the U.S. and Canada downstream to the Grand Coulee Dam, and those areas in proximity to the contamination which are suitable and necessary for implementation of the response actions described in the settlement agreement.

Sum ESB-TU$_{PAHs}$ – Methods for calculating the Sum Equilibrium Partitioning-Based Sediment Benchmark-Toxic Units for Polycyclic Aromatic Hydrocarbons can be found in USEPA (2005). The following 13 PAHs were used for generating Sum ESB-TU$_{\text{PAHs}}$: acenaphthene, acenaphthylene, anthracene, benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene. See Appendix 4.4 for additional information.

Sum SEM-AVS – Methods for calculating Sum Simultaneously Extracted Metals Minus Acid Volatile Sulfide are described in USEPA (2003b). The metric is calculated by summing the concentrations (in µmol/g) of simultaneously extracted divalent metals (i.e., SEM). The calculation for Sum Simultaneously Extracted Metals Divided by Acid Volatile Sulfide (*Sum SEM /AVS*) relies upon the same set of divalent metals, but instead of subtracting the molar AVS concentration from the SEM, AVS is used as the denominator. See Appendix 4.4 for additional information.

Supernatant – Denoting the liquid lying above a solid residue after crystallization, precipitation, centrifugation, or other process

Threshold effect concentration – Concentration of a chemical in sediment below which adverse biological effects are unlikely to occur.

Threshold for Predicting Sediment Toxicity – Chemical benchmarks for sediment quality that define the concentrations of chemicals of potential concern that are associated with low or high probabilities of observing harmful biological effects.

Threshold for Predicting Sediment Toxicity (High Impact) – Chemical benchmarks for sediment quality that define the concentrations of chemicals of potential concern that are associated with high probabilities of observing harmful biological effects (i.e., survival, growth, biomass, or reproduction >10% below the lower limit of the reference envelope)

Threshold for Predicting Sediment Toxicity (Low Impact) – Chemical benchmarks for sediment quality that define the concentrations of chemicals of potential concern that are associated with low probabilities of observing harmful biological effects (i.e., survival, growth, biomass, or reproduction <10% below the lower limit of the reference envelope).

Total organic carbon – A measure of the amount of carbon bound in organic compounds.

Toxic – Sediment samples with survival, growth, biomass, or reproduction lower than the minimum value of the reference envelope (includes both the moderately impacted and highly impacted categories).

Toxicity threshold – Chemical benchmark for water or sediment quality that defines the concentration of a chemical of potential concern that is associated with a high or low probability of observing harmful biological effects, depending on the narrative intent.

Transverse variation – Variation in an area running horizontal (across).

Trustee – Any Federal natural resources management agency designated in the National Contingency Plan and any State agency designated by the Governor of each State, pursuant to Section 107(f)(2)(B) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), that may prosecute claims for damages under Section 107(f) or 111(b) of CERCLA; or an Indiana tribe, that may commence an action under Section 126(d) of CERCLA.

Type I Error – Incorrectly classifying a not toxic sample as toxic. Also referred to as a false positive.

Type II Error – Incorrectly classifying a toxic sample as not toxic. Also referred to as a false negative.

Typical sediment samples – Sediment samples where the indicator metal to reference metal ratios were similar to sediments in reference areas and may, or may not, be impacted by other hazardous substances, such as historic smelter effluent wastes (also referred to as non slag-affected sediment samples).

Van Veen grab sampler – Lightweight sampler designed to take large samples in soft bottoms. It has long lever arms and the sharp cutting edge on the bottom of the scoops enable it to cut deep into soft bottoms and excavate relatively undisturbed sediments.

Vertical variation – Variation in an area running up and down (higher to lower and vice versa).

Whole sediment – Sediment and associated pore water.

Executive Summary

ES1.0 Introduction

This study was conducted to evaluate and interpret sediment chemistry and sediment toxicity data that were collected in the Upper Columbia River (UCR), including data collected by United States Environmental Protection Agency (USEPA) and others in 2005 to support the Remedial Investigation (RI) of the UCR (i.e., CEE 2006a; Schut and Stefanoff 2007; Stefanoff *et al.* 2006), and two comparable data sets (Besser *et al.* 2008; Bortleson *et al.* 1994). This report is intended to inform the design of future sampling programs and assessments of sediment toxicity in the UCR. To support this goal, the following study objectives were identified:

- Acquire and collate sediment chemistry and sediment toxicity data from the study area, including (but not limited to) the data collected in the USEPA Phase 1 Sediment Sampling Program under the RI of the UCR;
- Develop methods for advancing interpretation of the sediment toxicity data that facilitate designation of sediment samples as toxic or not toxic through consideration of reference conditions in the study area (i.e., using a reference envelope approach);
- Develop methods for advancing the interpretation of sediment chemistry and/or pore-water chemistry data from the study area [i.e., by developing and evaluating site-specific thresholds for predicting sediment toxicity (TPSTs) for individual chemicals of potential concern (COPCs), COPC mixtures, and/or slag indicators in sediment and/or pore water]; and,
- Identify gaps in the existing knowledge base and the actions that need to be taken to fill such data gaps.

ES2.0 Study Area

The study area is defined as the areas within or adjacent to the UCR that have been contaminated by releases of hazardous substances from the Teck facility between the Canada-U.S. border to the Grand Coulee Dam. To facilitate this evaluation, the study area was subdivided into six reaches including:

- Reach 1: U.S.-Canadian Border at USGS River Mile (RM) 745 to RM 730;
- Reach 2: USGS RM 730 to RM 712;
- Reach 3: USGS RM 712 to RM 700;

- Reach 4: USGS RM 700 to RM 640;
- Reach 5: USGS RM 640 to RM 617; and,
- Reach 6: USGS RM 617 to Grand Coulee Dam near RM 597.

ES3.0 Study Approach

This investigation was conducted to evaluate and interpret the sediment toxicity and sediment chemistry data that were collected during the Phase 1 Sediment Sampling Program of the UCR and other investigations of sediment quality conditions in the study area. A step-wise process was used to evaluate and compile the chemistry and toxicity data obtained during the sediment sampling programs that have been conducted in the UCR watershed, to develop site-specific TPSTs, and to evaluate the reliability and predictive ability of the TPSTs. This process consisted of ten main steps, including:

- Acquire and evaluate potentially-relevant data sets (see Section 6.1);
- Compile sediment chemistry and sediment toxicity data in a geographic information system (GIS)-compatible relational database (see Section 6.2);
- Evaluate various approaches for designating sediment samples as toxic or not toxic to benthic invertebrates (see Section 6.3);
- Establish and apply criteria for identifying reference sediment samples within the study area (procedures for estimating the slag content of sediment samples from the UCR are discussed in Chapter 5);
- Develop a reference envelope for each toxicity test endpoint (see Section 6.5);
- Normalize toxicity test response data (see Section 6.6);
- Designate each sediment sample as toxic or not toxic for each toxicity test endpoint, for each toxicity test, and for all toxicity tests combined (see Section 6.7);
- Evaluate the nature and extent of sediment toxicity (see Section 6.8);
- Develop and refine preliminary concentration-response models (CRMs) for selected COPCs, COPC mixtures, and slag indicators (see Section 7.1);
- Derive TPSTs for each of the selected COPCs, COPC mixtures, and slag indicators (see Section 7.2);
- Evaluate the reliability and predictive ability of the TPSTs for selected COPCs, COPC mixtures, and slag indicators (see Section 7.3); and,

- Identify TPSTs that can be used to accurately classify sediment samples from the UCR as toxic and not toxic (see Section 8.0).

ES4.0 Database Development

A total of 18 candidate data sets were identified and evaluated for possible inclusion in the project database. Of these, three studies were considered to provide sediment chemistry and sediment toxicity of sufficient quality and/or spatial coverage to support evaluation of relationships between sediment toxicity and sediment chemistry in the UCR (Besser *et al.* 2008; Bortleson *et al.* 1994; CEE 2006a, Schut and Stefanoff 2007, and, Stefanoff *et al.* 2006). The results of these studies provided data on the concentrations of numerous COPCs and conventional variables in sediment samples from the UCR, including metals, uranium, semi-volatile organic compounds (SVOCs), pesticides, polychlorinated biphenyls (PCBs), acid volatile sulfides (AVS), simultaneously extracted metals (SEM), total organic carbon (TOC), and/or particle size. Pore-water samples were analyzed for dissolved target analyte list (TAL) metals and uranium. These studies also reported the results of whole-sediment toxicity tests with up to three indicator species, including amphipods, *Hyalella azteca*, in 28-d exposures (Endpoints: Survival, growth, and biomass), midges, *Chironomus dilutus*, in 10-d exposures (Endpoints: Survival, growth, and biomass), and cladocerans, *Ceriodaphnia dubia*, in 7-d exposures (Endpoints: Survival and reproduction). All of the data deemed to be relevant to the current investigation were compiled in a GIS-compatible relational database.

Although data from all three studies were considered to be useable in this evaluation, there were uncertainties associated with the chemistry and toxicity that could influence their interpretation. More specifically, the pore-water chemistry data in the 2005 USEPA study were generated using sediment samples that did not match the sediment toxicity data (i.e., samples for pore water analysis were generally co-located with, but not generated using splits of, sediment samples for chemical analysis and toxicity testing). The results of studies conducted on the Clark Fork River, MT indicate that within-station variability in the chemical characteristics of sediments can be similar to the variability in sediment chemistry across the entire site (Brumbaugh *et al.* 1994), which greatly increases uncertainty in the exposure estimates for toxicity test organisms. Furthermore, the pore-water samples in the 2005 USEPA study were obtained by centrifugation of field collected sediment samples. Application of such sampling methods tends to result in higher and more variable results for metal analyses (Carignan *et al.* 1985). Importantly, at least some of the toxicity test results for the 2005 USEPA study may have been influenced by the use of marginally suitable overlying water and/or nutritional challenges during toxicity testing. All of these factors contribute to uncertainty in the interpretation of the available data, particularly for developing relationships between chemistry and toxicity.

Sediment chemistry, pore-water chemistry, and sediment toxicity data were compiled for a total of 80 locations in the vicinity of the UCR (Besser *et al.* 2008, n = 8; Bortleson *et al.* 1994, n = 16; CEE 2006a, Schut and Stefanoff 2007, and Stefanoff *et al.* 2006, n = 56). Most of these sampling stations were located within the UCR (n = 71); the remainder of the sampling stations were located in tributaries to the UCR (n = 9). The available data for each of these stations were evaluated to identify the stations that could be used to characterize reference conditions within the study area. The samples that met both the chemical and biological criteria were identified as reference samples (including within-site and external reference samples) and used to develop the reference envelope for each toxicity test endpoint for each species. Because substantial inter-batch and inter-study variability was observed for both the control and reference samples in some of the studies, all of the response data was either reference- or control-normalized prior to conducting subsequent data analyses.

ES5.0 Evaluation of the Slag Content of Sediment Samples

Characterization of slag content of sediments is an important step in the evaluation of sediment chemistry and toxicity within the UCR study area. Slag contains elevated levels of metals, which may be differentially available compared to typical riverine sediments or sediments impacted by effluent wastes within the UCR, and may act as a confounding factor in the evaluation and interpretation of sediment chemistry and toxicity.

Slag content was characterized based on the normalization of the concentrations of indicator metals to the concentrations of a reference metal (i.e., the UCR study area). The characterization of slag content in UCR sediments included selection of reference metals, selection of indicator metals, development of slag identification models, and, model evaluation.

Three models were developed to aid in characterizing the slag content of sediments in the UCR: the Cu:Al model, based on the ratio of copper to aluminum concentrations in surficial sediments of the UCR; the Cu:Al and Zn:Cd model, which incorporated the ratio of zinc to cadmium in surficial sediments; and, the Fe:Al and Zn:Cd model, which was based on the ratio of iron to aluminum and the ratio of zinc to cadmium in surficial sediments. The three slag characterization models were evaluated to determine their applicability for characterizing sediment samples from the UCR.

Of the three models evaluated, only the Cu:Al ratio model met all four of the selection criteria. In addition, classifications of sediment samples relative to slag content using this model generally agreed with visual observations. Therefore, the Cu:Al ratio model is recommended for assisting the classification of sediment samples from the UCR as typical (i.e., non slag-affected), slag-influenced (i.e., potentially slag-affected), or slag-dominated (i.e., slag-affected) sediment samples. Other techniques for evaluating the nature and quantity of slag in UCR sediment samples should also be collected in future studies to help calibrate slag classification models based on geochemical data.

ES6.0 Sediment Toxicity

A reference-envelope approach was used to support identification of sediment samples that are toxic to benthic invertebrates on a site-wide basis. The reference-envelope approach is a procedure for assessing sediment toxicity that was developed to overcome the limitations associated with the use of control sediments for this purpose, including accounting for differences in the non-contaminant characteristics of test sediments and for overcoming the low statistical power associated with comparing many test results to a single control. This procedure involved identification of reference sediment samples, normalizing the toxicity data to reflect reference or control responses, developing a reference envelope for each toxicity test endpoint, and designating each sediment sample as toxic (i.e., effect value is lower than the normal range of responses for reference sediment samples) or not toxic (i.e., effect value is within or higher than the normal range of responses for reference sediment samples) for each toxicity test endpoint, for each toxicity test, and for all toxicity tests combined. The results of 28-d whole-sediment toxicity tests with amphipods (*H. azteca*; Endpoints: Survival, growth, and biomass) indicated that 19 to 53% of the sediment samples from the UCR (n = 57) were toxic, depending on the endpoints that were considered. By comparison, 18 to 81% of the sediment samples from the UCR (n = 57) were found to be toxic to midges ©*. dilutus*) in 10-d whole-sediment toxicity tests, depending on the endpoints considered. UCR sediments tended to be less toxic to the cladoceran, *C. dubia*, in 7-d whole-sediment toxicity tests, 16 to 25% of the sediment samples from the UCR (n = 64) were designated as toxic to this species (depending on the endpoints considered). Overall, 58 of the 71 (82%) sediment samples from the UCR that were evaluated using the reference envelope approach were found to be toxic to amphipods, midges, or cladocerans. When sediment samples are designated as toxic or not toxic based on any of the eight toxicity test endpoints, the incidence of toxicity (IOT) was similar in Reach 1 (89%; n = 19), Reach 3 (86%; n = 7), Reach 4 (95%; n = 19), Reach 5 (86%; n = 7), and Reach 6 (86%; n = 7). The IOT was lower in Reach 2, within which 5 of the 12 sediment samples were designated as toxic to benthic invertebrates (42%).

Somewhat different results were obtained when IOT was determined based on further classification of toxic sediment samples into two categories, including moderately impacted (i.e., < 10% reduction in survival, growth, or reproduction relative to lower limit of the reference envelope) and highly impacted (i.e., > 10% reduction in survival, growth, or reproduction relative to lower limit of the reference envelope) sediment samples. When only highly impacted sediment samples were considered, the highest IOT was observed in Reach 1 (84%; n = 19). By comparison, the IOT ranged from 57% to 71% in Reaches 3, 4, 5, and 6. In Reach 2, the IOT was 25% (n = 12) when only highly impacted samples were considered.

ES7.0 Concentration-Response Model Development

A step-wise approach was used to develop site-specific CRMs using the sediment chemistry, pore-water chemistry, and/or sediment toxicity data for the UCR. First, a series of preliminary analyses were conducted to identify the COPCs, COPC mixtures, and slag indicators that were most likely to be correlated with the responses to toxicity test organisms (e.g., frequency of detection, comparison to conservative sediment quality guidelines). In the next step of the process, potential relationships between the concentrations of COPCs and the responses of toxicity test organisms were identified by conducting Spearman-Rank correlation analysis on the underlying data. To support this analysis, the underlying data were divided into three groups based on estimated slag content. The results of this analyses showed that the relationships between concentration and response tended to be strongest for the slag-affected samples and, to a lesser extent, for all samples combined. Concentration-response models were developed for each of the COPCs, COPC mixtures, and slag indicators in sediment that were retained following these initial analyses. Following their development, these CRMs were examined to identify the COPC/COPC mixture/slag indicator-toxicity test endpoint pairs that would be most relevant for derivation of thresholds for predicting sediment toxicity (TPSTs; i.e., $r^2 > 0.4$; $p < 0.05$; MacDonald *et al.* 2002; 2003; 2005a; 2005b; 2009; 2010).

ES8.0 Development and Evaluation of Preliminary Thresholds for Predicting Sediment Toxicity

Overall, 61 COPC/COPC mixture/slag indicator-endpoint pairs were selected for deriving TPSTs. As none of the COPC/COPC mixture/slag indicator-pairs for pore water met the selection criteria for identifying potential risk drivers, TPSTs for pore water were not developed in this investigation. Two types of TPSTs, including low-impact ($TPST_{LI}$s) and high-impact ($TPST_{HI}$s), were developed using the CRMs for whole sediment. The low-impact TPSTs were established at the concentrations of COPCs/COPC mixtures/slag indicators that corresponded to the lower limit of the reference envelope for the selected toxicity test endpoint. The high-impact TPSTs were established as the concentrations of COPCs/COPC mixtures/slag indicators that corresponded to a 10% reduction in survival, growth, biomass, or reproduction, compared to the lower limit of the reference envelope.

The reliability and predictive ability of these TPSTs were evaluated using the available sediment chemistry and sediment toxicity data from the UCR. The TPSTs were considered to be reliable and/or predictive of sediment toxicity if the IOT was <20% below the TPST, the IOT was >50% above the TPST, and the rate of correct classification of sediment samples as toxic and not toxic was 80%.

The results of this evaluation indicated that most of the site-specific TPSTs developed in this investigation provide a reliable basis for identifying toxic and not toxic slag-affected sediment samples in the UCR (i.e., for correctly classifying the sediment samples used to derive the TPSTs as toxic or not toxic, for the endpoint used to derive the TPSTs; i.e., TPST based on midge biomass typically did a good job of predicting impacts on midge biomass associated with exposure to UCR sediments). The TPSTs developed using data on the measurement endpoints for the cladoceran toxicity test tended to be the most reliable, with the TPSTs for 10 of 13 COPCs/COPC mixtures/slag indicators based on survival and for 11 of 15 COPCs/COPC mixtures/slag indicators based on reproduction exhibiting high reliability. By comparison, the TPSTs for only one of the COPCs/COPC mixtures/slag indicators (i.e., Cu:Al ratio) based on midge growth or biomass were shown to be reliable. The TPSTs for several of the COPCs/COPC mixtures/slag indicators based on amphipod growth or biomass were reliable, with the TPSTs for metal mixtures performing better than the TPSTs for individual metals.

The site-specific TPSTs were also evaluated to determine their predictive ability. The results of this evaluation indicate that none of the TPSTs derived using sediment chemistry and sediment toxicity data from the UCR provide an accurate basis for classifying all types of sediment samples as toxic or not toxic for all of the endpoints measured. That is, the TPST correctly classified sediment samples relative to their toxicity to benthic invertebrates or some toxicity test endpoints, but not others. This result is not surprising considering the results of the sediment toxicity tests, which showed that the various species and endpoints exhibited differential sensitivity to the COPCs, COPC mixtures, and slag indicators in UCR sediments, and the variability of the fate and transport of smelter waste-associated contaminants in the system. It is also likely that the conditions maintained during toxicity testing were only marginally suitable for midges and/or amphipods. This factor may have contributed to the high IOT for the low chemistry sediment samples. It is also possibly that unmeasured COPCs contributed to the variability in the CRMs.

The results of this investigation indicate that slag content is an important determinant of sediment toxicity in the UCR. For this reason, a sediment assessment framework was developed that relies on:

- Classification of sediment samples based on slag content; and,

- Application of numerical TPSTs.

When used together, such assessment tools provide a reliable basis for classifying sediment samples from the UCR as toxic or not toxic. Additional data should be collected to support validation and/or refinement of the recommended framework.

ES9.0 Conclusions

This investigation was conducted to provide an independent interpretation of the sediment chemistry and sediment toxicity data collected by USEPA in 2005 to support the RI and by other investigators to support evaluations of sediment quality conditions in the UCR. The principal conclusions that emerged from this investigation include:

- Sediments from the UCR are primarily contaminated by metals. However, UCR sediments are also known to contain other COPCs, such as polycyclic aromatic hydrocarbons, PCBs, organochlorine pesticides, and polychlorinated dibenzo-*p*-dioxins/polychlorinated dibenzofurans. The highest concentrations of metals were typically observed in Reach 1 of the study area;
- The results of chemical analyses and visual observations of sediment samples show that discharges of smelter slag have contaminated sediments within the UCR. Several procedures for classifying sediment samples from the UCR relative to slag content were developed and evaluated. Sediments located within Reach 1 had the highest accumulation of coarse-grained slag in the samples analyzed, as indicated by Cu:Al ratios and logged visual observations;
- Adverse effects on the survival, growth, biomass, and reproduction of aquatic invertebrates, including sediment-dwelling organisms, are associated with exposure to sediments from the UCR. Sediment toxicity was observed throughout the study area. Based on available data, the highest IOT was observed in Reach 1 for amphipods, Reaches 4 and 5 for midges, and Reach 5 for cladocerans. Reach 4 had the highest IOT when any endpoint for any species was considered, however, the differences in IOT among the upper reaches were generally relatively small. Therefore, exposure to contaminated sediments poses potential risks to benthic communities utilizing habitats in the UCR;
- The highest IOT was observed in slag-affected sediment samples for most of the toxicity test endpoints considered (i.e., when slag-affected sediment samples were identified using the Cu:Al model). However, non slag-affected sediment samples had the highest

IOT when midge survival was evaluated. These results emphasize the importance of accurately identifying and considering slag content in future evaluations of sediment toxicity in the UCR;

- Among the three species tested, sediment samples from the UCR were most toxic to midge, with the biomass endpoint being the most sensitive for this species (based on IOT). Amphipods exhibited intermediate sensitivity, with survival being the most sensitive endpoint. Cladocerans appeared to be less sensitive than either of the other two species. While midge exhibited the highest frequency of toxicity, the magnitude of toxicity (MOT) tended to be highest for amphipods in the most contaminated sediment samples;
- None of the species tested responded consistently across chemical gradients, generally resulting in weak relationships between the concentrations of COPCs or slag indicators and organism responses. The strongest modeled correlations between concentration and response were observed for: aluminum and beryllium vs. midge biomass; Mean probable effect concentration-quotient (PEC-Q) and Mean PEC-$Q_{METALS(1\%OC)}$ (i.e., normalized to 1% organic carbon) vs. amphipod survival; and, beryllium, chromium, cobalt, and iron vs. amphipod growth or biomass;
- The data that were used in this investigation have certain limitations that influence their applicability for comprehensively assessing site-wide sediment quality conditions and fully resolving CRMs in the UCR. In particular, the sediment toxicity and pore-water chemistry data from the 2005 USEPA study were generated using co-located sediment samples from the UCR, rather than from splits of composite samples collected at each sampling location. Accordingly, the pore-water chemistry data do not provide a reliable basis for assessing exposure of toxicity test organisms to COPCs. In addition, pore-water chemistry data obtained by analysis of pore-water samples generated by centrifugation of UCR sediments do not provide an adequate basis for determining exposure of benthic invertebrates to COPCs in pore water. Inherent challenges and limitations in obtaining consistent and comparable pore-water samples in the field is a limiting factor. Controlled laboratory methods for obtaining pore-water samples in association with toxicity tests are preferred (e.g., through the use of peepers). Furthermore, it appears that at least some of the toxicity test results may have been influenced by the use of marginally suitable overlying water and/or toxicity test organisms may have responded to nutritional challenges during toxicity testing;
- The available sediment chemistry and sediment toxicity data do not support the development of robust CRMs that apply throughout the UCR or site-specific TPSTs that provide a consistently accurate basis for comprehensively classifying the sediment samples from the study area as toxic or not toxic (i.e., for predicting the presence and

absence of sediment toxicity). Therefore, it is essential that sufficient quantities of high quality data be generated in the near term to support model development and validation;

- Generic sediment quality guidelines do not always provide an accurate basis for classifying all sediment samples from the study area as toxic or not toxic (i.e., based on the concentrations of COPCs). The sediment quality standards (mean PEC-Q of 0.1) established by the Confederated Tribes of the Colville Reservation (MacDonald and Ingersoll 2002) are adequately protective against sediment toxicity in the UCR (i.e., sediment toxicity is only infrequently observed at mean PEC-Qs of ≤0.1). However, they may not be consistently predictive of sediment toxicity, when used alone (i.e., the IOT to benthic invertebrates is variable at mean PEC-Qs of >0.1). Their applicability in this regard is likely to be enhanced by applying them selectively to non slag-affected and possibly slag-affected sediments from the study area (i.e., the IOT to benthic invertebrates is likely to be higher when the slag-affected samples are eliminated from the analyses);
- The Phase 1 sediment sampling program data set has limitations that constrain its use for establishing site-wide CRMs for predicting sediment toxicity in the UCR. The underlying sediment chemistry or sediment toxicity data can be used separately in evaluations of sediment quality conditions in the UCR. These conclusions also emphasize the need to establish clear expectations for the Phase 2 Sediment Sampling Program that provide detailed descriptions of requirements relative to:

  1. Site-wide study design, including (but not limited to) the selection of representative sampling sites, selection of reference sites, types of samples to be collected, and timing of the sampling program;
  2. Methods for collecting, handling, processing and preparing whole-sediment and pore-water samples, including sieving of sediment samples to optimize collection of the <2.00 mm size fraction for toxicity testing and pore-water sampling using peepers during laboratory toxicity testing;
  3. Chemical analytes that need to be measured in each media type;
  4. Independent classification of sediment samples relative to slag content and effluent-impacted aquatic environments over a range of spatial locations along the system;
  5. Toxicity testing, including, species (e.g., amphipods, midges, mussels), endpoints (e.g., survival, growth, biomass, reproduction), holding times, and associated methods;
  6. Bioaccumulation testing that may be important in support of toxicity assessment, including species and associated methods;
  7. Collection and analysis for invertebrate-tissue samples from hard-bottom and soft-bottom areas within the UCR, including freshwater mussels;

8. Toxicity identification evaluation procedures, which might be appropriate for selected sediment samples that are found to be toxic, but whose responses cannot be adequately understood; and,
9. Systematic toxicity testing to ensure that the selected toxicity testing laboratories have the capability to conduct the required toxicity tests successfully (e.g., to demonstrate the quality of overlying water and control sediments).

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Chapter 1 Introduction

1.0 Background

The Upper Columbia River (UCR) is located in north-central Washington. The UCR extends from the Canada-U.S. border to the Grand Coulee Dam, a distance of about 240 km. The UCR includes both the free-flowing reach of the Columbia River and the reservoir that was created following construction of the dam (Lake Roosevelt). At full pool, the lake spans a distance of about 215 km from about Onion Creek (River Mile 730 or RM 730) to the dam.

Concerns relative to contamination of aquatic ecosystems within the UCR and Lake Roosevelt are primarily focused on historical discharges from the Teck lead-zinc smelter at Trail, B.C. Other established secondary sources include the Zellstoff Celgar pulp mill in Castlegar, B.C., the historic Le Roi Smelter in Northport, the Spokane River, and potentially, localized effects from historic mine milling operations. The results of various investigations have demonstrated that metals, such as arsenic, cadmium, copper, lead, mercury, and zinc, and organic contaminants, such as polychlorinated biphenyls (PCBs), chlorinated phenols, polychlorinated dibenzo-*p*-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) have been released into the Columbia River from these facilities (CEE 2006a; TCAI 2006; UCR NRTC 2010).

In 1999, the Confederated Tribes of the Colville Reservation (CTCR) petitioned U.S. Environmental Protection Agency (USEPA) to conduct an assessment of hazardous substance contamination in the UCR (CEE 2006a). The petition expressed concerns about possible risks to human health and the environment associated with contamination in the river. In 2000, USEPA completed a preliminary assessment and concluded that further data collection was warranted. Accordingly, USEPA conducted an expanded site assessment in 2001, which included collection of sediment samples to evaluate sediment contamination. The results of this investigation indicated that contamination was widespread in riverine and lacustrine sediments, and that a remedial investigation/feasability study (RI/FS) was needed to evaluate potential risks to human health and the environment associated with exposure to contaminants at the UCR. The USEPA initiated the RI/FS in 2004 and the Phase 1 sediment sampling program was completed in 2005 (CEE 2006a).

In 2006, Teck American Inc. entered into a voluntary agreement with the USEPA to fund and conduct an RI/FS of the UCR from the International Border to the Grand Coulee Dam. Under the terms of this settlement agreement, the RI/FS is being conducted by Teck, with oversight provided by USEPA. In addition, USEPA is responsible for conducting the human health risk assessment (HHRA). The Confederated Tribes of the Colville Reservation, the Spokane Tribe of Indians, the State of Washington, and the U.S. Department of the Interior, have been designated as participating parties under the settlement agreement.

The Natural Resource Trustees (NRTs), including the Confederated Tribes of the Colville Reservation, the Spokane Tribe of Indians, the State of Washington, and the U.S. Department of the Interior, are also planning a natural resource damage assessment (NRDA) of the UCR. The NRDA is the process that is used to evaluate the nature and extent of injury to trust resources caused by discharges of oil or releases of other hazardous substances to the environment. The NRTs have completed a pre-assessment screen and determined that there is a reasonable probability of achieving a successful claim for injuries and damages to natural resources resulting from releases of hazardous substances to the UCR. Therefore, the NRTs can proceed to assessment planning, injury determination, injury quantification, damage calculation, and/or restoration phases of the NRDA.

1.1 Purpose of this Document

This investigation was conducted to evaluate and interpret existing sediment chemistry and sediment toxicity data for the UCR. More specifically, the objectives of this investigation are to:

- Acquire, compile, and evaluate synoptically-collected sediment chemistry and toxicity data from the UCR;
- Develop a procedure for conducting preliminary classifications of UCR sediments relative to slag content;
- Evaluate relationships between sediment chemistry (and pore-water chemistry) and sediment toxicity for UCR sediments;
- Develop and evaluate preliminary site-specific thresholds for predicting toxicity in sediment and/or pore water from the UCR;
- Recommend procedures for classifying sediment samples from the UCR relative to their potential for toxicity to benthic invertebrates; and,
- Identify gaps in the existing knowledge base and actions needed to fill such data gaps.

The results of this investigation are intended to provide a technical basis for interpreting sediment chemistry and sediment toxicity data from the UCR. This evaluation resulted in the development of procedures for identifying slag-influenced/dominated sediments, assessing the toxicity of UCR sediments to benthic invertebrates, and determining relationships between toxicity and chemistry. Risk-based thresholds for predicting sediment toxicity were also developed and evaluated during this investigation. These tools are intended to support assessments of sediment quality conditions in the UCR. In so doing, this report informs the design of future investigations of sediment quality conditions, supports ongoing evaluations of injuries to sediments and sediment-dwelling organisms, and contributes to assessments of the effects on ecological receptors associated with exposure to UCR sediments. However, the results of this evaluation should not be interpreted as either an ecological risk assessment (ERA) or a NRDA. USEPA and Teck are conducting an RI/FS of the study area, which includes a baseline ecological risk assessment (BERA) and a HHRA. In addition, the Upper Columbia River/Lake Roosevelt Natural Resources Trustees are assessing injuries to natural resources and any damages that have occurred in conjunction with releases of hazardous substances at the UCR.

1.2 Overview of Study Approach and Associated Rationale

Assessments of sediment quality conditions are commonly conducted using whole-sediment chemistry data for evaluating the potential for effects on benthic invertebrates associated with exposure to contaminated sediments. Such assessments are typically supported by numerical sediment quality guidelines (SQGs). In the UCR, generic and/or site-specific SQGs are needed for identifying chemicals of potential concern (COPCs), determining the contaminants of concern (COC) in sediment samples (i.e., the substances that are causing or substantially contributing to sediment toxicity or other adverse effects), for classifying sediment samples as toxic and not toxic (impaired or not impaired; i.e., based on the concentrations of COPCs that were measured in each sample), and for evaluating the incidence or magnitude of predicted toxicity in the sediment samples.

A number of approaches have been developed to support classification of sediment samples based on whole-sediment chemistry. For example, Barrick *et al.* (1988) developed apparent effect thresholds (AET; i.e., the concentrations of sediment-associated COPCs above which sediment samples were always toxic) for assessing sediment quality conditions in Puget Sound, WA. Using these SQGs, sediment samples are predicted to be toxic if the concentration of one or more COPCs exceeds the AET for the specified biological endpoint under consideration (e.g., amphipod survival, benthic invertebrate community structure). In an effort to evaluate the combined effects of multiple COPCs, Swartz *et al.* (1995) developed a model to predict the toxicity of polycyclic aromatic hydrocarbon (PAH) mixtures in field-collected sediments using a combination of equilibrium partitioning, quantitative structure activity relationship, toxic unit, and concentration-response models (CRMs). Likewise, Berry *et al.* (1996) developed a model for predicting the toxicity of sediment-associated trace metals based on measurements of simultaneously extracted metal (SEM) and acid volatile sulfide (AVS) concentrations.

To support the assessment of sediments contaminated with a broader suite of COPCs, Long *et al.* (1998a) and Long and MacDonald (1998) evaluated the incidence of toxicity (IOT) and the magnitude of toxicity (MOT; i.e., based on the results of 10-d toxicity tests with marine amphipods) in sediments containing trace metals, PAHs, PCBs, and organochlorine pesticides, based on the number of exceedances of SQGs (i.e., effects range median - ERMs and probable effect levels - PELs). Recognizing that toxicity of contaminated sediments was likely to be influenced by both the number of exceedances and the magnitude of such exceedances, Long *et al.* (1998a) developed a model for evaluating the combined effects of the four major classes of COPCs in sediments (i.e., metals, PAHs, PCBs, and organochlorine pesticides). More specifically, mean SQG quotients (SQG-Q; i.e., mean ERM-Qs or mean PEL-Qs) were derived as the average of the ratios between the chemical concentrations in the samples and the respective ERM or PEL values (Long and MacDonald 1998). These SQG-Qs were used together with the results of the whole-sediment toxicity tests with marine amphipods to determine the incidence and MOT within ranges of mean SQG-Qs (i.e., ERM-Qs of <0.1, 0.1 to 0.5, >0.5 to 1.5, and >1.5).

More recently, USEPA (2000) and Ingersoll *et al.* (2001) developed CRMs for the freshwater amphipod, *Hyalella azteca* and the midges, *Chironomus tentans* and *Chironomus riparius*. These investigators evaluated 11 difference procedures for calculating mean SQG-Qs (in this case, using the consensus-based probable effect concentrations (PECs), that were derived by MacDonald *et al.* 2000). The results of this evaluation indicated that sediment samples were most accurately classified as toxic and not toxic when Mean PEC-quotients (PEC-Qs) were calculated based on the measured concentrations of seven trace metals, total PAHs, and/or total PCBs. Subsequently, concentration-interval plots and associated CRMs were developed for the survival and for the survival or growth of the amphipod *Hyalella azteca* (i.e., in 10- to 14-d and 28- to 42-d toxicity tests) and midges (i.e., in 10- to 14-d toxicity tests). Again, these CRMs can be used together with whole-sediment chemistry data to estimate the probability that a sediment sample will be toxic to sediment-dwelling organisms (i.e., specifically for the toxicity test species, endpoint, and duration of interest).

To further refine the tools available for assessing mixtures of a broad range of COPCs in sediment, Field *et al.* (1999; 2002) developed logistic regression models (LRMs) for 37 COPCs in contaminated sediments. These LRMs provide a basis for predicting the probability of observing acute sediment toxicity to the marine amphipods, *Ampelisca abdita* or *Rhepoxynius abronius* (i.e.,10-d toxicity tests), based on the measured concentration of the COPC in sediment samples. Subsequently, the individual chemical LRMs were combined into a single model, using either the maximum (P-Max model) or average (P-Avg model) probability predicted from the chemicals analyzed in a sediment sample, to estimate the probability of observing toxicity for a sample. In this way, the concentrations of up to 37 COPCs are considered for predicting the probability of toxicity to marine amphipods.

The results of numerous evaluations of the aforementioned SQGs and associated chemical mixture models indicate that they provide reliable and/or predictive tools for assessing sediment quality conditions throughout the United States (Barrick *et al.* 1988; Long *et al.* 1995; MacDonald *et al.* 1996; Long *et al.* 1998a; 1998b; Long and MacDonald 1998; Field *et al.* 1999; MacDonald *et al.* 2000; USEPA 2000; Ingersoll *et al.* 2001; Field *et al.* 2002). Nevertheless, establishment of site-specific thresholds for predicting sediment toxicity (TPSTs) for benthic invertebrates has been identified as a high priority at a number of sites with contaminated sediments. At such sites, the incremental costs associated with conducting the studies needed to develop site-specific relationships between sediment chemistry and sediment toxicity are warranted, considering the potential costs associated with remediation of contaminated sediments and/or restoring any injured natural resources. While approaches vary among sites, two thresholds for predicting sediment toxicity are commonly established for each COPC, COPC mixture and/or slag-indicator, including a low-impact ($TPST_{LI}$) and a high-impact ($TPST_{HI}$) TPST (based on toxicity thresholds from MacDonald *et al.* 2002; 2004; 2005a; 2005b; 2009; 2011). Together, these TPSTs define three ranges of concentrations including:

- A range within which exposure to the COPC/COPC mixture/slag indicator is likely to pose low impacts to benthic invertebrates (i.e., $<TPST_{LI}$);
- A range within which exposure to the COPC/COPC mixture/slag indicator is likely to pose increased risks to benthic invertebrates (i.e., $TPST_{LI}$ to $TPST_{HI}$); and,
- A range within which exposure to the COPC/COPC mixture/slag indicator is likely to pose a higher risk to benthic invertebrates (MacDonald *et al.* 2010).

Such site-specific TPSTs are typically evaluated using matching sediment chemistry and sediment toxicity data from the UCR to confirm that they provide a reliable basis for predicting the presence and absence of toxicity to benthic invertebrates.

This investigation was conducted to evaluate and interpret sediment chemistry and toxicity data from the UCR, with a focus on the development and evaluation of site-specific thresholds for predicting sediment toxicity for selected COPCs/COPC mixtures/slag indicators. Accordingly, matching sediment chemistry and sediment toxicity data from multiple sources were acquired and compiled. These data were then evaluated to determine if they could be used to support the derivation of site-specific thresholds for predicting sediment toxicity for benthic invertebrates. Because relationships between sediment chemistry and sediment toxicity could be different for various types of sediments (i.e., for sediments that have COPCs that originated primarily from liquid effluents or slag), a procedure for conducting preliminary classifications of sediment samples from the UCR based on slag content was developed and evaluated.

Subsequently, preliminary CRMs were developed for individual COPCs, selected COPC mixtures and slag indicators. Site-specific TPSTs were then developed for the individual COPCs, various COPC mixtures, and slag indicators in UCR sediments that were well-correlated with the results of the selected toxicity tests. These TPSTs were then evaluated to determine which ones provided the most reliable basis for classifying sediment samples from the UCR as toxic or not toxic to benthic invertebrates. The results of the reliability and predictive ability evaluations were then used to recommend an interim framework for predicting toxicity to benthic invertebrates utilizing aquatic habitats within the study area.

1.3 Organization of this Report

This report is organized into a number of sections to facilitate access to information on the methods that were used to interpret the sediment chemistry and toxicity data from the UCR and to the results of those evaluations, including:

- Introduction (Chapter 1);
- Geographic Scope of Study Area (Chapter 2);
- Identification of Chemicals of Potential Concern in the Upper Columbia (Chapter 3)
- Design and Implementation of the Phase 1 Sediment Sampling Program of the Upper Columbia River (Chapter 4);
- Characterization of the Slag Content of Sediment Samples from the Upper Columbia River (Chapter 5);

- Evaluation of Relationships Between Sediment Chemistry and Sediment Toxicity in the Upper Columbia River (Chapter 6);
- Development and Evaluation of Site-Specific Thresholds for Predicting Sediment Toxicity for Sediments in the Upper Columbia River (Chapter 7);
- Consideration for Selecting Methods for Classifying Sediment Samples from the UCR (Chapter 8)
- Summary and Conclusions (Chapter 9);
- References Cited (Chapter 10).

A complete list of the sediment samples that were collected during the 2005 sediment sampling program conducted by USEPA is provided in Appendix 1. A listing of all of the candidate data sets considered in this investigation is provided in Appendix 2, while Appendix 3 describes the procedures that were used to evaluate candidate data sets. Appendix 4 describes the data auditing and treatment procedures applied to selected data sets. Appendix 5 presents Spearman-rank correlations between sediment chemistry data and sediment toxicity data. The full set of CRMs that were developed for selected COPCs, COPC mixtures, and slag indicators is provided in Appendix 6. Appendix 7 summarizes the COPC/COPC mixture/slag indicator low- and high-impact TPSTs that were derived using the CRMs for slag-affected sediment samples, as well as an evaluation of the reliability and predictive ability of the TPSTs. Appendix 8 contains the results of supplemental data analyses including sensitivity analyses. Appendix 9 provides a summary of all whole sediment toxicity and chemistry data used in the analyses. Finally, a glossary of terms and a list of acronyms are provided to define the various scientific terms that are used throughout this document.

Chapter 2 Geographic Scope of the Study Area

2.0 Introduction

Under the terms of the settlement agreement between Teck (i.e., Teck, as represented by Teck Cominco American Inc.) and USEPA (dated June 2, 2006), the UCR is defined as the areal extent of contamination by hazardous substances within the United States in or adjacent to the UCR, including the Franklin D. Roosevelt Lake, from the border between the U.S. and Canada downstream to the Grand Coulee Dam, and those areas in proximity to the contamination which are suitable and necessary for implementation of the response actions described in the settlement agreement. This chapter provides a description of the geographic scope of the study area that is consistent with the definition of the UCR included in the settlement agreement.

2.1 Description of the Study Area

The UCR is located wholly within Washington State and includes approximately 150 river miles (i.e., 240 km) of the Columbia River extending from the U.S.-Canadian border to the Grand Coulee Dam. Brought into service in 1942, the Grand Coulee Dam is a multipurpose structure, providing flood control, irrigation, hydropower production, recreation, and fish and wildlife benefits (USEPA 2003a). Located immediately behind the dam is Lake Roosevelt, a large reservoir extending approximately 130 river miles (i.e., 210 km) north of the dam at full pool and bordered by approximately 312 miles of publicly available shoreline (NPS 2006; USEPA 2003a; NHC 2007). The first 10 to 15 miles (16 to 24 km) of the UCR south of the international border is a free-flowing riverine environment. The Columbia, Kootenay, and Pend Oreille rivers represent the primary sources of water to Lake Roosevelt. The Spokane River and, to a lesser extent, the Colville, Kettle, and Sanpoil rivers also contribute water to the reservoir (LRF 2006). Normal operation of the dam can result in seasonal reservoir level fluctuations in excess of 80 ft, ranging from full pool conditions at 1,290 ft above mean sea level (AMSL) to low pool conditions at 1,208 ft AMSL (USEPA 2003a). As a result, bed and bank sediments along the length of the reservoir are exposed during spring draw-down periods (USEPA 2003a). Figure 2.1 shows the location of the UCR.

Ferry County and Stevens County border the upper and central UCR on the west and east, respectively, from the international border to approximately U.S. Geological Survey (USGS) River Mile (RM) 640. The lower UCR (USGS RM 640 to the Grand Coulee Dam) is primarily bordered to the south by Lincoln County and to the north by Ferry County. Highway 25 runs adjacent to the eastern shore of the UCR from about USGS RM 712 down to USGS RM 640. The lands of the Confederated Tribes of the Colville Indian Reservation border the UCR from approximately USGS RM 690 to the Grand Coulee Dam. The Spokane Indian Reservation borders the UCR to the east from approximately USGS RM 646 to USGS RM 689

The upland areas immediately surrounding the UCR are generally sparsely populated and consist primarily of forests and farmland. Much of the land surrounding the upper UCR on the west is contained within the Colville National Forest. National Forest land also occurs within Stevens County, but does not abut the UCR as closely as to the west.

The reservoir has been designated as the Lake Roosevelt National Recreation Area (LRNRA) and is managed by the National Park Service, U.S. Department of the Interior. Portions of the reservoir are cooperatively managed by the Confederated Tribes of the Colville Reservation and the Spokane Tribe of Indians.

The National Parks Service, Confederated Tribes of the Colville Reservation, and Spokane Tribe of Indians cooperate as managing partners in designating acceptable recreational uses for Lake Roosevelt. The purpose of the LRNRA is to: provide opportunities for outdoor recreational experiences for the public; to preserve, conserve, and protect the integrity of natural, cultural, and scenic resources; and, to enhance public appreciation and understanding of those resources (NPS 2006). Designated recreational uses of the LRNRA include boating, fishing, swimming, wading, camping, canoeing, and hunting.

Historically, the UCR provided a subsistence fishery for Native American peoples. For the Colville Tribes, both anadromous and resident fish (primarily salmon, but also steelhead, whitefish, bull trout, and others) were targeted in the subsistence fishery (USEPA 2003a). Since the construction of the Columbia River dams, resident fish have become even more important to tribal members utilizing fisheries resources (USEPA 2003a). The draft Fish and Wildlife Resource Management Plan for the Colville Indian Reservation includes several provisions for maintaining both ceremonial and subsistence fisheries on resident and anadromous fish in Lake Roosevelt (CTCR 2006).

2.2 Areas of Interest

To facilitate sediment toxicity investigations conducted under the RI, TCAI (2006) subdivided the UCR into six river reaches that correspond to relatively distinct physiographic units. The delineation of the various river reaches is generally consistent with those used in past USGS studies by Bortleson *et al.* (2001) and Cox *et al.* (2005), as summarized below:

- **Reach 1: U.S.-Canadian Border at USGS RM 745 to RM 730** – This reach is consistent with the Northport Reach identified by USGS. It begins at the upstream boundary of the UCR and extends approximately to Onion Creek. This reach can be characterized as a swift river environment (i.e., riverine) that is typically unaffected by the reservoir.
- **Reach 2: USGS RM 730 to RM 712** – This reach is consistent with the Upper Reservoir Reach identified by USGS. It extends to the vicinity of

Evans and Powell, Washington, and can be characterized as a narrow channel within the reservoir that has few shoreline embayments or irregularities.

- **Reach 3: USGS RM 712 to RM 700** – This reach is consistent with the upper portion of the Middle Reservoir Reach identified by USGS, and consists primarily of Marcus Flats. This reach can be characterized as a depositional area for coarse-grained sediments in the historical river channel and for fine-grained sediments in many of the shallower areas.
- **Reach 4: USGS RM 700 to RM 640** – This reach is consistent with the lower portion of the Middle Reservoir Reach identified by USGS and extends from above the mouth of the Colville River to above the mouth of the Spokane River. It can be further subdivided into Reaches 4a and 4b, with the boundary occurring at USGS RM 676 near Inchelium and Gifford, where the width of the overall reach narrows considerably.
- **Reach 5: USGS RM 640 to RM 617** – This reach is consistent with the upper portion of the Lower Reservoir Reach identified by USGS, and it extends to above the mouth of the Sanpoil River. It can be characterized as a lacustrine environment with slow moving water.
- **Reach 6: USGS RM 617 to Grand Coulee Dam near RM 597** – This reach is consistent with the lower portion of the Lower Reservoir Reach identified by USGS, and it extends to the downstream boundary of the UCR. It can be characterized as a lacustrine environment with slow-moving water.

For the purposes of interpreting the sediment chemistry and sediment toxicity data collected by USEPA in 2005, the six reaches identified by TCAI (2006) were adopted as areas of interest (AOIs). These AOIs were also used to evaluate current spatial patterns of toxicity in the UCR. Figure 2.2 shows the locations of the six AOI's within the UCR.

Chapter 3 Identification of Chemicals of Potential Concern in the Upper Columbia River

3.0 Introduction

This chapter is intended to provide key background information needed to support the evaluation of the sediment chemistry and sediment toxicity data that have been collected in the UCR. More specifically, this chapter provides information on the sources and releases of environmental contaminants in the UCR. Additionally, this chapter describes the process that was used to identify the COPCs in the study area.

3.1 Sources and Releases of Environmental Contaminants

Concerns relative to contamination of aquatic ecosystems within the UCR and Lake Roosevelt are primarily focused on historical discharges from the Teck lead-zinc smelter at Trail, B.C. Other established secondary sources include the Zellstoff Celgar pulp mill in Castlegar, B.C., the historic Le Roi Smelter in Northport, the Spokane River, and potentially, localized effects from historic mine milling operations.

3.2 Chemicals of Potential Concern in the Study Area

The identification of COPCs represents an essential element of the environmental assessment process (USEPA 1998). To initiate this process, the available information on the various sources and releases of chemical substances was reviewed and evaluated. The results of this evaluation resulted in identification of the following COI's (Table 3.1):

- Metals and metalloids (aluminum, antimony, arsenic, barium, beryllium, bismuth, cadmium, chromium, cobalt, copper, germanium, gold, indium, iron, lead, lithium, manganese, mercury, methyl mercury, nickel, selenium, silver, thallium, tin, vanadium, zinc);
- Major ions (calcium, potassium, sodium, sulfate);
- Nutrients (ammonia - NH_3 and NH_4^+, nitrite, nitrate);
- PAHs (parent and alkylated PAHs);
- Chlorine;
- Pesticides (in-use and historic use insecticides, herbicides, and fungicides);
- Chlorinated organic compounds (e.g., chlorophenols, chlorocatechols, chloroguaiacols, and chloroveratroles);
- Conventional variables (total suspended solids, total gas pressure, total dissolved gas);
- PCBs (Aroclors, homologs, and/or PCB congeners - 209 congeners in total);
- Resin acids and fatty acids (abietic acid, dehydroabietic acid, isopimaric acid, palustric acid, lauric acid, linoleic acid, myristic acid, palmitric acid, stearic acid); and,
- PCDDs/PCDFs (targeting the 2,3,7,8-substituted congeners).

As part of the RI process, Parametrix *et al.* (2008) conducted a screening-level ecological risk assessment (SLERA) of the UCR on behalf of Teck. The results of the SLERA indicated that there was insufficient data to evaluate the potential risks to ecological receptors associated with exposure to contaminants in surface water or pore water. Therefore, all of the chemicals of interest identified should be carried into the BERA process. For sediments, metals, metalloids, and PCDDs/PCDFs were identified as COPCs based on exceedances of toxicity screening values. The uncertain COPCs that need to be addressed in the BERA include PCBs, certain pesticides, and numerous semi-volatile organic compounds (SVOCs).

One of the first steps in the BERA process is refinement of the list of COPCs. In December, 2009, Parametrix *et al.* (2009) conducted an evaluation to support refinement of COPCs in sediment and associated pore water. The results of this evaluation indicated that there was potential risk to benthos associated with exposure to cadmium, copper, lead, mercury, and zinc in sediment and/or pore water. All other COPCs were considered by Parametrix *et al* (2009) to be unlikely risk drivers (to be addressed in the uncertainty section of the BERA) or not risk drivers (to be eliminated from further evaluation). As the COPC refinement was not conducted in a manner conducive to completing a reliable sediment toxicity assessment, additional contaminants (i.e., beyond those five metals) should be considered as evaluation of the existing data and planning for future investigations proceeds. For this reason, a broad suite of COPCs was considered in the current evaluation of sediment chemistry and toxicity data from the UCR (see Table 3.1)

Chapter 4 Design and Implementation of the Phase 1 Sediment Sampling Program of the Upper Columbia River

4.0 Introduction

In 2005, USEPA designed and implemented a Phase 1 sediment sampling program in the UCR. This sampling program was designed to improve understanding of the nature and extent of contamination and to support assessments of risks to human health and ecological receptors. This chapter provides a brief overview of the design of the Phase 1 sediment sampling program that was conducted by USEPA in 2005 to support the Remedial Investigation of the UCR. The Phase I sediment sampling program is explicitly described in this Chapter because it represents the most robust sources of sediment chemistry and toxicity data for the UCR. Other data sets considered in this investigation are identified in Chapter 6 and Appendix 2.

4.1 Design of the Sediment Sampling Program

In 2004, CH2M Hill and Ecology and Environment, Inc. designed a Phase 1 Sediment Sampling Program for the UCR (CEE 2004). This program was intended to provide the data and information required to support a variety of RI/FS and risk assessment needs. To address these data needs, seven types of sediment samples were collected within the UCR study area in 2005 (Table 4.1), including:

- Baseline sediment samples;
- Focus-area sediment samples;
- Beach sediment samples;
- Tributary sediment samples;

- Sediment core samples;
- Bioassay sediment samples; and,
- Reference area sediment samples.

The rationale for collecting these seven types of sediment samples is described in CEE (2004); hence, only a brief overview is provided here. The primary purpose of the baseline sediment samples was to better define the current nature and extent of contamination within the UCR and to support the HHRA and ERA. Within six focus areas, sediment samples were collected at a higher density than the sampling in other areas. The resultant data were intended to support evaluations of the transverse, longitudinal, and vertical variations in contamination. Beach sediment sampling was conducted to support characterization of risks to human health associated with exposure to contaminated sediments in high use areas of 16 recreational beaches in the study area. Sediment samples were also collected from the reservoir near the mouths of six major tributaries to evaluate the effects of other potential sources and/or dilution of contamination on the concentrations of COPCs in bed sediments in the UCR mainstem. Sediment cores were collected at a total of nine locations to characterize the vertical variability in COPC concentrations within the UCR. Additionally, sediment samples were collected at 50 locations within the UCR to support toxicity testing. Finally, reference-area samples were collected at six locations to support determination of background concentrations of COPCs and to support the toxicity testing portion of the sediment sampling program. At 26 of the transect locations and two of the coring locations, it was not possible to collect sediment samples due to the presence of a cobbly bottom and/or swift current. Four of these stations were relocated to facilitate sample collection.

In total, sediment samples were collected at a total of 298 unique locations in the study area during the 2005 sediment sampling program (Figure 4.1). Table 4.1 provides a summary of the sediment sample types and associated number of locations that were targeted for sampling to obtain each type of sediment sample. A complete list of the sediment samples that were collected during the 2005 sediment sampling program is provided in Appendix 1. The suite of analytes that were measured in each of the sediment types is described in Table 4.2.

The bioassay component of the Phase 1 sediment sampling program was designed to support the development of relationships between the concentrations of COPCs (and COPC mixtures and slag indicators) in UCR sediments and toxicity to invertebrates. To support this element of the study, sediment chemistry, sediment toxicity, and pore-water chemistry data were collected at a total of 50 locations within the UCR study area. Sampling locations were selected to provide broad spatial coverage of the study area and to provide a broad range of COPC concentrations (Figure 4.2). In addition, reference sediment samples were collected at the mouths of six major tributaries, including Five Mile Creek (RM 732), Crown Creek (RM 726), Flat Creek (RM 721), Nancy Creek (RM 705), Barnaby Creek (RM 686), and Cheweka Creek (RM 685; Figure 4.2). Sediment samples from all 56 locations were evaluated using a suite of toxicity tests.

4.2 Sediment and Pore-Water Sampling Methods

The methods for collecting sediment and pore-water samples during the 2005 sediment sampling program are described in the Phase 1 Sediment Quality Assurance Project Plan (CEE 2005) and the Phase 1 Sediment Sampling Field Summary Report (CEE 2006b). Accordingly, only a brief summary of the sampling methods are provided herein.

All of the bioassay sediment samples were collected from near-shore or side-bank locations of the reservoir or riverine reaches. Surface-water depths typically ranged from two to four feet, at the time of sampling. Pool elevation at that time ranged from approximately 1250 to 1255 feet. The EPA sampling design was fixed along preset transects and did not target specific environments, sediment types, or contamination histories. At all locations except one, the bioassay sediment samples were co-located with a corresponding transect sample to allow for direct comparison of bioassay testing results with the corresponding sediment chemical quality information (CEE 2006b).

Whole-sediment samples were collected using a variety of methods. In general, sediments located below the water were collected using van Veen grab samplers, while those sediment located on the river banks were sampled using stainless steel hand tools (e.g., trowels). For the below water sediment samples collected using the van Veen grab samplers, overlying water was drained from the sampler upon retrieval and the top 10-15 cm of material was transferred to a sample container. This process was repeated until the required volume of material was obtained. Sediment samples collected using hand tools were transferred directly to the sample container. At certain locations, sediment samples were collected using sediment cores (i.e., 10 cm diameter Lexan core tubes) to obtain material as deep as nine feet below the sediment-water interface (CEE 2006b). All sediment samples were then held in coolers until transported to the laboratory for further processing. The bioassay sediment samples were typically collected using stainless-steel spoons, trowels, or other hand tools. A separate sediment sample was collected at each of the bioassay sediment sampling stations and used to prepare a pore-water sample (CEE 2006b).

Pore-water samples were obtained from 1-L samples of field-collected sediment. Initially, each sediment sample was homogenized and transferred to a 1-L polyethylene centrifuge tube. Sediment was centrifuged for 30 minutes at 3,000g to extract pore water. Subsequently, the supernatant was decanted into clean plastic bottles, filtered with a 0.45-micron filter, and acidified with nitric acid. Pore-water samples were then submitted to the analytical laboratory for chemical analysis.

4.3 Chemical Analyses

At all of the locations selected for toxicity testing, co-located transect sediment samples were collected and submitted for chemical analysis (Table 4.2). For most of the sediment samples, a standard analytical suite of chemical analyses was conducted, including: target analyte list (TAL) metals, uranium, target compound list (TCL) SVOCs, TCL pesticides/PCBs, total organic carbon (TOC), and particle size (CEE 2006a). Polychlorinated dibenzo-*p*-dioxins and PCDFs were measured on a sub-set of the beach samples and all of the core samples. For the whole sediment samples selected for toxicity testing, the suite of COPCs that were measured included TAL metals, uranium, TCL SVOCs, TCL pesticides/PCB Aroclors, AVS, SEM, TOC, and particle size (CEE 2006a). Pore-water samples, obtained by centrifugation of sediment samples, were analyzed for dissolved TAL metals and uranium.

4.4 Toxicity Testing

A total of 56 sediment samples were collected from 50 locations along the length of the UCR and from six reference locations near the mouth of UCR tributaries to support toxicity testing. These sediment samples were obtained from shallow, near-shore areas, generally in the vicinity of the transect samples. All of these samples were evaluated using whole-sediment toxicity tests with three indicator species, including:

- Amphipods, *Hyalella azteca*, in 28-d exposures (Endpoints: Survival, growth, and biomass);
- Midges, *Chironomus dilutus*, in 10-d exposures (Endpoints: Survival, growth, and biomass); and,
- Cladocerans, *Ceriodaphnia dubia*, in 7-d exposures (Endpoints: Survival and reproduction).

The toxicity tests were conducted in two batches. As such, all six reference sediment samples were tested in both batches. No pore-water samples were collected in association with the toxicity tests. Additional information on the methods used to conduct the sediment toxicity tests is provided by Schut and Stefanoff (2007) and Stefanoff *et al.* (2006).

4.5 Quality Assurance/Quality Control

Quality assurance/quality control (QA/QC) measures were integrated into all aspects of the 2005 sediment sampling program to assure the quality of the resultant data. The QA/QC measures for the analytical chemistry component of the 2005 sediment sampling program included preparation and analysis of samples to support evaluations of accuracy, precision, sensitivity, and contamination (i.e., field replicates, laboratory duplicates, matrix spikes, matrix spike duplicates, and blanks). The results of the data evaluation indicated that the chemistry data generated were generally usable in the RI/FS.

For the toxicity testing program, QA/QC measures included testing of negative control samples, positive control samples (i.e., reference toxicant tests), and daily or more frequent monitoring of test conditions. In addition, the laboratories that conducted the toxicity tests were audited to evaluate test procedures and the results of the toxicity tests (Schut and Stefanoff 2007; Stefanoff *et al.* 2006). The results of the QA/QC evaluation showed that test acceptability criteria were met for all tests, no significant issues were identified by the laboratories or the external auditor that could affect test results, and all organisms used in the testing were within their normal sensitivity ranges (Table 4.3).

Chapter 5 Characterization of Slag Content of Sediment Samples in the Upper Columbia River

5.0 Introduction

Teck or its predecessors have operated a lead-zinc smelter on the Columbia River at Trail, B.C. since 1896. Historically (i.e., until 1995), Teck discharged approximately 400 tonnes per day of slag and various volumes of smelter-derived effluent wastes to the Columbia River (Nener 1992; Cox *et al.* 2005). While some of this material was deposited in the immediate vicinity of the discharge location, vast quantities of slag and smelter effluent wastes were transported to downstream areas of the UCR in Canada and the United States. The presence of "black-sand beaches" at various locations downstream of the facility provides evidence of the magnitude and extent of these slag discharges. Because slag contains elevated levels of metals and other constituents, and because these substances may be differentially available compared to metals in typical riverine sediments, interpretation of sediment chemistry and sediment toxicity data from the UCR may be enhanced by development of a procedure for characterizing the slag content of sediments within the UCR. This chapter provides a brief overview of the characteristics of slag and describes the procedures developed to characterize slag content of sediment samples collected by USEPA in 2005.

5.1 Characteristics of Slag

Slag is a by-product of the ore smelting process. Slag often has a glass-like appearance and has historically been discharged to the Columbia River from the Teck lead-zinc smelter in Trail, B.C. The material was discharged to the river in the form of a granulated slurry and contains elevated levels of various metals, including copper, lead, and zinc (Nener 1992; Bortleson *et al*. 1994). Approximately 1% by weight of slag is comprised of fines (less than 0.15 mm); as a result, between 4 and 5 tonnes of fines were historically discharged to the UCR each day (Nener 1992; Crozier and McDonald 1992). These fines have a broken eggshell or needle-like morphology and are less chemically stable than the larger-sized grains in the slag (Cominco 1991). Hence, slag is a distinct industrial waste stream that contributes to the metal load of the river. Nener (1992), using bioassays with the green alga *Selenastrum capricornutum*; the cladoceran, *Daphnia magna*; the midge, *Chironomus dilutus*; the amphipod, *Hyalella azteca*; and the rainbow trout, *Oncorhyncus mykiss*, demonstrated the negative impacts on ecological receptors associated with exposure to slag. For this reason, an initial evaluation was conducted to determine if procedures could be established for characterizing the slag content in sediment samples from the UCR in concert with toxicity assessment.

5.2 Approach to the Characterization of Slag Content in Upper Columbia River Sediments

The presence of slag in sediments can, in part, be characterized by elevated levels of various metals, including copper, lead, and zinc, and others (Nener 1992; Bortleson *et al.* 1994). In addition, slag-affected sediments may have unique physical characteristics, such as grain size, particle shape, or color. As such, a variety of approaches have been used to identify sediments that have been contaminated by slag or enriched by metals as a result of anthropogenic activities. These approaches include using relative concentrations of strontium isotopes (Bayless 2004), lead isotope compositions (Nelson 2011), scanning-electron microscopy (Cox *et al*. 2005; Nelson 2011), methylene iodide separation (Ryan and Mohanty 2011) grain size analysis (J. Roland and B. Dowling. Washington Department of Ecology. Pers. comm.), and the normalization of indicator metals to a reference metal (i.e., metal enrichment; Schropp *et al*. 1990). In addition, Teck has proposed using the presence of vanadium to characterize the slag content of sediments in the UCR (based on presentations made at various technical meetings convened to support the RI). Due to data availability and the need for application of the method on a regional basis (i.e., the UCR study area), normalization to a reference metal was considered to be one promising approach for characterizing the slag content of sediments in the UCR. To characterize the slag content of sediments in the UCR, the 56 samples for which sediment chemistry and toxicity data exist (i.e., 50 test sites and 6 reference sites) were used in the analysis. The data were compiled and three candidate reference element normalization procedures were developed to support interpretation of the sediment chemistry data from the study area and nearby reference sites. The approach used in this study for characterization of slag content in UCR sediments included the following steps:

- Selection of reference elements;
- Selection of indicator metals for slag;
- Development of slag-identification models; and,
- Evaluation of the resultant models.

5.2.1 Selection of Reference Elements

Due to the natural abundance and ubiquity in sediments, aluminum has often been used as a reference element to assess anthropogenic metal contamination in coastal and estuarine habitats (Schropp *et al*. 1990). Comparison of aluminum and vanadium concentrations in sediments collected from the UCR between the international border and Grand Coulee Dam (Figure 5.1) shows that, of the three candidate reference elements (i.e., aluminum, antimony, and vanadium), aluminum and vanadium concentrations are least affected by the discharges of slag material from the Teck Smelter in Trail, B.C. (i.e., both the concentrations and the variability in surficial sediment concentrations are generally consistent along the UCR). As the concentrations of both aluminum and vanadium are highly correlated along the UCR $r^2 = 0.818$; $p < 0.001$), either metal would suffice for use as a reference element. Due to the ubiquity of aluminum and its use in previous assessments of metal enrichment

(Schropp *et al*. 1990), it was selected to support characterization of the slag content of the sediments in the UCR.

5.2.2 Selection of Indicator Metals for Slag

The results of chemical analyses of slag samples obtained from the Teck lead-zinc smelter show that this material is enriched by several metals, including: cadmium, copper, iron, lead, manganese, and zinc (Nener 1992; Bortleson *et al.* 1994; CEE 2006a; Table 5.1). As such, these metals were identified as potential indicators of slag in the UCR. The ratio of the concentration of each indicator metal to the aluminum concentration was plotted against river mile to evaluate the spatial distribution of the normalized indicator metals in the UCR (Figure 5.2). The spatial distributions of Cu:Al, Fe:Al, and Zn:Al in the UCR from the international border to the Grand Coulee Dam exhibited patterns characteristic of anthropogenic metal enrichment downstream of the Teck Smelter, which then dissipated further downstream. In addition, reaches of the UCR where metals enrichment from slag was expected exhibited higher indicator metal to reference metal ratios than did reference sediments. Based on the results of the spatial distribution analysis, copper, iron and zinc were considered to provide the best indicators of slag presence in UCR sediments.

5.2.3 Development of Slag Identification Models

To support evaluations of the potential influence of slag on sediment toxicity, sediment samples from the UCR were classified into three functional working groups (i.e., classes) using data on the concentrations of slag-indicator metals. More specifically, ratios of slag-indicator metals to reference element concentrations were used to classify sediment samples relative to slag content in a manner consistent with contaminant fate and transport conditions at the UCR. The slag identification methods provided a basis for grouping sediment samples from the UCR into the following classes:

- **Slag-dominated sediment samples (i.e., slag-affected sediment samples)** - Such sediment samples were identified based on ratios of slag-typical indicator metal concentrations to reference element concentrations that were equal to or greater than the expected ratio for sediments containing about 5% slag (by weight) from the Teck facility (as characterized by Nener 1992). While other hazardous substances may be present in such samples, their chemical composition is likely to be dominated by the presence of visually recognizable, sand-sized slag particles;
- **Slag-influenced sediment samples (i.e., potentially slag-affected sediment samples) -** Such sediment samples were identified based on ratios of slag-typical indicator metal concentrations to reference element concentrations that were higher than those expected for reference sediment samples, but less than those expected for slag-dominated sediment samples. Such samples are likely to be impacted by slag to a lesser extent than the slag-dominated sediment samples, with contributions of slag-typical metals potentially originating from discharges and/or weathering of slag and from releases of historic smelter effluent waste. Other hazardous substances may also be present in slag-influenced sediment samples; and,
- **Typical sediment samples (i.e., non slag-affected sediment samples) -** Such sediment samples were identified based on ratios of slag-typical indicator metal concentrations to reference element concentrations that were similar to those for reference sediment samples. Such samples may have been impacted by releases of historic smelter effluent wastes and/or other hazardous substances. However, the influence of slag on the chemical composition of such sediments is likely to be minimal, compared to the other two groups of sediment samples.

Three models for classifying the influence of slag on the chemical composition of sediment samples in the UCR were created by normalizing copper, iron, and zinc concentrations to the concentrations of the selected reference element (i.e., aluminum). The expected indicator metal to reference element ratio for sediments containing approximately 5% slag was calculated using the mean metal concentration calculated for three samples of pure slag from Teck operations during the 1990s (Nener 1992; Table 5.1; Note: slag composition varied by process and over time at the Trail facility. These three slag samples provide an approximation of indicator metal concentrations present in the slag that is distributed within the UCR. Physical weathering and geochemical processes also affect slag composition throughout the UCR) and the maximum concentration of the reference element observed in six reference sediments (i.e., collected during the Phase 1 sediment sampling program in 2005), using the following equation:

$$\frac{\text{Ind. Metals}}{\text{Ref. Metals}}@5\%\,\text{Slag} = \frac{0.05(\text{Mean Ind. Metal in Slag}) + 0.95(\text{Mean Ind. Metal in Reference Sediments})}{0.05(\text{Mean Ref. Metal in Slag}) + 0.95(\text{Mean Ref. Metal in Reference Sediments})}$$

The metal:reference element ratio calculated for sediment with an estimated 5% slag [based on the Nener (1992) results] was applied as a working indicator of readily-evident influences from slag in a given sediment sample.

The first model was based on the ratios of copper to aluminum concentrations in surficial sediments of the UCR (the Cu:Al model; Figure 5.3). Copper to aluminum ratios in reference sediments ranged from 0.872×10^{-3} to 2.42×10^{-3}. Sediments collected in the UCR with Cu:Al ratios within this range were classified as non slag-affected samples. The expected ratio of copper to aluminum in sediments with approximately 5% slag was 19.2×10^{-3}; sediments with Cu:Al ratios below this value, but higher than the maximum Cu:Al ratio in reference sediments were classified as potentially slag-affected samples (i.e., slag-influenced sediment samples). The remaining sediments (i.e., sediments with Cu:Al ratios $\geq 19.2 \times 10^{-3}$) were classified as slag-affected samples (i.e., slag-dominated sediment samples).

The second model utilized information on both Cu:Al ratios and Zn:Cd ratios (i.e., the Cu:Al and Zn:Cd model). As zinc and cadmium have similar ionic structures, Zn:Cd ratios are fairly consistent in uncontaminated sediments (i.e., averaging about 200).

However, the Zn:Cd ratio is altered (i.e., increased) as a result of the smelting and fuming processes during ore smelting. The ratios of copper to aluminum were plotted against the ratios of zinc to cadmium in order to characterize the inferred slag content of the sediments in the UCR (Figure 5.4). Sediments were classified as non slag-affected samples if they had Cu:Al and Zn:Cd ratios consistent with those observed in reference samples (i.e., with Cu:Al ratios between 0.872 x 10^{-3} and 2.42 x 10^{-3} and Zn:Cd ratios between 37.7 and 194). Sediments that fell outside of these reference bounds, but exhibited Cu:Al ratios less than the expected ratio in sediments comprised of approximately 5% slag (i.e., 19.7x 10^{-3}) and Zn:Cd ratios less than the expected ratio in sediments comprised of approximately 5% slag (i.e., 741) were classified as potentially slag-affected samples (i.e., slag-influenced sediment samples). Sediment samples that showed both elevated Cu:Al ratios and Zn:Cd ratios (i.e., those above 19.7x 10^{-3} for Cu:Al and 741 for Zn:Cd) were classified as slag-affected samples (i.e., slag-dominated sediment samples).

In the third approach, the ratio of Fe:Al in surficial sediments was plotted against the ratio of Zn:Cd (the Fe:Al and Zn:Cd model; Figure 5.5). This procedure was developed because iron is added to the smelting process as a flux agent and, as such, iron enrichment is observed in slag and expected to be a characteristic of sediments affected by slag in the UCR. Using this model, sediments were classified as non slag-affected samples if the chemical characteristics were consistent with those observed in reference areas (i.e., with Fe:Al ratios between 1.20 and 2.09 and Zn:Cd ratios between 37.7 and 194). Sediments that fell outside of these reference bounds, but exhibited Fe:Al ratios less than the expected ratio in sediments comprised of approximately 5% slag (i.e., 3.09) and Zn:Cd ratios less than the expected ratio in sediments comprised of approximately 5% slag (i.e., 741) were classified as potentially slag-affected samples (i.e., slag-influenced sediment samples). Sediments with samples that showed both elevated Fe:Al ratios and Zn:Cd ratios (i.e., those above 3.09 for Fe:Al, and 741 for Zn:Cd) were classified as slag-affected samples (i.e., slag-dominated sediment samples).

The results of the classification of the 56 sediment samples using the three reference metal-normalization procedures are presented in Table 5.2.

5.2.4 Model Evaluation

The three indicator metal:reference element normalization procedures used in the analysis were compared to identify the most robust method for characterizing sediments relative to slag content within the UCR. The factors that were considered for selecting a model for classifying UCR sediments included:

- Separation of UCR sediment samples from those observed in reference sediments;
- Consistency between the observed spatial distribution of classified samples and the expected spatial distribution of slag-affected sediments in the UCR;
- Minimization of the number of samples that were classified as potentially slag-affected (i.e., uncertain samples); and,
- Consistency of classification of sediments among the different methods, with those presented in previous studies, and/or with visual observations of slag in sediments from the UCR.

Slag from the Teck facility in Trail, B.C. is known to contain elevated levels of various metals and trace elements. As such, slag has been released to the UCR and has been distributed throughout the study area. A reliable slag characterization procedure should provide a basis for separating samples of sediment from the UCR from those observed in reference sediments. The results of this evaluation indicate that all three models provided a reliable basis for separating sediment samples from the UCR from those that were collected in reference areas (Figure 5.2).

Most of the slag in the UCR was released via direct discharges from the Teck facility. This material was transported downstream during periods of high flow, either as suspended sediment or bedload. Accordingly, it is anticipated that the slag would be distributed within the UCR, with greater deposition of coarse-grained slag (i.e., fine to coarse sand) near the source. Hence, most of the slag-affected sediment samples would be expected to occur in the upstream reaches of the study area. The results of this evaluation indicate that the spatial distributions of sediment samples classified as slag-affected were similar for the three models, with slag-affected sediment samples primarily identified upstream of River Mile 723 (Figures 5.6 to 5.8). This result suggests that all three methods provide a reliable basis for identifying the presence of coarse slag in sediment samples from the UCR. The spatial distribution of the non slag-affected and potentially slag-affected sediment samples for the Cu:Al model was consistent with the expected distribution of coarse-grained slag in the UCR (i.e., a gradient of slag content in the near-shore sediments from upstream to downstream was observed; Figure 5.6). A similar gradient was not observed using the Cu:Al and Zn:Cd model (Figure 5.7) nor Fe:Al and Zn:Cd (Figure 5.8) model. More specifically, potentially slag-affected samples were identified as far downstream as River Mile 603 using these latter two models. These results suggest that the other two models may provide a more effective basis of identifying sediment samples that have been affected by fine-grained slag (i.e., smaller particles that have been transported into and throughout the reservoir.

Another desirable characteristic of a slag-identification tool is minimization of the number of sediment samples with uncertain classifications (i.e., potentially slag-affected sediment samples). The results of this evaluation indicated that the Cu:Al ratio model provided a basis for classifying most of the sediment samples from the UCR as slag-affected samples or non slag-affected samples [i.e., only 12 of 80 sediment samples (15%) were classified as potentially slag-affected using this model]. By comparison, 48 to 50% of the sediment samples from the UCR were classified into the potentially slag-affected category using the other two methods.

Consistency among the three methods that were developed for classifying UCR sediment samples relative slag content was evaluated to determine if one or more of the methods were providing unique information. The results of this evaluation indicated that all three models consistently identified the same sediment samples as being affected by slag. However, classification similarity was low between the Cu:Al model and the other two models for potentially slag-affected and non slag-affected sediment samples. More specifically, classification similarity was low between the Cu:Al and the Cu:Al and Zn:Cd models for potentially slag-affected (28.6%) and non slag-affected (26.1%) sediment samples (Table 5.3). Similarly, classification similarity was low between the Cu:Al and the Fe:Al and Zn:Cd models for potentially slag-affected (20%) and non slag-affected (16%) sediment samples (Table 5.3). While the classifications of sediments based on the Cu:Al and Zn:Cd model and the Fe:Al and Zn:Cd model were generally consistent for potentially slag-affected sediments (86.7%), they were less consistent for non slag-affected sediments (50%; Table 5.3). Furthermore, overall classification similarity between the Cu:Al model and the other models was generally low (Cu:Al and Zn:Cd - 60%; Fe:Al and Zn:Cd - 52%) relative to the classification similarity between the Cu:Al and Zn:Cd and the Fe:Al and Zn:Cd models (92%).

A variety of other techniques have been used to identify the presence of metallurgical slag in UCR sediment samples. While insufficient information is available for most of the data considered in this evaluation to apply these alternate techniques, the slag designations established in this study were compared to those identified by Bortleson *et al.* (1994). More specifically Bortleson *et al.* (1994), collected four sediment samples to determine the percentage of slag by particle count. Sediments collected at River Mile 745, River Mile 738, River Mile 730, and a reference site at River Mile 648 contained 48%, 28%, 5% and 0% slag by particle count, respectively. These results are consistent with predictions made using the Cu:Al ratio model.

As a final step in the model evaluation process, sample classifications undertaken using the Cu:Al model were compared to unaided visual observations by USEPA field personnel of the slag content of UCR sediments collected in 2005 (Table 5.4). While the readily-visible slag content in samples was estimated for only 25 of the 56 sediment samples, these visual observations were generally consistent with the slag classification determined using the Cu:Al model. More specifically, none of the six samples that were classified as non slag-affected had significant quantities of slag, based on the visual observations (100% correct classification). In addition, all of the samples classified as slag-affected (n = 16) had an estimated slag content of at least 5% based on visual observations (100% correct classification). Two of the three samples classified as potentially slag-affected had >5% slag, as approximated by visual observation. Therefore, the overall correct classification rate for the Cu:Al model was 92%, when evaluated against visual observations of slag content of sediment samples from the UCR (Table 5.5).

Based on the results of these evaluations of the reliability of the three slag classification systems, the Cu:Al model was selected to support analyses of the chemistry and toxicity data for the UCR. More specifically, the Cu:Al model appeared to provide the most reliable method for identifying sediment samples from the UCR affected by the presence of coarse-grained slag. However, the results of other studies indicate that slag undergoes various physical and chemical degradation process that result in the production of clay- to silt-sized particles (Nelson 2011). Such finer-grained materials can be transported substantial distances downstream from the release site or from secondary sources (i.e., depositional areas for coarse-grained sediments). Photomicrographic analysis of sediments has confirmed the presence of clay- to silt-sized slag grains at least as far downstream as Reach 4 (Cox *et al.* 2005). Other studies have shown that water velocities in Lake Roosevelt are sufficient to distribute fine-grained sediments all the way to Grand Coulee Dam (Bierman 2010; NHC 2011).

5.3 Summary and Conclusions

Characterization of slag content of sediments is an important step in the evaluation of sediment chemistry and toxicity within the UCR study area. Slag contains elevated levels of metals, which may be differentially available compared to typical riverine sediments or sediments impacted by effluent wastes within the UCR. Hence, slag content is expected to represent an important factor in the reference-based evaluation and interpretation of sediment chemistry and toxicity data.

In this study, three models for characterizing the slag content of sediments in the UCR were developed and evaluated. The Cu:Al model was based on the ratio of copper to aluminum concentrations in surficial sediments of the UCR (Figure 5.3). The Cu:Al and Zn:Cd model combined the ratio of zinc to cadmium in surficial sediments with the Cu:Al model (Figure 5.4). The Fe:Al and Zn:Cd model was based on the ratio of iron to aluminum and the ratio of zinc to cadmium in surficial sediments (Figure 5.5). The three slag characterization models were evaluated to determine their applicability for characterizing sediment samples from the UCR.

Of the three models, only the Cu:Al ratio model met all four of the selection criteria established for model evaluation. In addition, classifications of sediment samples relative to slag content using this model generally agreed with visual observations. Therefore, the Cu:Al ratio model was used to classify sediment samples from the UCR into three categories including:

- Slag-dominated sediment samples (which are also referred to as slag-affected sediment samples);
- Slag-influenced sediment samples (which are also referred to as potentially slag-affected sediment samples); and,
- Typical sediment samples (which are also referred to as non slag-affected sediment samples).

It is important to note, however, the Cu:Al ratio model is likely to be most applicable for identifying sediment samples that are contaminated by relatively unweathered slag within the fine- to coarse-sand particle size. The other two models that were developed may be more relevant for identifying sediment samples that are contaminated by sand-sized slag particles and/or finer slag particles produced during the slag-weathering process. This is important because finer-grained materials may be transported to areas located substantial distances downstream of the source. Hence, all three methods, as well as other techniques, may be relevant for classifying sediment samples from the UCR relative to slag content.

Chapter 6 Evaluation of Relationships Between Sediment Chemistry and Sediment Toxicity in the Upper Columbia River

6.0 Introduction

To date, evaluations of sediment quality conditions in the UCR have been conducted primarily using sediment chemistry and/or sediment toxicity data. While sediment toxicity data can be used directly to evaluate risks to benthic invertebrates associated with exposure to contaminated sediments, sediment chemistry data are frequently interpreted using sediment quality guidelines (SQGs) that were derived to support regional or national assessments. However, the results of studies conducted at other sites (e.g., Indiana Harbor, IN; Calcasieu Estuary, LA) indicate that generic SQGs can overestimate or underestimate sediment toxicity (MacDonald *et al.* 2002; 2003). Hence, the calibration of such SQGs has been identified as one of the key steps in the sediment quality assessment process (Ingersoll *et al.* 2005; Douglas *et al.* 2005; Word *et al.* 2005).

This investigation was conducted to evaluate and interpret the sediment toxicity and sediment chemistry data that were collected during the Phase 1 Sediment Sampling Program of the UCR and comparable data available from other investigations conducted in the study area. A step-wise process was used to evaluate and compile synoptically-collected chemistry and toxicity data, to develop site-specific thresholds for predicting toxicity (TPSTs), and to evaluate the reliability and predictive ability of the TPSTs. This process consisted of 12 main steps, including:

- Acquire and evaluate potentially-relevant data sets (see Section 6.1);
- Compile sediment chemistry and sediment toxicity data in a geographic information system (GIS)-compatible relational database (see Section 6.2);

- Evaluate various approaches for designating sediment samples as toxic or not toxic to benthic invertebrates (see Section 6.3);
- Establish and apply criteria for identifying reference sediment samples within the study area (procedures for estimating the slag content of sediment samples from the UCR are discussed in Chapter 5);
- Develop a reference envelope for each toxicity test endpoint (see Section 6.5);
- Normalize toxicity test response data (see Section 6.6);
- Designate each sediment sample as toxic or not toxic for each toxicity test endpoint, for each toxicity test, and for all toxicity tests combined (see Section 6.7);
- Evaluate the nature and extent of sediment toxicity (see Section 6.8);
- Develop and refine preliminary CRMs for selected COPCs, COPC mixtures, and slag indicators (see Section 7.1);
- Derive TPSTs for each of the selected COPCs, COPC mixtures, and slag indicators (see Section 7.2);
- Evaluate the reliability and predictive ability of the TPSTs for selected COPCs, COPC mixtures, and slag indicators (see Section 7.3); and,
- Identify TPSTs that can be used to accurately classify sediment samples from the UCR as toxic and not toxic (see Section 8.0).

This chapter describes the methods that were used to acquire, evaluate, and compile data, develop reference envelopes, and designate sediment samples as toxic or not toxic. The CRMs that were developed using the sediment chemistry and sediment toxicity data from the study area are presented and discussed in Chapter 7. The other steps undertaken to support the development and evaluation of TPSTs for site-related COPCs are discussed in Chapter 7. Recommended procedures for classifying sediment samples as toxic and not toxic are present in Chapter 8.

6.1 Acquisition and Evaluation of Candidate Data Sets

A substantial number of studies have been conducted to evaluate sediment quality conditions in the UCR basin. To ensure that the most relevant data sets were compiled into the project database, selection criteria were formulated to support systematic evaluation of the candidate data sets, which included:

- Sediment chemistry and sediment toxicity data were collected within the study area;
- Sediment chemistry data were generated using standard methods and adequate quality assurance information was available to support evaluations of data quality;
- Sediment chemistry data included measurements of the concentrations of relevant COPCs (i.e., metals and other substances that may have been released into aquatic habitats within the study area);
- Sediment toxicity data were generated using standard methods; and,
- Adequate quality assurance information was available to support evaluations of data quality.

Appendix 3 provides more detailed information on the criteria that were used to evaluate candidate data sets. Appendix 3 also summarizes the performance criteria for measurement data that were referenced during evaluations of candidate data sets.

A total of 19 candidate data sets were evaluated to identify relevant data for developing CRMs for the UCR (See Appendix 2; Table A2.1). Of these, three data sets met these evaluation criteria and were compiled in the project database (Table A2.1). These data sets that were selected to support development of site-specific CRMs (i.e., because they included acceptable sediment chemistry and sediment toxicity data from the UCR), included:

- Schut and Stefanoff (2007); Stefanoff *et al.* (2006); CH2M Hill (2012; n = 56);
- Bortleson *et al.* (1994; n = 16); and,
- Besser *et al.* (2008; n = 8).

While all three of these data sets met the selection criteria, certain limitations were identified that could influence the development and/or interpretation of CRMs for COPCs in the UCR. Limitations or uncertainties related to each of the three data sets considered in this evaluation are described below.

***Uncertainties Associated with the USEPA Data Set* - ** The sediment chemistry and toxicity data collected by USEPA in 2005 represent the largest data set of its kind for the UCR. Data are available on numerous chemical analytes and three standardized toxicity tests for a total of 56 sediment samples. While the resultant data are generally of acceptable quality, a number of uncertainties with these data were identified. First, the documentation available for the sediment samples that were collected by USEPA in 2005 does not clearly indicate that the chemistry and toxicity data were matching. Rather, the documentation indicates that "bioassay samples were co-located with a corresponding transect sample to allow for direct comparison of bioassay testing results with the corresponding sediment chemical quality information" (CEE 2006b). While follow-up discussions with the USEPA sampling team indicate that field-collected sediment samples were homogenized and split to facilitate chemical analysis and toxicity tests, the limitations of the field documentation add some uncertainty to the precise interpretation of these data.

Second, the pore-water samples collected by USEPA in 2005 were not intended to be collected in a manner that fully matched the sediment samples collected for chemical analysis and toxicity testing. Rather, "a separate sediment sample was collected at each of the bioassay sampling stations, and used to prepare a pore-water sample (via centrifugation) that could be used to compare to the solid-phase sediment quality results and associated bioassay results" (CEE 2006b). Centrifugate was subsequently filtered (0.45 µm) to obtain the pore-water samples for chemical characterization. Because the sediment samples used to isolate pore water were not splits of the sediment samples used for chemical analysis and toxicity testing, there is uncertainty in the interpretation of the resultant data due to the potential for small-scale spatial variability in sediment chemistry, dissolved organic carbon, and other variables that could influence porewater chemistry and interpretation of pore-water chemistry data (Brumbaugh *et al.* 1994).

The use of centrifugation to obtain pore-water samples for metals analysis adds uncertainty to data interpretation. The results of laboratory studies conducted to compare various pore-water collection methods have shown that centrifugation may yield higher and more variable concentrations of certain metals (e.g., Cu, Zn) and organic carbon (Carignan *et al.* 1985; Mason *et al.* 1998; Angelidis 1997). Such variability tends to confound interpretation of pore-water chemistry data relative to the results of sediment toxicity tests. Such uncertainties can be reduced by collecting pore-water samples using peepers that have been deployed in chemistry-only toxicity test replicates.

Third, the sediment toxicity data collected by USEPA in 2005 may also have other limitations that complicate their interpretation. More specifically, it appears that the overlying water used in, at least, some of these laboratory toxicity tests may have been only marginally suitable for the species used in the tests. In addition, the low level of organic carbon present in many of the sediment samples may have created nutritional challenges for one or more of the species tested. Furthermore, the adequacy of the control sediment to support the survival, growth, and reproduction of toxicity test organisms is uncertain. Such limitations can complicate interpretation of the toxicity test results. That is, relationships between sediment chemistry and sediment toxicity tend to be obscured when there are limitations to the sediment chemistry and/or toxicity data, making it more difficult to identify reliable TPSTs.

Uncertainties Associated with the Bortelson et al. (1994) Data Set - Bortleson *et al.* (1994) conducted an evaluation of sediment-quality conditions in Roosevelt Lake and the Columbia River in 1992. Sediment samples were collected at a total of 22 locations with the Columbia River Basin, with six of these stations located outside the UCR. Bed-sediment samples were collected with a van Veen sampler from three to five nearby locations, homogenized, sieved to <2.00 mm, and split to support chemical analysis and toxicity testing. Each of these samples was analyzed for metals, PAHs, phthalates, chlorinated phenols, resin and fatty acids, extractable organic halides, TOC, and particle size. In addition, three toxicity tests were conducted using sediment and/or porewater from the UCR, including a 7-d whole-sediment toxicity test with the amphipod, *Hyalella azteca* (Endpoint - survival), a 7-d whole sediment toxicity test with the cladoceran, *Ceriodaphnia dubia* (Endpoints - survival and reproduction), and a short-term whole sediment and pore-water toxicity test with the bacterium, *Photobacterium phosphoreum* (Endpoint - light emission).

Bortleson *et al.* (1994) is a well-designed and implemented study that provides useable data for evaluating relationships between toxicity and chemistry in UCR sediments. The sediment-chemistry data were shown to be reliable, as indicated by the evaluations of analytical accuracy and precision. In addition, the detection limits achieved were appropriate for most of the variables measured. However, pore-water chemistry data were not collected, which precludes comparison of the toxicity results to pore-water chemistry. In addition, the application of 7-d exposures with amphipods (as opposed to 28-d to 42-d exposures) limits the evaluation of sediment toxicity due to the shorter duration of the exposures. Finally, interpretation of the toxicity data would have been enhanced by inclusion of reference sediment samples in the study design, but, given the scope of the study, use of controls for interpreting toxicity test results is appropriate.

Uncertainties Associated with the Besser et al. (2008) Data Set - Besser *et al.* (2008) conducted an evaluation of sediment-quality conditions in Roosevelt Lake and the Columbia River in 2004. In this study, sediment samples were collected at eight locations in the UCR using box-coring methods. At each location, several sediment cores were collected, homogenized, and split for chemical analysis and toxicity testing. The analytes measured in whole sediment included total recoverable metals, SEM, AVS, TOC, and particle size distribution. Pore-water analytes included conventional variables, sulfides, dissolved organic carbon, metals, iron, and manganese. Toxicity tests included a 28-d whole-sediment toxicity test with the amphipod *H. azteca* (Endpoints - survival, growth, and biomass) and a 12-d whole-sediment toxicity test with the midge, *Chironomus dilutus* (Endpoints - survival, growth, and biomass). Twenty-eight day whole-sediment bioaccumulation tests were also conducted with the oligochate, *Lumbriculus variegatus*.

Besser *et al.* (2008) is a well-designed and implemented study that provides useable data for evaluating relationships between toxicity and chemistry in UCR sediments. The sediment-chemistry data were shown to be reliable, as indicated by the evaluations of analytical accuracy and precision (which were not presented in the publication, but are available from the authors). In addition, the detection limits achieved were appropriate for the variables measured. However, the absence of data on the levels of other COPCs, such as PAHs and PCBs, limits evaluation of exposure of benthic invertebrates to these COPCs. In addition, interpretation of the toxicity data would have been enhanced by inclusion of reference sediment samples in the study design but, given the scope of the study, use of controls for interpreting the toxicity test results is appropriate.

6.2 Compilation of Sediment Chemistry and Sediment Toxicity Data

To support the compilation and subsequent analysis of the information on environmental quality conditions in the UCR, a GIS-compatible, relational project database was developed in MS Access format. All of the data compiled in the database were georeferenced to facilitate mapping and spatial analysis using GIS-based applications [i.e., Environmental Systems Research Institute ArcMap and Spatial Analyst programs]. The database structure made it possible to retrieve data in several ways, including by data type (i.e., chemistry vs. toxicity), by analyte (e.g., copper), by toxicity test endpoint (e.g., amphipod growth), by geographic area, and by date. As such, the database facilitated a variety of data analyses to support interpretation of the underlying data. The studies that met the selection criteria and were compiled in the project database in MS Access format are listed in Appendix 2.

All of the data sets that were retrieved during the course of the study were critically reviewed to determine their applicability for assessing environmental quality conditions in the study area. The selection criteria that were used to evaluate each of the candidate data sets are listed in Section 6.1 of this report. The data sets that contained information on the study area and met the selection criteria were incorporated into the project database. Following translation into database format, the data were verified to assure the quality of the data used in the assessment. This auditing process involved analyses of outliers (i.e., to identify inconsistencies with units) and completeness (i.e., to identify missing samples or missing data), examination of data qualifier fields (i.e., to assure internal consistency in the project database), and, checking of sample identification numbers (i.e., to ensure that data were not duplicated or missing). Finally, the data were verified against the original data source. Appendix 4 provides further details on the data treatment and evaluation methods employed to ensure quality data were used in the analyses. The results of the data evaluation and data auditing indicated that the compiled information represents a reliable basis for developing CRMs for the UCR.

In a number of studies, additional samples were collected and/or analyzed as part of the quality assurance program. In this investigation, field replicate samples were treated as unique samples in the data analyses (i.e., by providing information on the small-scale spatial variability in sediment quality conditions). By comparison, laboratory split samples were treated as duplicates and averaged to support subsequent data analysis.

To support subsequent interpretation of the sediment chemistry data, the total concentrations of several chemical classes were determined for each sediment sample. Specifically, the concentrations of total PAHs were calculated by summing the concentrations of up to 13 individual PAHs, including acenaphthene, acenaphthylene, anthracene, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, benz(a)anthracene, dibenz(a,h)anthracene, benzo(a)pyrene, chrysene, fluoranthene, and pyrene. For PCBs, the concentrations of total PCBs were determined using various procedures, depending on how the data were reported in the original study. If only the concentrations of total PCBs was reported in the study, then those values were used directly. If the concentrations of various Aroclors (e.g., Aroclor 1242, Aroclor 1248) were reported, then the concentrations of the various Aroclors were summed to determine the concentration of total PCBs. In some cases, the concentrations of total PCBs may have been estimated by summing the concentrations of measured congeners and multiplying by 2.01 (Lauenstein and Cantillo 1993). This procedure has been shown to provide a reasonable basis for estimating the sum of 209 PCB congeners when only a limited number of congeners was measured. For DDTs, the concentrations of p,p’-DDD and o,p’-DDD, p,p’-DDE and o,p’-DDE, and p,p’-DDT and o,p’-DDT were summed to calculate the concentrations of sum DDD, sum DDE, and, sum DDT, respectively. Total DDTs was calculated by summing the concentrations of sum DDD, sum DDE, and, sum DDT. Finally, the concentrations of total chlordane were determined by summing the concentrations of alpha- and gamma-chlordane isomers. If only the concentrations of total chlordane were reported in the study, then those values were used directly.

In calculating the total concentrations of the various chemical classes, less than detection limit values were assigned a value of one-half of the detection limit.

A variety of procedures have been used to collect, and prepare for chemical analysis, the sediment samples represented in the project database. In some cases, whole-sediment samples were collected and submitted for chemical analysis. In other cases, the sediment samples were sieved to < 75 µm and/or > 75 µm to support the generation of sediment chemistry data. For the purposes of the current data analysis, only the whole-sediment chemistry data were considered.

6.3 Evaluation of Approaches to Assessing Sediment Toxicity

At the UCR, a number of whole-sediment toxicity tests have been conducted to evaluate the effects on benthic invertebrates associated with exposure to contaminated sediments. More specifically, 10- to 12-d whole-sediment toxicity tests with the midge, *Chironomus dilutus*, and 28-d whole-sediment toxicity tests with the amphipod, *Hyalella azteca*, have been conducted on over 60 sediment samples from the study area (Endpoints: survival, growth, and biomass for both tests). Information on the survival and reproduction of cladocerans (*Ceriodaphnia dubia*) exposed to UCR sediments during 7-d toxicity tests was also generated to support assessments of sediment toxicity. Interpretation of the results of these toxicity tests requires a procedure for designating the sediment samples as toxic or not toxic, based on the responses observed for exposed benthic invertebrates.

A number of approaches can be used to interpret the results of whole-sediment toxicity tests with benthic invertebrates. These approaches can be classified into four general categories, including control comparison approach, minimum significant difference (MSD) approach, reference envelope approach, and the multiple category approach. Each of these approaches are briefly described below:

- ***Control Comparison Approach*** - Application of the control comparison approach involves statistical comparison of the responses of test organisms exposed to site sediments to the responses of test organisms exposed to control sediments. Treatments that have responses that are statistically significantly different from those observed in the control treatment(s) are designated as toxic.

- ***Minimum Significant Difference (MSD) Approach*** - Application of the MSD approach is dependent on the completion of power analyses with data from multiple studies for a specific toxicity test. These results are used to identify the MSD (or minimum detectable difference) from the control treatment. Treatments with response levels greater than the MSD are designated as toxic (Thursby *et al.* 1997; Phillips *et al.* 2001). Determination of MSDs requires a substantial quantity of data for each test endpoint under consideration. As such data have not been assembled for this purpose, MSDs are not available for the toxicity test endpoints under consideration in the UCR.

- ***Reference Envelope Approach*** - The reference-envelope approach is a procedure for assessing sediment toxicity that was developed to overcome the limitations associated with the use of control sediments for this purpose, including accounting for differences in the non-contaminant characteristics of test sediments and for overcoming the low statistical power associated with comparing many test results to a single control. Application of the reference envelope approach involves collection and testing of sediment samples from a number of reference sites within or nearby the study area. In this context, a reference sediment sample is considered to be whole-sediment obtained near an area of concern used to assess sediment conditions exclusive of the materials of interest (i.e., COPCs; ASTM 2011a). The results of the toxicity tests conducted on these samples can be used to develop a reference envelope (i.e., normal range of responses of test organisms exposed to reference sediments, as defined by ASTM 2011a). Sediment samples with response levels that fall outside the normal range of responses (e.g., survival below the minimum value for the reference samples) are designated as toxic (MacDonald *et al.*. 2002; 2009; 2010). Various levels of toxicity can be assigned to each toxic sediment sample based on the magnitude of response relative tot he lower limit of the reference envelope.

- ***Multiple Category Approach*** - Application of the multiple category approach involves classifying sediment samples into various groups (e.g., not toxic, low toxicity, moderate toxicity, or high toxicity), based on the magnitude of the observed response. The results of statistical comparisons to the negative control results can also be used to classify sediment samples into the various categories.

All four of these approaches have certain advantages and limitations that influence their application in assessments of sediment quality conditions (See Table 6.1 for a summary of the advantages and limitations of each approach). In addition, application of one or more of these approaches may be limited by the design of the study. In this investigation, the results of sediment toxicity tests were preferentially evaluated using the reference envelope approach. The control comparison approach was applied when insufficient numbers of reference samples were available to utilize the reference envelope approach. In addition, a multiple category approach was used to provide additional information based on the magnitude of toxicity (MOT) for each sediment sample. This flexible framework for evaluating sediment toxicity was considered to provide a robust basis for interpreting the available toxicity data.

6.4 Identification of Reference Sediment Samples

Application of the reference-envelope approach necessitates identification of reference sediment samples for each toxicity test endpoint that was evaluated. In this study, sediment samples collected at both internal (i.e., within the UCR mainstem) and external (outside the UCR mainstem) locations were considered to be candidate reference sediment samples. Candidate reference sediment samples were evaluated using both chemical and biological criteria. As a first step, sediment samples with chemical characteristics representative of reference conditions were identified (i.e., substantially free of contamination). Reference sediment samples were identified using the following criteria relative to sediment chemistry (USEPA 2005; MacDonald *et al.* 2007):

- Mean PEC-Qs for metals at 1% organic carbon [$PEC\text{-}Q_{METALS(1\%OC)}$] was < 0.1 (Ingersoll *et al.* 2009);
- ($\sum$SEM-AVS)/f_{OC} <130 µmol/g (USEPA 2005);
- Sum equilibrium partitioning sediment benchmarks-toxic units (final chronic value; $\sum ESB\text{-}TU_{FCV}$) for PAHs< 0.1 (USEPA 2003b);
- Mean PEC-Q was < 0.1 (MacDonald *et al.* 2000);
- Concentrations of individual PAHs were below threshold effect concentration (TEC) values (MacDonald *et al.* 2000);
- Concentrations of total PCBs were below TEC values (MacDonald *et al.* 2000); and,
- Concentrations of organochlorine pesticides were below TEC values (MacDonald *et al.* 2000).

Reference sediment samples that met these chemical criteria were further evaluated to confirm that they did not contain elevated levels of unmeasured or unevaluated chemicals. More specifically, sediment samples for which toxicity test response rates were consistent with the acceptability criteria for negative control samples (ATSM 2010) were considered to be substantially unaffected by unmeasured or unevaluated chemicals. The biological criteria were applied to ensure that samples that were adversely affected due to the presence of unmeasured COPCs were not used in the reference envelope calculation. The following biological criteria were used in these evaluations:

- *Hyalella azteca* (28-d): Survival $\geq$80%;
- *Chironomus dilutus* (10-d): Survival $\geq$70%, Minimum weight of 0.48 mg; and,
- *Ceriodaphnia dubia* (7-d): Survival $\geq$80%, Average brood size $\geq$1.

Sediment samples that met both the chemical and biological criteria were included in the reference pool (Table 6.2). The reference stations were selected independently for each of the laboratory toxicity tests. If the ASTM (2011b) test acceptability criteria were not met for all of the endpoints for a species, the toxicity test results for that sediment sample were not considered in the calculation of the reference envelope for any of the endpoints for that species.

In total, nine stations from Bortleson *et al.* (1994), Schut and Stefanoff (2007), and Stefanoff *et al.* (2006), were chosen for developing the reference envelopes for the toxicity test endpoints for the cladocerans, *C. dubia* (Table 6.2). By comparison, seven stations from Besser *et al.* (2008), Schut and Stefanoff (2007), and Stefanoff *et al.* (2006) and were chosen for developing the reference envelopes for the midge, *C. dilutus*. Finally, eight stations from Besser *et al.* (2008), Schut and Stefanoff (2007), and Stefanoff *et al.* (2006) were chosen for developing the reference envelopes for the amphipods, *H. azteca* (Table 6.2).

6.5 Normalization of the Toxicity Test Response Data

Sediment chemistry and sediment toxicity data from three studies were evaluated to support the development of CRMs for selected COPCs, COPC mixtures, and slag indicators. Because these data were generated by different laboratories, and/or in different batches of samples, there was a need to normalize the data in a manner that assured that the toxicity test results were comparable. More specifically, normalization of toxicity data is intended to account for variability in the test response data due to organism health, test procedures, test conditions, and the local physical characteristics of the sediments (when using reference normalization). The response data for the control treatments tested in the three studies included in this evaluation are presented in Table 6.3. In this evaluation, the toxicity test response data for each endpoint were normalized to either the average response observed in the control treatment or to the median response rate observed for the reference sediment samples for a given endpoint, using the following procedures (Ingersoll *et al*. 2008; Moran *et al*. 2011):

- *Reference-Normalization Procedure*: If there were at least three reference sediment samples available for a batch of samples tested within a study, the response data for each sediment sample were normalized using the median response value calculated for the reference sediment samples tested within each batch (i.e., on an endpoint-by-endpoint basis). The reference-normalized response rate was calculated as follows:

$$\text{Normalized Response} = \frac{\text{Raw Response Value}}{\text{Median Reference Value}} \times 100$$

- *Control-Normalization Procedure*: If there were fewer than three reference sediment samples available for a batch of samples tested within a study, the response data for each sediment sample were normalized using the mean response value calculated for the control sample(s) tested within each batch (i.e., on an endpoint-by-endpoint basis). The control-normalized response rate was calculated as follows:

$$\text{Normalized Response} = \frac{\text{Raw Response Value}}{\text{Mean Control Value}} \times 100$$

The response data reported by Schut and Stefanoff (2007) and Stefanoff *et al.* (2006) were normalized to the median value of the reference stations for each batch of sediment samples that were tested. The median value was used in these calculations to minimize the potential for outliers to unduly influence the normalization procedure. As insufficient data for reference stations were available to support reference normalization, the response data reported in Besser *et al.* (2008) and Bortleson *et al.* (1994) were normalized to the mean control response values reported for the study (i.e., the mean of the responses reported for the various replicates for the control treatment; Table 6.4).

Many investigators have used the control-normalization method described above to support interpretation of sediment toxicity data generated in multiple batches and/or studies (i.e., to account for variability in organism health, test procedures, and/or test conditions). More recently, the reference-normalization procedure has been developed and used to account for all of the variables addressed by the control-normalization method and to better account for variability in the organism's response associated with differences in the physical characteristics of the sediments throughout the study area (Moran *et al.* 2011).

A summary of the physical characteristics (i.e., grain size and TOC) of sediment samples from the UCR and from selected reference locations is presented in Table 6.5. These data emphasize the importance of accounting for TOC and grain size within the study area as a whole (Figures 6.1 to 6.3) and within each of the reaches identified (Table 6.5).

In the data collected in 2005 by USEPA 2005, the concentration of TOC (measured as % TOC) in whole-sediments of the UCR differed between the reference stations and test stations. As such, the effect of TOC concentration in reference sediments on the survival and biomass of the amphipod, *H. azteca*, and the midge, *C. dilutus,* was evaluated. In addition, the effect of other physical characteristics of the reference sediments (i.e., % <73 µm and % fines) on the toxicity test response data was also evaluated using linear regression analysis (Figures 6.4 to 6.9). The results of these evaluations showed that the only significant linear relationships observed were all negative [i.e., between *H. azteca* growth and <73 µm in sediments ($r^2 = 0.42$, $p = 0.017$), between *H. azteca* growth and % fines in sediments ($r^2 = 0.67$, $p < 0.001$), between *H. azteca* biomass and <73 µm in sediments ($r^2 = 0.43$, $p = 0.015$), and between *H. azteca* biomass and % fines in sediments ($r^2 = 0.68$, $p < 0.001$)]. In summary, these results showed:

- The level of TOC did not substantially influence the responses of test organisms exposed to reference sediments collected within the UCR study area; and,
- Amphipods exposed to finer-grained reference sediments generally had lower biomass than those that were exposed to coarser grained sediments. As reference sediment samples generally had higher levels of fine sediment than did sediments from the UCR mainstem and the response data for test organisms exposed to reference sediments were used to designate sediment samples as toxic or not toxic, it is likely that use of the reference envelopes generated from these data would tend to underestimate sediment toxicity.

Therefore, it was concluded that TOC and grain-size characteristics for reference samples would not influence calculations of reference envelopes for the various endpoints in a way that would over estimate sediment toxicity.

6.6 Development of Reference Envelope

Following the identification of reference sediment samples, the range of the biological responses in these samples was determined for each toxicity test conducted and endpoint measured. In this study, the reference envelope was defined as the range of biological responses that encompassed 100% of the response data for the reference sediment samples. Accordingly, the lower limit of the reference envelope was calculated as the minimum reference-adjusted or control-adjusted response value for each toxicity test and endpoint, using the data for the reference sediment samples that were selected for each toxicity test (Besser *et al*. 2008; Moran *et al*. 2011). For the reference stations that were tested in two or more batches of sediment samples (i.e., CEE 2006a; Schut and Stefanoff 2007; and, Stefanoff *et al.* 2006), the average of the normalized response values was used in the reference envelope calculations.

For each toxicity test endpoint, the reference envelope encompassed all of the reference-adjusted or control-adjusted response data between the minimum value and the maximum value. The reference envelopes for each of the eight toxicity test endpoints are presented in Table 6.6. The sediment chemistry data for the stations that had the minimum value for the reference envelope for each toxicity test endpoint are presented in Table 6.7.

6.7 Designation of Toxicity to Invertebrates

The reference envelope was considered to define the normal range of responses associated with exposure of toxicity test organisms to relatively uncontaminated sediment samples. Sediment samples with effect values lower than the lower limit of the normal range of control-adjusted responses for the reference samples (i.e., lower than the minimum value) were designated as toxic for the endpoint under consideration. The sediment samples in the project database were also designated as toxic or not toxic based on the results of multiple endpoints for each toxicity test (i.e., survival, growth, or biomass of amphipods; survival, growth, or biomass of midges;

or, survival or reproduction of cladocerans). Finally, sediment samples were designated as toxic or not toxic based on the results obtained from any of the eight toxicity test endpoints. The toxicity designations that were assigned to each of the sediment samples that were included in the project database are listed in Table 6.8.

While classification of sediment samples as toxic or not toxic provides important information for assessing sediment quality conditions, additional information on the MOT can contribute to such evaluations. For this reason, toxic sediment samples were further classified. Highly-impacted (HI) sediment samples were identified based on a greater than 10% reduction in survival, growth, biomass, or reproduction relative to the lower limit of the reference envelope (MacDonald *et al*. 2002; 2011; Table 6.9). Moderately-impacted (MI) sediment samples were identified based on survival, growth, biomass, or reproduction that fell less than 10% below the lower limit of the reference envelope. Previous studies have applied this relative toxicity evaluation method and classified the categories as highly toxic (>10% reduction) and moderately toxic ($\leq$10% lower limit of reference envelope; MacDonald *et al.* 2002; 2009; 2010).

Toxicity designations for individual endpoints and multiple endpoints provide essential information for interpreting the available data for the UCR. First, this information provides a basis for evaluating the nature and extent of sediment toxicity within the study area. In addition, this information supports the development of CRMs for individual COPCs, COPC mixtures, and slag indicators in the UCR. Furthermore, this information is required for evaluating the reliability and predictive ability of the various TPST that are derived to supports assessment of sediment chemistry and pore-water chemistry data.

6.8 Preliminary Evaluation of the Nature and Extent of Sediment Toxicity

The toxicity of UCR sediments has been evaluated using the results of three whole-sediment toxicity tests ranging in duration from seven to 28 days. The results of this evaluation indicate that exposure to sediments in the UCR adversely affects the survival, growth, biomass, and/or reproduction of benthic invertebrates. Of the 71 sediment samples from the UCR that were evaluated using the reference envelope approach, a total of 58 (82%) were found to be toxic to amphipods, midges, or cladocerans (i.e., survival, growth, biomass, and/or reproduction was reduced relative to the lower limit of responses for samples from reference areas; Table 6.10; Figure 6.10). By comparison, only one of the reference sediment samples was found to be toxic to freshwater amphipods, midges, and/or cladocerans (Tables 6.8 and 6.10; Figure 6.10). Only one of the within-site sediment samples qualified as a reference sediment sample [RM 706A2(X7)] and was found to be toxic to one or more of the species that were evaluated (Table 6.8). The failure of RM 706A2(X7) is explained by the fact that this station is located within the influence of the reservoir and associated smelter impacts and, as noted in Table 5.4, contained a field estimate of 10 to 20% slag. Collectively, these data confirm that the reference envelope approach provides a reasonable basis for distinguishing between sediment samples collected within the UCR and those collected in reference areas. The incidence of toxicity (IOT) was lower (i.e., 65%; n = 71) when only highly-impacted sediment samples were considered, as classified as toxic based on any endpoint measured (Table 6.11).

The available data provide information on the toxicity of whole-sediment samples from all six reaches of the UCR (Figures 6.11 to 6.17; Table 6.10; See Chapter 3 for a description of the study area). When sediment samples are designated as toxic or not toxic based on any of the eight toxicity test endpoints considered in this evaluation, 17 of the 19 sediment samples (89%) collected in Reach 1 were found to be toxic (i.e., moderately or highly impacted; Figure 6.9). The IOT was similar for Reach 3 (86%; 6 of 7 samples were toxic; Figure 6.14), Reach 4 (86%; 18 of 21 samples were toxic; Figure 6.15), Reach 5 (86%; 6 of 7 samples; Figure 6.16), and Reach 6 (86%; 6 of 7 samples were toxic; Figure 6.17). The lowest IOT was observed in Reach 2, within which 5 of the 12 sediment samples were designated as toxic to benthic invertebrates (42%; Figure 6.13).

Data were compiled on the results of 28-d whole-sediment toxicity tests with amphipods (*H. azteca*; Endpoints: Survival, growth, and biomass) for a total of 64 sediment samples from the UCR or nearby reference areas (Besser *et al.* 2008; Bortleson *et al.* 1994; CEE 2006a, Schut and Stefanoff 2007, and Stefanoff *et al.* 2006). The results of these toxicity tests demonstrated that the survival (53%; 30 of 57 samples), growth (14%; 8 of 57 samples), biomass (28%; 16 of 57 samples), and survival, growth, or biomass (60%; 34 of 57 samples) of amphipods was adversely affected in many of the sediment samples collected within the UCR (Table 6.12). By comparison, none of the samples (0%; 0 of 8 samples) that qualified as reference sediments were considered to be toxic to amphipods when survival, growth, biomass, or survival, growth, or biomass were considered (Table 6.12). When only highly-impacted sediment samples were classified as toxic, the IOT to amphipods was lower for all three endpoints (i.e., 25% overall, when any of the three endpoints was considered; n = 57; Table 6.13; Figure 6.18). These results demonstrate that exposure to sediments from throughout the UCR is likely to adversely affect amphipods, with samples from Reach 1 exhibiting the highest frequency of toxicity (60%; 9 of 15 samples were classified as moderately or highly impacted; Table 6.12; Figures 6.19 to 6.22).

To evaluate toxicity to midges (*C. dilutus*), data from 10-d whole-sediment toxicity tests (Endpoints: Survival, growth, and biomass) were collected for a total of 64 sediment samples that were obtained from the UCR or nearby reference areas (Besser *et al.* 2008; Bortleson *et al.* 1994; CEE 2006a; Schut and Stefanoff 2007; and, Stefanoff *et al.* 2006). The results of these toxicity tests demonstrated that many of the sediment samples collected within the UCR were toxic to midges when considering survival (18%; 10 of 57 samples), growth (56%; 32 of 57 samples), biomass (81%; 46 of 57 samples), or survival, growth, or biomass (84%; 48 of 57 samples; Table 6.14). By comparison, none of the reference sediment samples (0 of 7) were considered to be toxic to midges when survival, growth, biomass, or survival, growth, or biomass, were considered. These results demonstrate that conditions sufficient to adversely affect midges occur in sediments from the UCR (Table 6.14). When highly-impacted samples only were considered, the IOT of overall toxicity to midges decreased to 63% (36 of 57 samples; Table 6.15; Figure 6.23). The highest frequency of toxicity (i.e., moderately- or highly-impacted samples) was observed in the sediment samples from Reach 4 (100%; 17 of 17 samples) and Reach 5 (100%; 5 of 5 samples) of the study area (Table 6.14; Figures 6.24 to 6.27).

Sediment toxicity was also evaluated by conducting 7-d whole-sediment toxicity tests with the cladoceran, *C. dubia*, on a total of 72 sediment samples that were obtained from the UCR or nearby reference areas (Besser *et al.* 2008; Bortleson *et al.* 1994; CEE 2006a; Schut and Stefanoff 2007; and, Stefanoff *et al.* 2006). The results of these toxicity tests demonstrated that, for the 64 sediment samples collected within the UCR, characteristics existed that were sufficient to adversely affect cladoceran survival (16%; 10 of 64 samples), reproduction (17%; 11 of 64 samples), and survival or reproduction (25%; 16 of 64 samples; Table 6.16). By comparison, none of the nine reference sediment samples were considered to be toxic to cladocerans when survival, reproduction, or survival or reproduction, respectively, were considered (Table 6.16). The observed IOT was similar when only highly-impacted sediment samples were considered (20%; 13 of 64 samples for survival or reproduction; Table 6.17; Figure 6.28). These results demonstrate that conditions sufficient to adversely affect cladocerans occur in sediments from the UCR, with the highest IOT (50%; n = 6) observed in Reach 5 (Table 6.16; Figures 6.29 to 6.31).

Among the eight endpoints that were measured in the studies that evaluated sediment toxicity in the UCR, midge growth and biomass appeared to be the most sensitive. Fifty-six percent of the sediment samples from the study area (n = 57) were found to be toxic when considering midge growth, while 81% were toxic when considering midge biomass (n = 57; Table 6.14). Fifty-three percent of the sediment samples tested from the UCR (n = 57) were toxic to amphipods when the survival endpoint was considered. Amphipod growth and biomass, midge survival, and cladoceran survival and reproduction appeared to be less sensitive endpoints, with 11 to 28% of the samples tested showing toxicity when these endpoints are considered. Table 6.18 presents the IOT for non slag-affected, potentially slag-affected, and slag-affected sediment samples from the UCR, considering each of the eight toxicity test endpoints separately.

The results of toxicity testing conducted 1992 (Bortleson *et al.* 1994), 2004 (Besser *et al.* 2008), and 2005 (CEE 2004; 2005; 2006a; 2006b; Stefanoff *et al.* 2006; Schut and Stefanoff 2007) indicate that many sediment samples collected over the length of the UCR are toxic to sediment-dwelling organisms. Even when only the highly impacted category of samples was considered, a substantial number of samples were demonstrated to be toxic to amphipods (i.e., 14 of 57 samples), midge (i.e., 36 of 57 samples) and cladocerans (i.e., 13 of 64 samples). Such sediment samples are distributed throughout the UCR. The results of a similar evaluation of the data collected by USEPA in 2005 confirmed that sediment samples that produce adverse responses in toxicity test organisms are frequently encountered in the UCR (i.e., 43 of 50 samples produced responses outside the lower limits of the reference envelopes, based on survival, growth, or reproduction; CH2M Hill 2012). More recently (2008), Fairchild *et al.* (2012) evaluated the toxicity of UCR sediments to amphipods in 28-d exposures and midge in 10-d exposures. The results of that study demonstrated that exposure to sediment samples contaminated by sand-sized slag particles caused toxicity to amphipods and/or midge in laboratory toxicity tests. Colonization of benthic invertebrates was also impaired by the presence of slag in sediment samples outplanted in an experimental pond (8-week exposure). Collectively, these results show that exposure to contaminated sediments from the UCR adversely affects benthic invertebrates.

6.9 Summary

Sediment chemistry, pore-water chemistry, and sediment toxicity data were compiled for a total of 80 locations in the vicinity of the UCR (Besser *et al.* 2008; Bortleson *et al.* 1994; CEE 2006a, Schut and Stefanoff 2007, and, Stefanoff *et al.* 2006). All of the samples were evaluated and those that met both chemical and biological selection criteria were identified as reference samples (including both within-site and external reference samples) and used to develop the reference envelope for each toxicity test endpoint. Because substantial inter-batch and inter-study variability was observed for both the control and reference samples, all of the response data was reference- or control-normalized prior to conducting subsequent data analyses.

A reference-envelope approach was used to identify the sediment samples that were toxic to benthic invertebrates. This procedure involved identification of reference sediment samples, normalizing the toxicity data to reflect reference or control responses, developing a reference envelope for each toxicity test endpoint, and designating each sediment sample as toxic or not toxic for each toxicity test endpoint, for each species, and for all species combined.

The results of 28-d whole-sediment toxicity tests with amphipods (*H. azteca*; Endpoints: Survival, growth, and biomass) indicated that 14 to 60% of the sediment samples from the UCR (n = 57) were toxic, depending on the endpoints that were considered (Table 6.12). By comparison, 18 to 84% of the sediment samples from the UCR (n = 57) were found to be toxic to midges (*C. dilutus*) in 10-d whole-sediment toxicity tests, depending on the endpoints considered (Table 6.14). UCR sediments tended to be less toxic to the cladoceran, *C. dubia*, in 7-d whole-sediment toxicity tests; 16 to 25% of the sediment samples from the UCR (n = 64) were designated as toxic to this species (depending on the endpoints considered; Table 6.16). Overall, 58 of the 71 (82%) sediment samples from the UCR, evaluated using the reference envelope approach, were found to be toxic to amphipods, midges, or cladocerans (Table 6.10). When sediment samples are designated as toxic or not toxic based on any of the eight toxicity test endpoints, the IOTs were similar in Reach 1 (89%; n = 19), Reach 3 (86%; n = 7), Reach 4 (95%; n = 19), Reach 5 (86%; n = 7), and Reach 6 (86%; n = 7). The IOT was lower in Reach 2, within which five of the 12 sediment samples (42%) were designated as toxic to benthic invertebrates (Table 6.10).

Somewhat different IOT results were obtained when the toxicity of UCR sediment samples was identified based on highly-impacted samples only. For amphipods, 14 of 57 sediment samples (25%) were classified as highly toxic, considering the survival, growth, or biomass endpoints (Table 6.13). By comparison, 36 of 57 sediment samples from the UCR (63%) were found to be highly impacted to midges, based on consideration of all three endpoints (Table 6.15). The lowest IOT was observed for cladocerans, with 13 of 64 sediments samples (20%) designated as highly impacted based on survival or reproduction. When all eight endpoints were considered, 46 of 71 sediment samples from the UCR (65%) were classified as highly impacted to amphipods, midges, or cladocerans (Table 6.11). The highest IOT, based on any of the eight endpoints measured, was observed in Reach 1 (84%; n = 19; Table 6.11). By comparison, IOT to amphipods, midges, or cladocerans ranged from 57% to 71% in Reaches 3, 4, 5, and 6 (Table 6.11). In Reach 2, the IOT was 25% (n = 12) when the highly impacted classification to amphipods, midges, or cladocerans was considered (Table 6.11).

Chapter 7 Development and Evaluation of Preliminary Site-Specific Thresholds for Predicting Sediment Toxicity in the Upper Columbia River

7.0 Introduction

This chapter describes the methods that were used to derive preliminary thresholds for predicting sediment toxicity (TPSTs) within the study area. In this study, TPSTs are defined as the concentrations of COPCs above which adverse effects on benthic invertebrates are likely to be observed. The preliminary TPSTs derived for the UCR were established using CRMs developed from matching sediment chemistry and toxicity data (Section 7.1). Two types of TPSTs were developed in this study, including a low-impact TPST (which corresponds to the lower limit of the reference envelope) and a high-impact TPST (which corresponds with a 10% reduction in survival, growth, biomass, or reproduction, relative to the lower limit of the reference envelope (Section 7.2). The procedures that were used to evaluate the reliability and predictive ability of the TPSTs for the selected COPCs, COPC mixtures, and indicators of slag presence are also described.

7.1 Development of Preliminary Concentration-Response Models

Sediment chemistry and sediment toxicity data were obtained for up to 80 sediment samples in the vicinity of the UCR. For each of these sediment samples, the concentrations of up to 194 COPCs have been measured. In addition, information on up to four endpoints for up to three species is available to evaluate the toxicity of these sediment samples to benthic invertebrates. Two preliminary analyses were conducted to help focus the development of CRMs on the COPC-endpoint combinations that would be most relevant for TPSTs derivations.

As a first step, a screening-level evaluation was conducted to identify the COPCs, COPC mixtures, and slag indicators that were unlikely to cause or substantially contribute to sediment toxicity (see Appendix 4 for more details on the screening step). More specifically, the concentrations of each analyte that were measured in sediment samples from the UCR from all three studies were compared to TECs (MacDonald *et al.* 2000). In addition, the concentrations of COPCs in pore water measured in the 2005 USEPA study were compared to criterion continuous concentrations (CCCs; USEPA 2009). The COPCs that did not occur at concentrations in excess of the TECs in any of the whole-sediment or in any of the pore-water samples at concentrations in excess of the CCCs were considered to pose a low risk to benthic invertebrates and other aquatic organisms in the UCR. Such COPCs were not considered in the CRM development process. Furthermore, analytes that did not exceed detection limits in any of the samples collected in the UCR study area were excluded from further analyses. Those analytes for which no benchmarks existed were identified as uncertain COPCs and carried forward into the subsequent steps of the CRM development process. While the current evaluation considered a broad suite of COPCs, it is possible that one or more unmeasured contaminants could be contributing to sediment toxicity in the UCR. Therefore, future sampling and analysis programs should evaluate existing data and current land and water uses in the study area and determine the need for inclusion of additional analytes in assessments of sediment and/or pore-water chemistry. For example, additional sediment chemistry data collected in 2005 by USEPA showed that certain individual PAHs, total PAHs, ESB-TUs, total PCBs, and certain organochlorine pesticides occurred at elevated concentrations in various sediment samples.

In the next step of the process, Spearman's rank correlation analysis (SRCA) was used to evaluate the correlation between whole-sediment chemistry (i.e., concentration of COPCs) and toxicity (i.e., organism response), with the objective of identifying probable drivers of toxicity in the study area. The SRCA is used instead of other correlation methods (e.g., Pearson's product-moment correlation) because it's application is not limited to linear relationships, and can be used to identify correlation in any monotonic relationship as the ranks of the ordered variables are evaluated. As the relationships between whole sediment chemistry and toxicity are typically non-linear, SRCA is appropriate for this use. COPCs were identified as probable drivers of toxicity if the associated Spearman's rank correlation coefficient (r_s) < -0.4 and significant at the 0.005 significance level. This significance level was used (based on the Bonferroni method of correction) to minimize experiment-wise error rates (i.e., Type I errors) associated with performing multiple comparisons. To support this analysis, the data were divided into three groups based on slag content (i.e., non slag-affected, potentially slag-affected, and slag-affected sediment samples using Cu:Al ratios as an indicator of the slag content of sediment samples; See Chapter 5 for more information). Then, Spearman-rank correlation analysis was conducted to identify potential relationships between COPC concentrations and organism responses for slag-affected sediment samples (Table A5.1), potentially slag-affected samples (Table A5.2), non slag-affected samples (Table A5.3), and all samples (Table A5.4). Any COPC that did not exhibit a significant correlation ($p < 0.005$) with one or more of the toxicity test endpoints was eliminated from further consideration. Comparable Spearman-rank correlation analyses were also conducted using the pore-water chemistry data for slag-affected (Table A5.5), potentially slag-affected (Table A5.6), non slag-affected (Table A5.7), and all (Table A5.8) samples. In this way, the results of the preliminary data analyses provided a basis for identifying the COPCs, COPC mixtures, and slag indicators that were most likely to be causing or substantially contributing to sediment toxicity in the UCR study area within and across the three sediment sample types, classified by slag content.

Examination of the results of the Spearman-rank correlation analyses showed that the relationships between concentration and response tended to be strongest for the slag-affected samples. The COPCs and indicators of slag that were significantly correlated with one or more of the response variables included metals (i.e., total or SE metals, including antimony, barium, calcium, chromium, cobalt, copper, iron, manganese, sodium, vanadium, zinc), and various COPC mixtures models (Table A5.1). For the potentially slag-affected samples, significant correlations with one or more of the response variables were observed for percent fines (i.e., silt+clay), TOC (%), DDTs (i.e., p,p'-DDT, sum DDTs, and total DDTs), metals (i.e., total and/or SEM including aluminum, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, mercury, nickel, potassium, sodium, zinc), SEM-AVS (Table A5.2). However, the significant correlations for DDTs were largely driven by a small number of samples with atypically high concentrations of these substances. Accordingly, development of relationships between concentration and response were not pursued for these analytes. Significant correlations between one or more of the response variables and the concentrations of numerous COPCs were observed for the non slag-affected samples, including conventionals (e.g., percent fines), metals (i.e., total aluminum, arsenic, barium, beryllium, chromium, cobalt, copper, iron, manganese, nickel, potassium, sodium, vanadium, zinc), and various COPC mixture models (Table A5.3). For all sediment samples, significant correlations with one or more of the response variables were observed for conventionals (e.g., percent fines), metals (i.e., total and/or SEM, including aluminum, antimony, arsenic, barium, beryllium, chromium, cobalt, copper, iron, manganese, nickel, potassium, sodium, vanadium, zinc), ($\sum$SEM-AVS)/f_{OC}, and various COPC mixture models (Table A5.4). The available pore-water chemistry data were generally poorly correlated with the toxicity test endpoints (Tables A5.5 to A5.8).

Preliminary CRMs were developed for each of the COPCs, COPC mixtures, and indicators of slag in sediment that were retained following these initial analyses (with a few exceptions, see Appendix A4.9). The site-specific chemistry and toxicity data for these COPCs, COPC mixtures, and slag indicators were used to develop CRMs based on the MOT to the amphipod, *H. azteca* (i.e., control-adjusted or reference-adjusted survival, growth, and biomass), the midge, *C. dilutus* (i.e., control-adjusted or reference-adjusted survival, growth, and biomass), and the daphnid, *C. dubia* (control-adjusted or reference-adjusted survival and reproduction). Biomass of toxicity test organisms was calculated as the product of the survival and weight endpoints for amphipods and midges.

Development of the CRMs involved plotting the COPC concentration data against the response data and determining the dependence of the toxicity test response data (dependent variables) on the COPC concentration data (independent variables) as described in MacDonald *et al*. 2002; 2003; 2005a; 2005b; 2009; 2010). The CRM for each endpoint response and COPC concentration was developed using a log-logistic CRM (Seefeldt *et al*. 1995; MacDonald *et al*. 2010) using the following equation:

$$f(x) = \frac{a}{1 + \left(\frac{x}{EC_{50}}\right)^{b}}$$

Where:

a	=	Upper limit of the response data (asymptote);
EC_{50}	=	Estimated median effect concentration; and,
b	=	Slope at the estimated median effect concentration.

The log-logistic CRM defined above is a sigmoidal relationship and, therefore, the upper limit of the response data (*a*) corresponds to the concentration of the COPC at which no effects are predicted to be observed. The median effect concentration in the above model provides an estimate of the COPC concentration at which a 50% effect is induced (e.g., 50% decline in survival relative to the upper limit and the baseline). The distribution of responses for each of the endpoints was tested for normality prior to CRM development. Only the data for *Ceriodaphnia dubia* survival and reproduction significantly differed from normality using the Shapiro-Wilk test for normality ($W = 0.7306$, $p < 0.001$ and $W = 0.8126$, $p < 0.001$). However, no improvements to the negative skew of the distribution could be made by transformation (i.e., using the square-root transformation). As non-linear regression is sensitive to deviations from normality in the dependent variables, this introduces uncertainty into the subsequent model development. All of the relationships were described using the R environment for statistical computing and graphics (www.r-project.org) using these methods, CRMs were developed for the following COPCs, COPC mixtures, and indicators of slag, using data on one or more toxicity test endpoints:

- Total barium;
- Total beryllium;
- Total calcium;
- Total chromium;
- Total cobalt;
- Total copper;
- Total iron;
- Total manganese;
- Total vanadium;
- Simultaneously extracted chromium;
- Simultaneously extracted zinc;
- $\sum$PEC-Q_{METALS};
- $\sum$PEC-$Q_{METALS(1\%OC)}$;
- $\sum$PEC-$Q_{EXTMETALS}$;
- $\sum$PEC-$Q_{EXTMETALS(1\%OC)}$;
- Mean PEC-Q;
- Mean PEC-$Q_{METALS(1\%OC)}$;
- Mean PEC-$Q_{EXTMETALS}$;
- Mean PEC-$Q_{EXTMETALS(1\%OC)}$;
- ($\sum$SEM-AVS)/f_{OC};

- Cu:Al; and,
- Zn:Cd.

Following their development, the CRMs were examined to identify the COPC/COPC mixture/slag indicator-toxicity test endpoint pairs that would be most relevant for TPST derivation (i.e., $r^2 > 0.4$; $p < 0.05$; MacDonald *et al.* 2002; 2003; 2009; 2010). Overall, 57 COPC/COPC mixture/slag indicator-endpoint pairs were selected for deriving TPSTs for slag-affected sediment samples (Figures A6.1 to A6.61). No CRMs were developed for potentially slag-affected, non slag-affected, or all groups of sediment samples

None of the COPC/COPC mixture/slag indicator-pairs for pore water were selected for developing concentration-response, as the available pore-water chemistry data were generally poorly correlated with the toxicity test endpoints (i.e., significant relationships between COPC concentrations and toxicity test organism response with $r^2 > 0.4$ were not observed for pore water). Accordingly, TPSTs for pore water were not developed in this investigation.

7.2 Derivation of Site-Specific Thresholds for Predicting Sediment Toxicity

Preliminary TPSTs were established for selected COPCs/COPC mixtures/slag indicators and toxicity metrics, based on the refined site-specific CRMs derived from chemistry and toxicity data for amphipods, midges, and cladocerans. Preliminary TPSTs were also derived for several indicators of the presence of slag in UCR sediments, such as barium, calcium, iron, vanadium, Cu:Al ratio, and Zn:Cd ratio. These analytes were selected based on the coefficients of determination (r^2) and associated level of significance (*p*-values) that were calculated for the regression equations that described the CRMs. COPCs, COPC mixtures, and slag indicators were selected for TPST derivation if $r^2 \geq 0.40$ and $p < 0.05$ (as per MacDonald *et al.*

2002; 2010). Experience at other sites suggests that TPSTs derived for COPCs or COPC mixtures that exhibited such correlations with survival or biomass of invertebrates tended to be the most reliable (i.e., such TPSTs accurately predict toxicity based on chemical concentration; MacDonald *et al.* 2002; 2009). Following selection of the key COPCs, COPC mixtures, and slag indicators, the preliminary CRMs were refined by fitting the data using a series of models and selecting the model that best described the toxicity and chemistry data (based on r^2 values; i.e., definitive plots; Appendix 6).

Thresholds for predicting sediment toxicity were established for selected COPCs, COPC mixtures, and slag indicators using the CRMs generated using data on the survival, growth, biomass, or reproduction of amphipods, midges, and cladocerans. Various procedures have been used to derive numerical TPSTs for benthic invertebrates (for details, see: MacDonald *et al.* 2002; 2004; 2009; Field *et al.* 2002; Wenning *et al.* 2005). In this study, two TPSTs were calculated for each COPC-endpoint pair, including a low-impact (i.e., $TPST_{LI}$) and a high-impact (i.e., $TPST_{HI}$) TPSTs. The $TPST_{LI}$ values were calculated by determining the concentrations of COPCs/COPC mixtures/slag indicators that corresponded to the response rates at the lower limit of the reference envelope (Besser *et al.* 2009; Moran *et al.* 2011). By comparison, the $TPST_{HI}$ values were calculated by determining the concentrations of COPCs/COPC mixtures/slag indicators that corresponded to the response rates at 10% below the lower limit of the reference envelope. Such low-impact and high-impact TPSTs are consistent with low-risk and high-risk toxicity thresholds, that have been developed for evaluating risks to benthic invertebrates associated with response to contaminated sediments at the Calcasieu Estuary (MacDonald *et al.* 2002), Indiana Harbor (MacDonald *et al.* 2006), and the Tristate Mining District (MacDonald *et al.* 2009; 2010). These toxicity thresholds were estimated using the regression equations that were developed for the corresponding CRM.

As indicated above, low-impact TPSTs were determined by calculating the concentration of each COPC, COPC mixture, or slag indicator that corresponded to a lower limit of the control- or reference-adjusted survival, growth, biomass, or reproduction of the toxicity test organisms exposed to reference sediment samples. Therefore, such response rates (i.e., those consistent with the reference envelope) are likely to be associated with conditions that would support healthy benthic invertebrate communities at uncontaminated reference sites.

The high-impact TPSTs were derived by calculating the concentration of each COPC, COPC mixture, or slag indicator that corresponded to at least a 10% increase in the MOT (i.e., control- or reference-adjusted survival, growth, biomass, or reproduction; MacDonald *et al.* 2002; 2010). This response rate generally corresponds to the minimum significant difference from control responses for certain toxicity tests, based on the results of power analyses (e.g., Thursby *et al.* 1997). In addition, MacDonald *et al.* (2004) reported that samples from Tampa Bay, Florida that exhibited approximately such response rates in amphipod toxicity tests also had impaired benthic invertebrate community structure, including reduced abundance and diversity of benthic invertebrates. Similar results have been reported elsewhere in the U.S. (e.g., Swartz *et al.* 1994; Long *et al.* 2002). Therefore, 10% increases in the MOT relative to the lower limit of the reference envelope is likely to be associated with conditions that would impair benthic invertebrate communities. Hence, the $TPST_{LI}$ and $TPST_{HI}$ are considered to provide a basis for identifying the concentrations of COPCs, COPC mixtures, and/or slag indicators that pose low or negligible impacts (< $TPST_{LI}$), moderate impacts ($TPST_{LI}$ to $TPST_{HI}$), and high impacts (i.e., > $TPST_{HI}$) to the benthic invertebrate community.

In total, preliminary $TPST_{LI}$s and $TPST_{HI}$s were derived for 57 COPC/COPC mixture/slag indicator-toxicity test endpoint pairs using sediment chemistry and sediment toxicity data from the UCR (Table A7.1). Using the data on cladoceran survival, preliminary site-specific TPSTs were derived for seven individual COPCs and six COPC mixtures (Table A7.1). Similarly, site-specific TPSTs were derived for seven individual COPCs and seven COPC mixtures based on cladoceran reproduction (Table A7.1). While the CRMs did not support derivation of TPSTs for any COPC or COPC mixture based on midge survival, TPSTs were derived for five COPCs or COPC mixtures based on midge growth and for eight individual COPCs or COPC mixtures based on midge biomass (Table A7.1). Using the amphipod response data, site-specific TPSTs were derived for nine individual COPCs or COPC mixtures based on amphipod growth and biomass, respectively (Table A7.1). No TPSTs were derived based on amphipod survival, however (i.e., due to the absence of significant relationships between COPC concentrations and amphipod survival).

As indicated above, TPSTs were developed for a total of seven chemical mixture models. Descriptions of these chemical mixture models are provided in Appendix 4.

7.3 Evaluation of the Site-Specific Thresholds for Predicting Sediment Toxicity

One of the principal objectives of this report is to establish TPSTs, based on existing data, that can be used to assess risks and/or injury to benthic invertebrates associated with exposure to contaminated sediments within the UCR. As such, the TPSTs developed for each of the selected COPCs, COPC mixtures, and indicators of slag were evaluated to support selection of TPSTs for assessing risks and/or injury to benthic invertebrates and other aquatic receptors throughout the study area. The reliability and the predictive ability of the TPSTs were considered in this evaluation. All of the TPSTs evaluated were generated using the chemistry and toxicity data for slag-affected sediment samples.

7.3.1 Reliability of the Site-Specific Thresholds for Predicting Sediment Toxicity

The evaluation of reliability provides a basis for assessing the ability of the site-specific TPSTs to correctly classify sediment samples as toxic or not toxic, using the same data that were applied to derive the TPST. In the first step of the process, the

TPSTs were used to classify sediment samples into two categories (i.e., toxic or not toxic to the test organisms) based on the concentrations of individual COPCs, COPC mixtures, or indicators of slag in sediment samples from the UCR. More specifically, samples with concentrations of the selected analytes that exceeded the TPST were predicted to be toxic to the test organisms. The samples that had chemical concentrations less than the corresponding TPST were predicted to be not toxic to any of the test organisms [e.g., any sample with a Mean PEC-$Q_{METALS(1\%OC)}$ less than the $TPST_{LI}$ of 1.63 in sediment was predicted to be not toxic]. The accuracy of these predictions was then evaluated by determining the proportion of samples within each group of samples (i.e., predicted toxic and predicted not toxic) that were actually toxic to the test organisms, based on the results of the sediment toxicity tests. For the reliability calculation, the frequency of toxicity above and below the TPST was determined using data on the toxicity test endpoint and test organism used to derive the TPST.

Criteria for evaluating the reliability of the TPSTs were established on an *a priori* basis, using the procedures that had been established previously for evaluating TPSTs at sites such as the Calcasieu Estuary, Indiana Harbor, and the Tri-State Mining District. More specifically, a TPST was considered to be reliable if the IOT was <20% below the TPST, if the IOT was >50% above the TPST, and if the overall correct classification rate was $\geq$80% (MacDonald *et al.* 2002; 2003; 2005a; 2005b; 2009; 2010). The TPSTs that met these criteria were considered to provide a reliable basis for classifying sediment samples from the UCR as toxic or not toxic (i.e., the overall error rate would be no greater than 20%). Such TPSTs also minimize the potential for false negative errors (i.e., Type II error rate would be less than 20%) and for identifying sediment samples that would be toxic, more likely than not (i.e., Type I error rate would be less than 50%).

The results of the reliability assessment for the preliminary TPSTs developed using the results of 7-d whole-sediment toxicity tests with the cladoceran, *C. dubia*, are presented in Table A7.2. For the survival endpoint, the $TPST_{LI}$s for 10 of the 13

COPCs, COPC mixtures, or slag indicators were found to provide a reliable basis for classifying slag-affected sediment samples as toxic or not toxic. Similar results were obtained for the $TPST_{HI}$s that were established based on cladoceran survival. Of the TPSTs evaluated for cladoceran, the highest reliability was observed for the $TPST_{LI}$s and $TPST_{HI}$s for beryllium, iron, and vanadium. Correct classification rates were 95% for all six of these TPSTs (n = 19).

Thresholds for predicting sediment toxicity were developed for 14 COPCs, COPC mixtures, and slag indicators using data on the reproduction of cladocerans exposed to UCR sediments for 7 days. Of these, the $TPST_{LI}$s and/or $TPST_{HI}$s for 6 of the 14 COPCs/COPC mixtures/slag indicators provided a reliable basis for classifying slag-affected sediment samples from the UCR as toxic and not toxic (Table A7.2). The TPSTs for barium, beryllium, calcium, iron and Mean $PEC\text{-}Q_{EXTMETALS}$, were considered to be the most reliable, based on the results of this evaluation. Correct classification rates ranged from 79 to 100% for the TPSTs for all of these COPCs/COPC mixtures/slag indicators (n = 15; Table A7.2).

Thresholds for predicting sediment toxicity based on midge survival were not developed for any COPC, COPC mixture, or slag indicator for any type of sediment sample. However, five COPC mixture models did meet the selection criteria and supported the derivation of numerical TPSTs based on 10-d midge growth. None of the resultant TPSTs were found to be reliable, however (Table A7.2). For midge biomass, TPSTs were derived for five individual COPCs and three COPC mixtures. Of these, only the $TPST_{LI}$ for copper and Cu:Al ratio were found to provide an accurate basis for classifying slag-affected sediment samples as toxic or not toxic based on midge biomass.

The sediment chemistry and sediment toxicity data for the amphipod, *H. azteca*, did not provide a basis for deriving site-specific TPSTs using the survival endpoint. However, TPSTs for two individual COPCs (total and simultaneously extracted chromium) and five COPC mixtures [($\sum$SEM-AVS)/f_{OC}; Mean $PEC\text{-}Q_{METALS1\%OC}$, Mean PEC-$Q_{EXTMETALS(1\%OC)}$, ∑PEC-$Q_{METALS(1\%OC)}$, ∑PEC-$Q_{EXTMETALS(1\%OC)}$], were derived using the data on amphipod growth. Subsequent evaluation of these TPSTs showed that all of these TPSTs provided a reliable basis for classifying slag-affected sediment samples as toxic or not. The overall correct classification rate for this TPSTs ranged from 51 to 100% (n = 21; Table A7.2). By comparison, the $TPST_{LI}$s derived for four of the eight COPCs or COPC mixtures based on amphipod biomass met the criteria for reliable TPSTs. More specifically, the $TPST_{LI}$s for Mean PEC-$Q_{METALS(1\%OC)}$, Mean PEC-$Q_{EXTMETALS(1\%OC)}$, ∑PEC-$Q_{METALS(1\%OC)}$, and ∑PEC-$Q_{EXTMETALS(1\%OC)}$ correctly classified slag-affected sediment samples as toxic or not toxic based on the amphipod biomass endpoint.

7.3.2 Predictive Ability of the Site-Specific Thresholds for Predicting Sediment Toxicity

All of the TPSTs that were derived during the course of this investigation were evaluated to determine their predictive ability. In this study, predictive ability is defined as the ability of the TPSTs to correctly classify sediment samples from the UCR as toxic or not toxic, using an independent data set. First, the TPSTs were used to classify sediment samples into two categories (i.e., toxic or not toxic to the test organisms) based on the measured concentrations of individual COPCs, COPC mixtures, or slag indicators in sediment samples from the UCR. More specifically, samples with measured concentrations of the selected COPC, COPC mixture, or slag indicator that exceeded the $TPST_{LI}$ or $TPST_{HI}$ were predicted to be toxic to the test organisms. The samples that had chemical concentrations less than the corresponding $TPST_{LI}$ or $TPST_{HI}$ were predicted to be not toxic to the test organisms. The accuracy of these predictions was then evaluated by determining the proportion of samples within each group of samples (i.e., predicted toxic and predicted not toxic) that were actually toxic to the test organisms, based on the results of the sediment toxicity tests. For the predictive ability calculation, the frequency of toxicity above and below the TPST was determined using up to 12 indicators of sediment toxicity, including:

- Cladoceran survival (cladoceran 7-d, survival);
- Cladoceran reproduction (cladoceran 7-d, reproduction);
- Cladoceran survival or reproduction (cladoceran 7-d, all endpoints);
- Midge survival (midge 10-d, survival);
- Midge growth (midge 10-d, growth);
- Midge biomass (midge 10-d, biomass);
- Midge survival, growth, or biomass (midge 10-d, all endpoints);
- Amphipod survival (amphipod 28-d, survival);
- Amphipod growth (amphipod 28-d, growth);
- Amphipod biomass (amphipod 28-d, biomass);
- Amphipod survival, growth, or biomass (amphipod, 28-d all endpoints); and,
- Any of the eight endpoints (all endpoints).

The same criteria that were used to evaluate reliability were applied in the predictive ability evaluation. That is, a TPST was considered to be predictive of sediment toxicity if the IOT was <20% below the TPST, if the IOT was >50% above the TPST, and if the overall correct classification rate was ≥80% (MacDonald *et al.* 2002; 2003; 2005a; 2005b; 2009; 2010). The TPSTs that met these criteria were considered to provide an accurate basis for classifying sediment samples as toxic or not toxic (i.e., the overall error rate would be no greater than 20%). The predictive ability of the TPSTs was evaluated for slag-affected sediment samples, for non slag and potentially slag-affected sediment samples, and for all bioassay sediment samples from the UCR combined.

7.3.2.1 Predictive Ability of Thresholds for Predicting Sediment Toxicity Derived Based on Cladoceran Survival or Reproduction

The predictive ability of the TPSTs derived using data on the survival or reproduction of cladocerans was evaluated using information on all 12 indicators of sediment toxicity. These TPSTs were applied to three groups of sediment samples from the UCR, including slag-affected sediment samples, non slag-affected and potentially slag-affected sediment samples, and all types of sediment samples.

The results of this evaluation indicated that the $TPST_{LI}$s and $TPST_{HI}$s based on cladoceran survival, developed using the data for slag-affected sediment samples, generally provided an accurate basis for classifying sediment samples as toxic and not toxic for cladoceran reproduction and for cladoceran survival or reproduction (Table A7.3). For all of the endpoints measured in the 7-d toxicity tests with the cladoceran, *C. dubia*, the IOT was low (i.e., $< 20\%$) when the concentrations of COPCs, COPC mixtures, or slag indicators were below the $TPST_{LI}$s or $TPST_{HI}$s. The highest predictive ability was observed for the cladoceran-based $TPST_{LI}$s and $TPST_{HI}$s for beryllium, chromium, copper, iron, vanadium, Mean PEC-$Q_{EXTMETALS}$, $\sum$PEC-Q_{METALS}, $\sum$PEC-$Q_{METALS(1\%OC)}$, $\sum$PEC-$Q_{EXTMETALS(1\%OC)}$,and $\sum$PEC-$Q_{EXTMETALS}$. However, none of the $TPST_{LI}$s or $TPST_{HI}$s based on cladoceran survival provided an accurate basis for classifying sediment samples as toxic or not toxic based on the endpoints measured in the 28-d toxicity tests with amphipods (with the exception of 28-d amphipod growth (Table A7.3). For non slag and potentially slag-affected samples, none of the TPSTs based on cladoceran survival provide an accurate basis for classifying sediment samples as toxic or not toxic for any endpoint (Table A7.4). Predictive ability was higher for the cladoceran survival $TPST_{LI}$s and $TPST_{HI}$s when evaluated using the sediment toxicity data for all sediment samples, with the $TPST_{LI}$ for copper of 1090 mg/kg SW having the highest predictability (i.e., all three evaluation criteria were met for five of the 12 indicators of sediment toxicity; Table A7.5). Collectively, these results indicate that cladoceran survival is less sensitive than most of the other toxicity test endpoints examined in this investigation. This is not surprising considering that cladocerans tend to have little direct interaction with sediments.

The predictive ability of the TPSTs based on cladoceran reproduction was also evaluated using information on 12 indicators of sediment toxicity in three types of sediment samples. For the slag-affected sediments, the $TPST_{LI}$s and $TPST_{HI}$s for barium, beryllium, calcium, iron, SE chromium, SE zinc, and Mean PEC-$Q_{EXTMETALS}$, based on cladoceran reproduction, provided the most accurate tools for classifying samples as toxic or not toxic (Table A7.6). However, these TPSTs did not accurately predict toxicity for any of the amphipod or midge endpoints in slag-affected samples, with the exception of amphipod growth; Table A7.6). These TPSTs were typically too high to be useful for evaluating the potential for observing toxicity in non slag and potentially slag-affected samples, as most of the sediment samples within this group had COPC/COPC mixture/slag indicator concentrations below the $TPST_{LI}$s and $TPST_{HI}$s (Table A7.7). For all samples combined, the $TPST_{LI}$s and/or $TPST_{HI}$s for barium, iron, SE chromium, SE zinc, and Mean PEC-$Q_{EXTMETALS}$ had the highest predictive ability. These TPSTs accurately classified sediment samples as toxic or not toxic for up to four of the 11 indicators of sediment toxicity (Table A7.8).

7.3.2.2 Predictive Ability of Thresholds for Predicting Sediment Toxicity Derived Based on Midge Growth or Biomass

The predictive ability of the TPSTs derived using data on the growth or biomass of midges was evaluated using information on all 12 indicators of sediment toxicity. These TPSTs were applied to three groups of sediment samples from the UCR, including slag-affected sediment samples, non slag-affected and potentially slag-affected sediment samples, and all types of sediment samples.

Numerical sediment TPSTs were developed for four COPC mixtures using the available data on midge growth in slag-affected sediments from the UCR. The predictive ability of most of these TPSTs were typically low for slag-affected sediment samples from the UCR (Table A7.9). The predictive ability of these TPSTs was even lower when applied to non slag-affected and potentially slag-affected sediment samples (i.e., the evaluation criteria for the TPSTs were never met when these types of sediment samples were evaluated; Table A7.10). The TPSTs based on midge growth correctly classified sediment samples as toxic when all three groups of sediment samples were evaluated (particularly for midge growth, midge biomass, midge survival, growth, or biomass, amphipod biomass, amphipod survival, growth, or biomass, or all endpoints measured). However, the IOT often exceeded 20% at COPC mixture concentrations below these TPSTs (Table A7.11). Therefore, the TPSTs based on midge growth were not considered to be predictive of sediment toxicity in the UCR.

Numerical TPSTs were derived for eight COPCs, COPC mixtures, or indicators of slag based on the biomass of midges exposed to slag-affected sediment samples (Table A7.12). None of these $TPST_{LI}$s or $TPST_{HI}$s met the evaluation criteria for more than one toxicity test endpoint in slag-affected sediment samples (Table A7.12). Similar results were obtained when these TPSTs were applied to non slag and potentially slag-affected sediment samples from the UCR (Table A7.13). The IOT for five of the endpoints measured was also <20% at Mean PEC-Qs of < 0.85, suggesting that this TPST may provide a reasonable basis for identifying lack of toxicity in these types of sediment samples (Table A7.13). While few of the TPSTs based on midge biomass met the evaluation criteria when applied to all types sediment samples from the UCR, the $TPST_{HI}$ for copper (498 mg/kg DW) provided a reliable tool for classifying sediment samples as toxic or not toxic relative to amphipod growth and amphipod biomass. For six of the endpoints measured, the IOT was <20% when copper concentrations were below this TPST (Table A7.14).

7.3.2.3 Predictive Ability of Thresholds for Predicting Sediment Toxicity Derived Based on Amphipod Growth or Biomass

The predictive ability of the TPSTs derived using data on the growth or biomass of amphipods was evaluated using information on all 12 indicators of sediment toxicity. These TPSTs were applied to three groups of sediment samples from the UCR, including slag-affected sediment samples, non slag-affected and potentially slag-affected sediment samples, and all types of sediment samples.

Using the available data on the growth of amphipods exposed to slag-affected sediment samples from the UCR, site-specific TPSTs were developed for nine COPCs, COPC mixtures, or slag indicators. With the exception of total chromium ($TPST_{LI}$ and $TPST_{HI}$) and SE chromium ($TPST_{LI}$), which accurately predicted toxicity to cladocerans for all three indicators of toxicity and toxicity to amphipods for the growth endpoint, the TPSTs based on amphipod growth generally did not meet the evaluation criteria when applied to slag-affected sediment samples (Table A7.15). None of the TPSTs derived based on amphipod growth provided accurate tools for classifying non slag and potentially slag-affected sediment samples relative to their toxicity to benthic invertebrates (Table A7.16). However, the IOT to cladocerans (all three indicators of toxicity) and amphipods (growth and biomass) was generally low at COPC concentrations below the $TPST_{LI}$ or $TPST_{HI}$ values (Table A7.16). The predictive ability of these TPSTs was somewhat higher when the data for all sediment samples was considered (Table A7.17). Overall, the $TPST_{LI}$ and $TPST_{HI}$ for total chromium and the $TPST_{LI}$ for SE chromium were the most predictive of sediment toxicity in all types of sediment samples from the UCR, meeting the evaluation criteria for four of the 12 endpoints that were considered (Table A7.17).

Low-impact and high-impact TPSTs were derived using data on the biomass of amphipods exposed to slag-affected sediment samples for seven COPCs, COPC mixtures, and/or slag indicators (Table A7.18). When applied to slag-affected sediment samples, the $TPST_{HI}$s for total chromium and SE chromium, and the $TPST_{LI}$s for Mean $PEC\text{-}Q_{METALS(1\%OC)}$, Mean $PEC\text{-}Q_{EXTMETALS(1\%OC)}$, $\sum PEC\text{-}Q_{METALS(1\%OC)}$, and

$\sum$PEC-$Q_{EXTMETALS(1\%OC)}$ met the evaluation criteria for four of the 12 toxicity test endpoints considered (Table A7.18). In contrast, the evaluation criteria were not met for any endpoint for any of the $TPST_{LI}$s or $TPST_{HI}$s applied to non slag or potentially slag-affected sediment samples (Table A7.19). The predictive ability of the TPSTs derived using amphipod biomass data for classifying all types of sediment samples in the UCR was similar to that for slag-affected sediment samples. More specifically, the $TPST_{HI}$s for total chromium and SE chromium met the evaluation criteria when cladoceran survival, cladoceran reproduction, cladoceran survival or reproduction, and amphipod growth were considered (Table A7.20). The IOT exceeded 50% for all but one endpoint (midge survival) when these TPSTs were exceeded. Application of the $TPST_{LI}$s for Mean PEC-$Q_{METALS(1\%OC)}$, Mean PEC-$Q_{EXTMETALS(1\%OC)}$, $\sum$PEC-$Q_{METALS(1\%OC)}$, and $\sum$PEC-$Q_{EXTMETALS(1\%OC)}$ to all types of samples in the UCR yielded similar results, with the evaluation criteria met for cladoceran reproduction, cladoceran survival or reproduction, amphipod growth, and amphipod biomass for all sediment samples from the UCR (Table A7.20).

7.3.2.4 Predictive Ability of Sediment Quality Guidelines and Standards

Numerical SQGs and/or standards (SQSs) have been developed by various jurisdictions to support sediment quality assessments. While such decisions have not yet been made, certain SQGs and/or SQSs could be identified as applicable or relevant and appropriate requirements (ARARs) under the Comprehensive Environmental Response, Compensation, and Liability Act. To assist decision makers determine the implications of adopting such SQGs and/or SQSs as ARARs, the predictive ability of three sets of SQGs and SQSs were evaluated to determine if they could be used to accurately predict the presence and absence of toxicity in the UCR.

First, the SQS that have been established for the waters managed by the Confederated Tribes of the Colville Reservation for mixtures of metals, PAHs, and PCBs (i.e., Mean PEC-Q of 0.1) was evaluated (MacDonald and Ingersoll 2002). The predictive ability of the Mean PEC-Q of 1.0 was also evaluated using data on all types of sediment samples in the UCR. The results of this evaluation indicated that the IOT was <20% below the $TPST_{LI}$ of 0.1 for Mean PEC-Q for five of the 12 indicators of sediment toxicity considered (Table A7.21). In addition, a moderate IOT to midges (survival, growth) and amphipods (survival) was observed below this SQS for the UCR. The IOT was variable above the SQS, while higher incidences of toxicity were observed when Mean PEC-Qs exceeded 1.0 (Table A7.21). Hence, the SQS (i.e., Mean PEC-Q of 0.1) would likely provide an effective tool for protecting benthic invertebrates against adverse effects associated with exposure to site COPCs.

Benthic sediment quality values for freshwater sediments in Washington, Oregon, and Idaho were developed in 2010 (WDOE 2011). Although the draft SQGs do not include values for any chemical mixtures, numerical SQGs are presented for several metals of concern in the UCR, including antimony, cadmium, copper, lead, and zinc [i.e., a screening level 1(SL1) and screening level 2 (SL2) value is reported for each metal]. Evaluation of the predictive ability of the SQGs in all types of sediment samples in the UCR indicates that, among the SQGs for the five metals, the SL2 for copper provides the most reliable basis for classifying sediment samples from the UCR as toxic and not toxic. More specifically, the SL2 for copper of 1200 mg/kg DW accurately predicted the presence and absence of toxicity for cladoceran survival, cladoceran reproduction, cladoceran survival or reproduction, amphipod growth, and amphipod biomass (Table A7.22). The IOTs ranged from 17 to 73% below the SL2 for copper when toxicity to midges (survival, growth, or biomass) was considered (Table A7.22). Hence, adverse effects on certain benthic invertebrate species could be observed if these SQGs were adopted as ARARs at the UCR.

In 2005, USEPA (2005) developed the ESBs for the protection of benthic organisms for metal mixtures. Two indicators of sediment chemistry were used to characterize exposure of benthic organisms to metals, including ∑SEM-AVS and (∑SEM-AVS)/f_{OC}. The corresponding ESBs for these metrics were evaluated to determine their predictive ability in all types of sediment samples in the UCR. The results of this evaluation indicate that the IOT for sediment-dwelling organisms is <20% for five of the 12 indicators of sediment toxicity when ∑SEM-AVS was <1.7µmol/g (n = 26 to 29) or ≤20% for five of the 12 indicators of sediment toxicity when ∑SEM-AVS was <120 µmol/g (n = 53 to 60; Table A7.23). Sediment samples from the UCR are frequently toxic (i.e., IOT ranges from 67 to 100% for 11 of the 12 indicators of sediment toxicity) when ∑SEM-AVS exceeded 120 µmol/g (n = 3 to 4; Table A7.23). This ESB generally performed better than the OC-normalized ESBs in UCR sediments [i.e., (∑SEM-AVS)/f_{OC}; Table A7.23].

7.4 Summary

A step-wise approach was used to develop site-specific concentration models using the sediment chemistry and sediment toxicity data for the UCR. First, a series of preliminary analyses were conducted to identify the COPCs, COPC mixtures, and slag indicators that were most likely to be correlated with the responses to toxicity test organisms (e.g., evaluation of the frequency of detection, comparison to conservative SQGs). In the next step of the process, potential relationships between the concentrations of selected analytes and the responses of toxicity test organisms were identified by conducting Spearman-rank correlation analysis on the underlying data. To support this analysis, the underlying data were divided into three groups based on slag content. The results of these analyses showed that the relationships between concentration and response tended to be strongest for the slag-affected samples and, to a lesser extent, for all samples combined. Concentration-response models were developed for each of the COPCs, COPC mixtures, and slag indicators in sediment that were retained following these initial analyses. Following their development, these CRMs were examined to identify the COPC/COPC mixture/slag indicator toxicity test endpoint pairs that would be most relevant for TPST derivation (i.e., $r^2 > 0.4$; $p < 0.05$; MacDonald *et al.* 2002; 2003; 2005a; 2005b; 2009; 2010). Overall, 57 COPC/COPC mixture/slag indicator-endpoint pairs were selected for deriving TPSTs (Figures A6.1 to A6.61). As none of the COPC/COPC mixture/indicator pairs for pore water met the selection criteria for identifying potential risk drivers, TPSTs for pore water were not developed in this investigation.

Two types of TPSTs, including low impact ($TPST_{LI}$s) and high impact ($TPST_{HI}$s), were developed using the CRMs for 57 COPC/COPC mixture/slag indicator-endpoint pairs for whole sediment (Table A7.1). As none of the COPC/COPC mixture/slag indicator-endpoint pairs for pore water met the selection criteria for identifying potential risk drivers, TPSTs for pore water were not developed in this investigation. This is likely because the pore-water chemistry data and sediment toxicity data were not synoptically collected and because pore-water samples were obtained by centrifugation of field-collected sediment samples. The low-impact TPSTs were established at the concentrations of COPCs/COPC mixtures/slag indicators that corresponded to the lower limit of the reference envelope for the selected toxicity test endpoint. The highly impacted-TPSTs were established as the concentrations of COPCs/COPC mixtures/slag indicators that corresponded to a 10% reduction in survival, growth, biomass, or reproduction, compared to the lower limit of the reference envelope (MacDonald *et al.* 2002; 2009; 2010).

The reliability and predictive ability of the resultant TPSTs were then evaluated using sediment chemistry and sediment toxicity data from the UCR. Thresholds for predicting sediment toxicity were considered to be reliable and/or predictive of sediment toxicity if the IOT was <20% below the TPST, the IOT was >50% above the TPST, and the rate of correct classification of sediment samples as toxic and not toxic was ≥80% (MacDonald *et al.* 2002; 2009; 2010).

The results of this evaluation indicated that most of the site-specific TPSTs developed in this investigation provide a reliable basis for identifying toxic and not toxic slag-affected sediment samples in the UCR (i.e., for correctly classifying the sediment samples used to derive the TPSTs as toxic or not toxic, for the endpoint used to derive the TPSTs). The TPSTs developed using data on the measurement endpoints for the cladoceran toxicity test tended to be the most reliable, with the TPSTs for 12 of 13

COPC/COPC mixture/slag indicators based on survival and for 14 of 14 COPC/COPC mixture/slag indicators based on reproduction exhibiting high reliability. By comparison, only the $TPST_{LI}$ for copper and Cu:Al ratio based on midge biomass were shown to be reliable for predicting the toxicity of slag-affected sediment samples. The TPSTs for several of the COPCs/COPC mixtures/slag indicators based on amphipod growth or biomass were also found to be reliable, with the TPSTs for metal mixtures performing better than the TPSTs for individual metals.

The site-specific TPSTs were also evaluated to determine their predictive ability. The results of this evaluation indicate that none of the TPSTs derived using sediment chemistry and sediment toxicity data from the UCR provide an accurate basis for classifying all types of contaminated sediment samples as toxic or not toxic for all of the endpoints measured. This result is not surprising considering the variability in contaminant transport and fate at the UCR and results of the sediment toxicity tests, which showed that the various species and endpoints exhibited differential sensitivity to the COPCs, COPC mixtures, and slag indicators in UCR sediments. It is also likely that the conditions maintained during toxicity testing were only marginally suitable for midges and/or amphipods. This factor may have contributed to the high IOT for the sediment samples with relatively low contaminant chemistry. That matching sediment chemistry and toxicity data were not available for the many of the sediment samples considered in this investigation likely contributed to variability in the resultant TPSTs.

Certain TPSTs evaluated provided an accurate basis for classifying sediment samples as toxic or not toxic in the UCR. While most of the TPSTs had only moderate predictive ability, the Mean PEC-Q of 0.397, derived based on midge biomass, provided an accurate predictor of the absence of toxicity in all types of sediment samples from the UCR. The $TPST_{LI}$ for copper of 1090 mg/kg DW, based on cladoceran survival, provided among the best predictor of toxicity to benthic invertebrates for all types of sediment samples from the UCR. Percent slag was also an accurate predictor of toxicity to benthic invertebrates for slag-affected samples.

In the absence of a single TPST that accurately predicts toxicity to all of the organisms tested in all types of sediment, it is recommended that multiple TPSTs be used together to evaluate sediments for various types from the UCR (as described in Section 8.2).

Chapter 8 Considerations for Selecting Methods for Classifying Sediment Samples from the Upper Columbia River Relative to Toxicity to Benthic Invertebrates

8.0 Introduction

A substantial number of TPSTs were derived in this investigation using the chemistry and toxicity data for cladocerans, midges, and amphipods exposed to slag-affected sediment samples collected from the UCR (as identified using the Cu:Al model; see Chapters 5, 6, and 7 for details). All of these TPSTs were evaluated to determine their reliability and predictive ability (i.e., ability to correctly classify sediment samples from the study area as toxic or not toxic to benthic invertebrates). The results of these evaluations, presented in Chapter 7, showed that many of the TPSTs for sediment provided reliable tools for classifying UCR sediments relative to their toxicity to benthic invertebrates. In addition, a sub-set of the TPSTs can be used to accurately predict the presence or absence of toxicity for other endpoints and/or other species (i.e., other than the species and endpoint considered for deriving the TPST). Accordingly, the preliminary TPSTs derived in this investigation can be used together with other tools to support reliable assessments of sediment quality conditions in the UCR (See Chapter 7 for more information).

While the results of the reliability and predictive ability evaluations of the TPSTs were encouraging, it is apparent that sediment chemistry was not strongly correlated with sediment toxicity on a site-wide basis for all types of the sediment samples considered in this evaluation. Such variability in the concentration and response data leads to uncertainty in the applicability of the TPSTs to individual sediment samples in the UCR. This variability in the underlying CRMs is likely due to differences in the bioavailability of COPCs depending on the contaminant source (i.e., slag, liquid effluent, weathering of natural rock), differences in the slag content of individual samples, and/or other factors. Among the other factors that could influence these relationships, sediment and pore-water sampling methods may be among the most important, as a portion of the data used in the current evaluation were generated using co-located sediment samples (rather than composite samples from a single location that are split to support evaluations of sediment chemistry, pore-water chemistry, and sediment toxicity). This chapter provides a discussion of some of the factors that need to be considered during the design of future sampling programs that are intended to support the development of CRMs for COPCs in the UCR.

8.1 Influence of Slag Content on the Toxicity of Sediment Samples from the Upper Columbia River

Information from various sources demonstrates that substantial quantities of slag were released to the UCR from the Teck facility in Trail, B.C. (Nener 1992; Ryan and Mohanty 2011). Slag released to the UCR has been transported to downstream areas in the United States and, over time, has been subjected to various transport and weathering processes. Sediment samples that have been contaminated by coarse-grained and finer slag are located primarily upstream of RM 723 (Bortleson *et al.* 1994; Chapter 5). The results of other studies indicate that coarse-grained slag can undergo various physical and chemical degradation processes that result in the production of clay- to silt-sized slag particles (Nelson 2011). Photomicrographic analysis of sediment samples from the UCR has confirmed that clay- to silt-sized slag particles have contaminated sediments at least as far downstream as Reach 4 (Cox *et al.* 2005) and likely have been transported downstream as far as the Grand Coulee Dam (NHC 2011).

The results of this study confirm that evaluations of relationships between sediment chemistry and sediment toxicity are not consistent throughout the UCR. Importantly, application of methods for accounting for the factors that typically influence the bioavailability of metals in sediments, such as AVS and TOC concentrations, decreased the variability in the relationships between, for example, ∑SEM–AVS and Mean PEC_{METALS} and the survival, growth, biomass, or reproduction of cladocerans, midges, or amphipods. However, such normalization procedures did not provide a basis for developing significant, broadly applicable CRMs using the chemistry and toxicity data for all of the sediment samples considered in this evaluation (n = 80). As slag is an important source of metals to UCR sediments and the bioavailability of slag-affected metals may differ from that of metals originating from other sources (e.g., liquid effluents or natural sources), it is not surprising that consideration of slag content of UCR sediments decreased variability on the CRMs that were developed for site-related COPCs, COPC mixtures, and slag indicators (see Chapter 7 for more information).

In this investigation, three models were developed to support identification of sediment samples that were contaminated by slag based on ratios of slag-indicator and reference metals, including: the Cu:Al model; the Cu:Al and Zn:Cd model; and, the Fe:Al and Zn:Cd model. Because it provided a basis for identifying the presence of either coarse-grained slag that met all four of the evaluation criteria (see Chapter 5 for details), the Cu:Al model was used to identify sediment samples from the UCR that were affected by the presence of slag. This method was used to classify sediment samples from the UCR into three categories, including non slag-affected, potentially slag-affected, and slag-affected sediment samples. The other two models also provided a basis for classifying sediment samples into these three groups. Examination of the results of the three toxicity tests for the sediment samples that were classified using the Cu:Al model revealed that, for each endpoint, the IOT was similar among these three groups of sediment samples (e.g., 70.7%, 66.7%, and 77.8%, respectively, when all species and all endpoints were considered; Table 8.1). By comparison, IOT was higher for the potentially slag-affected and slag-affected sediment samples when either the Cu:Al and Zn:Cd model or the Fe:Al and Zn:Cd model were used to classify sediment samples from the UCR relative to slag content (Table 8.1). For example, the IOT (i.e., for all species and endpoints) was 43.8% for non slag-affected samples, 80.0% for potentially slag-affected, and 79.2% for slag-affected sediment samples when the Cu:Al and Zn:Cd model was used for classifying UCR sediment samples (Table 8.1). Similarly, IOT (i.e., for all species and endpoints) was 43.8% for non slag-affected samples, 81.6% for potentially slag-affected samples, and 76.9% for slag-affected samples when the Fe:Al and Zn:Cd model was used. Relationships between estimated slag content and the survival, growth, biomass, or reproduction of benthic invertebrates, as estimated using the three models, are presented in Figures A8.1 to A8.24. Collectively, these results suggest that the Cu:Al and Zn:Cd model and/or the Fe:Al and Zn:Cd model may be more relevant for interpreting sediment toxicity data, most likely because they account for the presence of fine-grained and/or coarse-grained slag in the UCR sediment samples.

A supplemental data analysis was conducted to determine the predictive ability of selected generic SQGs (i.e., $(\sum \text{SEM-AVS})/f_{OC}$, Mean PEC-Q, Mean PEC-$Q_{METALS@1\%OC}$, and SUM PEC-$Q_{METALS@1\%OC}$) considering only those sediment samples that were classified as non slag-affected using the Cu:Al and Zn:Cd model (Table 8.2). This analysis was premised on the hypothesis that generic SQGs should be able to accurately classify such samples as toxic and not-toxic if metals were not present in association with slag (i.e., if the sediments were similar to those that were evaluated to derive the generic SQGs). The results of this analysis demonstrated that the IOT was low when $(\sum \text{SEM-AVS})/f_{OC}$ was below the ESB of 130 µmole/g (i.e., 0 to 12% for the various toxicity test endpoints; n = 7 or 8), a Mean PEC-$Q_{METALS@1\%OC}$ of 0.1 (i.e., 0% for all endpoints; n = 7 to 9), and $\sum$PEC-$Q_{METALS@1\%OC}$ of 1.0 (i.e., 0% for all endpoints; n = 7 to 9; Table 8.2).

When $(\sum \text{SEM-AVS})/f_{OC}$ was between 130 and 3000 µmole/g, the IOT ranged from 0% to 100% (n = 5) depending on the endpoint measured. The highest IOTs (80 to 100%; n = 5) were observed for midge growth, biomass, survival, growth, or biomass, and any endpoint measured when $(\sum \text{SEM-AVS})/f_{OC}$ was within this range (i.e., 130 to 3000 µmol/g). No samples had $(\sum \text{SEM-AVS})/f_{OC} > 3000$. Similarly, the IOT was variable when Mean PEC-$Q_{METALS@1\%OC}$ exceeded 0.1 (0 to 100%) or $\sum$PEC-

$Q_{METALS@1\%OC}$ exceeded 1.0 (0 to 100%), with the highest IOTs observed for midge growth, biomass, survival, growth, or biomass, and any endpoint measured (Table 8.2). Hence, the generic SQGs generally provided an accurate basis for classifying the non slag-affected group of sediment samples as toxic or not toxic.

Collectively, these results show that the Cu:Al and Zn:Cd model (and by extension, the Fe:Al and Zn:Cd model) provides an important tool that should be applied for interpreting data from future investigations (i.e., for separating sediment samples that are influenced by slag from those that are not). The results of these analyses also indicate that any future studies intended to evaluate relationships between sediment chemistry and sediment toxicity must consider the slag content of UCR sediments. Such evaluations of slag content should include multiple methods of assessing the presence and content of slag in sediment samples (including visual observations of slag, various geochemical methods, electron microscopy, and/or other methods) to provide a weight-of-evidence relative to slag identification and facilitate a range of analyses of the resultant data.

8.2 Procedures for Evaluating the Bioavailability of Sediment Samples

According to USEPA (2005), organic carbon concentration is a key factor influencing the bioavailability of divalent metals in sediments. To account for the influence of TOC on metal bioavailability, USEPA derived alternative equilibrium-partitioning sediment benchmarks (ESB) for ∑SEM–AVS that account for the TOC concentration in sediment samples [i.e., $(\sum SEM\text{-}AVS)/f_{OC}$]. In addition, many of the COPC mixture models evaluated in this investigation rely on OC-normalization to account for the influence of TOC on the bioavailability of metals and other contaminants. In general, such normalization procedures are considered to be applicable to sediments that have typical concentrations of organic carbon (i.e., > 0.2 or > 0.5%; USEPA 2003b; 2005).

The sediment samples from the UCR that were evaluated in this investigation had TOC concentrations that ranged from (0.037 to 3.81%). Roughly half of these sediment samples (39 of 80 samples; 49%) had TOC levels less than 0.5%, a concentration below which the appropriateness of OC-normalization is less certain. To determine the potential influence of OC-normalization of COPC concentrations at low levels of TOC on the relationships between toxicity and chemistry in UCR sediment, a sensitivity analysis was conducted using two COPC mixture models: (∑SEM-AVS)/f_{OC}; and, Mean $PEC_{METALS@1\%OC}$. As a first step, all of the slag-affected sediment samples with TOC levels < 0.5% were assigned a TOC concentration of 0.5% (D. Mount, USEPA, Duluth, MN; C. Ingersoll, USGS, Columbia, MO. Personal communication). Next, CRMs were developed and used to support the derivation of TPSTs for these COPC mixtures. Finally, these resultant CRMs were compared to the original CRMs to determine if the modified OC-normalization procedure reduced variability in the CRMs.

The results of this sensitivity analysis indicate that TOC-adjustment prior to OC-normalization did not substantially reduce variability (i.e., based on r^2 values) in the CRMs for (∑SEM-AVS)/f_{OC} or Mean $PEC_{METALSs@1\%OC}$ (Figures A8.25 to 8.40). While the relationships between (∑SEM-AVS)/f_{OC} or Mean $PEC_{METALS@1\%OC}$ and the reproduction of cladocerans *C. dubia*) improved by TOC-adjustment (Figure A8.2 and A8.10), the CRMs for the other seven endpoints either remained similar or became more variable (as indicated by r^2 values). Therefore, TOC-adjustment supported the development of alternative TPSTs for only two COPC mixture-endpoint pairs. Nevertheless, it would be prudent to evaluate this and other TOC-adjustment methods in analyses of any additional sediment chemistry and toxicity data that are collected at the UCR. Such TOC-normalization procedures may be more effective for evaluating the matching chemistry and toxicity data that are collected in future investigations than they were for interpreting chemistry and toxicity data for co-located sediment samples (i.e., the USEPA study), which comprised the majority of the data used in this investigations).

8.3 Procedures for Classifying Sediment Samples from the Upper Columbia River as Toxic and Not Toxic

In this investigation, site-specific TPSTs, generic SQGs, and slag content were evaluated to determine if they provided reliable tools for predicting toxicity to benthic invertebrates, including the survival and/or reproduction of cladocerans (*Ceriodaphnia dubia*), the survival, growth and/or biomass of midge (*Chironomus dilutus*) and amphipods (*Hyalella azteca*). However, none of these tools, alone, provided a basis for consistently classifying sediment samples from the UCR as toxic and not toxic. For this reason, a supplemental evaluation was conducted to determine if such tools could be used together to more accurately classify UCR sediment samples relative to their toxicity to benthic invertebrates. Specifically, the sediment samples categorized as non slag-affected, potentially slag-affected, or slag-affected using the Cu:Al slag identification method were further classified using Mean PEC-Q (non and potentially slag-affected) and estimated slag content (slag-affected). In addition, sediment samples categorized using the Cu:Al and Zn:Cd slag identification model were further classified using the Mean PEC-$Q_{METALS\,(1\%OC)}$ (non slag-affected) and estimated slag content (potentially slag-affected and slag-affected).

In the first analysis, the site-specific TPST for Mean PEC-Q based on *C. dilutus* of 0.85 was used to classify the non slag-affected and potentially slag-affected sediment samples (based on the Cu:Al slag identification model) for all endpoints (Table 8.3). The results of this evaluation show that only 2.6% (1 of 39) sediment samples in this group (when considering the cladoceran endpoints only) exceeded the Mean PEC-Q threshold of 0.85. The mean response for both survival and reproduction decreased in the sediment samples that exceeded this benchmark. In addition, none (0 of 37) of the non slag-affected or potentially slag-affected samples (based on the Cu:Al method) exceeded the TPST of 0.85 when considering either the midge or amphipod endpoints. The slag-affected samples (identified using the Cu:Al slag identification model) were classified based on estimated slag content (i.e., between 5% and 20% slag, 20% and 40% slag, and greater than 40% slag). For *C. dubia* survival and reproduction, mean control or reference-adjusted response decreased consistently with increasing slag content (97.8%, 83.5% , and 70.7% for survival; 102%, 81.4%, and 47.6% for reproduction; Table 8.4). Similarly, for both midge ©. *dilutus*) and amphipod (*H. azteca*) growth and biomass, a similar trend was observed (Table 8.4). However, neither midge nor amphipod survival decreased across the estimated slag content gradient, indicating the importance of considering non-lethal endpoints in sediment assessments in the UCR (Table 8.4). Overall, 80% of the matching sediment chemistry and sediment toxicity samples (64 of 80) were classified using these two methods. These results demonstrate that slag content is an important determinant of sediment toxicity for slag-affected sediment samples and can be used to classify samples relative to their toxicity to benthic invertebrates.

In the second analysis, the Mean PEC-$Q_{METALS\ (1\%OC)}$ of 0.1 (which is generally consistent with the SQS sediment toxicity thresholds established by the Confederated Tribes of the Colville Reservation) was used to classify the non slag-affected sediment samples (identified using the Cu:Al and Zn:Cd slag identification model) for all endpoints (Table 8.5). The results of this evaluation show that the control or reference-adjusted responses generally decrease above the PEC-$Q_{METALS\ (1\%OC)}$ threshold of 0.1 relative to sediment samples with PEC-$Q_{METALS\ (1\%OC)}$ below 0.1 (midge survival, growth and biomass; and amphipod survival, growth, and biomass; Table 8.5). The potentially slag-affected, and slag-affected sediment samples (identified using the Cu:Al and Zn:Cd slag identification model) were further classified based on the estimated slag content in the sediments (i.e., less than 5% slag, between 5% and 20% slag, 20% and 40% slag, and greater than 40% slag). For *C. dubia* survival and reproduction, mean control or reference-adjusted responses decreased when slag content exceeded 40% (Table 8.6). A similar pattern was exhibited for both midge ©. *dilutus*) growth and biomass and for amphipod (*H. azteca*) survival, growth, and biomass (Table 8.6). Overall, 90% of the matching sediment chemistry and sediment toxicity samples (72 of 80) were classified using these methods. These results show that slag content is an important factor that needs to be considered when evaluating sediment samples from the UCR. In addition, these results show that the toxicity of potentially slag-affected samples cannot be accurately predicted based on slag content alone. Therefore, other, chemical-related factors, need to be considered when evaluating potentially slag-affected sediment samples from the UCR.

Based on the results of the primary and supplemental data analyses, it is apparent that no single tool can provide a consistently accurate basis for classifying sediment samples from the UCR as impacted and not impacted to benthic invertebrates. However, it may be possible to improve correct classification rates by integrating two or more assessment tools into a framework that explicitly acknowledges one of the key factors that fundamentally influences sediment toxicity in the study area (i.e., the slag content of sediment samples). Accordingly, a sediment classification system was developed for the UCR that integrates two types of sediment assessment tools, including (Figure 8.1):

- Slag identification methods; and,
- Site-specific TPSTs.

In this framework, sediment samples are first classified based on the estimated percent slag in the sample (using methods described in Appendix 4). Sediment samples with < 5% slag (i.e., non slag-affected and potentially slag-affected samples) are first classified based on the Mean PEC-$Q_{METALS(1\%OC)}$. Samples with a Mean PEC-$Q_{METALS(1\%OC)}$ < 0.1 are classified as not toxic, whereas samples with a Mean PEC-$Q_{METALS(1\%OC)}$ $\geq$ 0.1 are classified as potentially toxic, samples in this latter classification are subsequently categorized as likely not toxic, possibly toxic, or likely toxic based on the Mean PEC-Q. Samples with a Mean PEC-Q of < 0.1 are deemed likely not toxic, samples with a Mean PEC-Q between 0.1 and 0.67 are categorized as possibly toxic and those with a Mean PEC-Q > 0.67 are categorized as likely toxic. Sediment samples with $\geq$ 5% slag are classified based on the estimated percent slag of the sample; samples with between 5 and 20% slag are classified as potentially toxic, samples with between 20 and 40% slag are classified as likely toxic, and those samples with $\geq$ 40% slag are classified as highly toxic.

8.4 Procedures for Collecting Matching Sediment Chemistry and Toxicity Data

The results of this investigation indicate that the CRMs for many COPCs/COPC mixtures/slag indicators and toxicity test endpoints exhibit substantial variability. While some of the variability observed in these relationships likely reflects the inherent variability in the measurements of sediment chemistry and/or sediment toxicity, it is likely that the methods used, or not used, to collect the sediment and associated samples for chemical analysis, toxicity testing, and pore-water characterizations in the Phase 1 Sediment Sampling Program contributed substantially to the variability in the underlying data. In addition, the sample handling and preparation methods used in the Phase 1 Sediment Sampling program may have contributed to the observed variability in the CRMs derived from the sediment chemistry and toxicity data collected by USEPA in 2005.

Development of reliable TPSTs with high predictive ability for site-related COPCs, COPC mixtures, and/or indicators of slag content will be a primary focus of the Phase 2 Sediment Sampling Program for the UCR. To maximize the likelihood that the data collected in the future will support the development of stronger relationships between sediment chemistry, pore-water chemistry, and sediment toxicity, several factors need to be considered in the design of the sampling program, including:

- Sampling locations need to be carefully selected to provide broad gradients in the concentrations of site-related COPCs/COPC mixtures/slag indicators for the various types (or groups) of sediment samples that occur within the UCR. The methods used to select sampling stations need to consider the distribution of COPCs in the study area, including metals, PAHs, PCBs, pesticides, and PCDDs/PCDFs;

- Sediment samples need to be collected in a manner that ensures that toxicity test results can reliably be interpreted relative to accurate measures of exposure of benthic invertebrates (i.e., toxicity test organisms) to COPCs, COPC mixtures, and slag indicators. To achieve this objective, samples for chemical analysis and toxicity testing should be true splits of field-collected sediment. Samples of sediments for analysis for SEM and AVS should be obtained from chemistry-only replicates prepared in advance of toxicity testing. Pore-water samples for evaluating exposure to COPCs during the toxicity tests need to be obtained, using peepers, from the chemistry-only replicates prepared in advance of toxicity testing (Centrifugation of sediment samples can be used to obtain pore-water samples for certain analysis that require larger volumes of water; e.g., major ions); and,
- Sediment samples should be sieved in the field to ensure that measurements of sediment chemistry (which should be conducted principally on the <2.00 mm fraction) and evaluations of toxicity to benthic invertebrates generate data that are comparable (note: many of the samples collected in the Phase 1 Sediment Sampling Program included material greater than 2.00 mm in diameter, which was not reflected in the sediment chemistry data).

While a variety of other factors must be considered in the design of the Phase 2 Sediment Sampling Program, the three factors identified should be considered in the design and implementation of future investigations of sediment chemistry and toxicity it the UCR.

Chapter 9 Summary and Conclusions

9.0 Introduction

This study was conducted to evaluate and interpret sediment chemistry and sediment toxicity data that were collected in the Upper Columbia River (UCR), including data collected by United States Environmental Protection Agency (USEPA) and others in 2005 to support the Remedial Investigation (RI) of the UCR (i.e., CEE 2006a; Schut and Stefanoff 2007; Stefanoff *et al.* 2006), and two comparable data sets (Besser *et al.* 2008; Bortleson *et al.* 1994). This report is intended to inform the design of future sampling programs and assessments of sediment toxicity in the UCR. To support this goal, the following study objectives were identified:

- Acquire and collate sediment chemistry and sediment toxicity data from the study area, including (but not limited to) the data collected in the USEPA Phase 1 Sediment Sampling Program under the RI of the UCR;
- Develop methods for advancing interpretation of the sediment toxicity data that facilitate designation of sediment samples as toxic or not toxic through consideration of reference conditions in the study area (i.e., using a reference envelope approach);
- Develop methods for advancing the interpretation of sediment chemistry and/or pore-water chemistry data from the study area [i.e., by developing and evaluating site-specific thresholds for predicting sediment toxicity (TPSTs) for individual chemicals of potential concern (COPCs), COPC mixtures, and/or slag indicators in sediment and/or pore water]; and,
- Identify gaps in the existing knowledge base and the actions that need to be taken to fill such data gaps.

9.1 Summary

9.1.1 Study Approach

This investigation was conducted to evaluate and interpret the sediment toxicity and sediment chemistry data that were collected during the Phase 1 Sediment Sampling Program of the UCR and other investigations of sediment quality conditions in the study area. A step-wise process was used to evaluate and compile the chemistry and toxicity data obtained during the sediment sampling programs that have been conducted in the UCR watershed, to develop site-specific TPSTs, and to evaluate the reliability and predictive ability of the TPSTs. This process consisted of ten main steps, including:

- Acquire and evaluate potentially-relevant data sets (see Section 6.1);
- Compile sediment chemistry and sediment toxicity data in a geographic information system (GIS)-compatible relational database (see Section 6.2);
- Evaluate various approaches for designating sediment samples as toxic or not toxic to benthic invertebrates (see Section 6.3);
- Establish and apply criteria for identifying reference sediment samples within the study area (procedures for estimating the slag content of sediment samples from the UCR are discussed in Chapter 5);
- Develop a reference envelope for each toxicity test endpoint (see Section 6.5);
- Normalize toxicity test response data (see Section 6.6);
- Designate each sediment sample as toxic or not toxic for each toxicity test endpoint, for each toxicity test, and for all toxicity tests combined (see Section 6.7);
- Evaluate the nature and extent of sediment toxicity (see Section 6.8);
- Develop and refine preliminary concentration-response models (CRMs) for selected COPCs, COPC mixtures, and slag indicators (see Section 7.1);

- Derive TPSTs for each of the selected COPCs, COPC mixtures, and slag indicators (see Section 7.2);
- Evaluate the reliability and predictive ability of the TPSTs for selected COPCs, COPC mixtures, and slag indicators (see Section 7.3); and,
- Identify TPSTs that can be used to accurately classify sediment samples from the UCR as toxic and not toxic (see Section 8.0).

9.1.2 Database Development

A total of 18 candidate data sets were identified and evaluated for possible inclusion in the project database. Of these, three studies were considered to provide sediment chemistry and sediment toxicity of sufficient quality and/or spatial coverage to support evaluation of relationships between sediment toxicity and sediment chemistry in the UCR (Besser *et al.* 2008; Bortleson *et al.* 1994; CEE 2006a, Schut and Stefanoff 2007, and, Stefanoff *et al.* 2006). The results of these studies provided data on the concentrations of numerous COPCs and conventional variables in sediment samples from the UCR, including metals, uranium, semi-volatile organic compounds (SVOCs), pesticides, polychlorinated biphenyls (PCBs), acid volatile sulfides (AVS), simultaneously extracted metals (SEM), total organic carbon (TOC), and/or particle size. Pore-water samples were analyzed for dissolved target analyte list (TAL) metals and uranium. These studies also reported the results of whole-sediment toxicity tests with up to three indicator species, including amphipods, *Hyalella azteca*, in 28-d exposures (Endpoints: Survival, growth, and biomass), midges, *Chironomus dilutus*, in 10-d exposures (Endpoints: Survival, growth, and biomass), and cladocerans, *Ceriodaphnia dubia*, in 7-d exposures (Endpoints: Survival and reproduction). All of the data deemed to be relevant to the current investigation were compiled in a GIS-compatible relational database.

Although data from all three studies were considered to be useable in this evaluation, there were uncertainties associated with the chemistry and toxicity that could influence their interpretation. More specifically, the pore-water chemistry data in the 2005 USEPA study were generated using sediment samples that did not match the sediment toxicity data (i.e., samples for pore water analysis were generally co-located with, but not generated using splits of, sediment samples for chemical analysis and toxicity testing). The results of studies conducted on the Clark Fork River, MT indicate that within-station variability in the chemical characteristics of sediments can be similar to the variability in sediment chemistry across the entire site (Brumbaugh *et al.* 1994), which greatly increases uncertainty in the exposure estimates for toxicity test organisms. Furthermore, the pore-water samples in the 2005 USEPA study were obtained by centrifugation of field collected sediment samples. Application of such sampling methods tends to result in higher and more variable results for metal analyses (Carignan *et al.* 1985). Importantly, at least some of the toxicity test results for the 2005 USEPA study may have been influenced by the use of marginally suitable overlying water and/or nutritional challenges during toxicity testing. All of these factors contribute to uncertainty in the interpretation of the available data, particularly for developing relationships between chemistry and toxicity.

Sediment chemistry, pore-water chemistry, and sediment toxicity data were compiled for a total of 80 locations in the vicinity of the UCR (Besser *et al.* 2008, n = 8; Bortleson *et al.* 1994, n = 16; CEE 2006a, Schut and Stefanoff 2007, and Stefanoff *et al.* 2006, n = 56). Most of these sampling stations were located within the UCR (n = 71); the remainder of the sampling stations were located in tributaries to the UCR (n = 9). The available data for each of these stations were evaluated to identify the stations that could be used to characterize reference conditions within the study area. The samples that met both the chemical and biological criteria were identified as reference samples (including within-site and external reference samples) and used to develop the reference envelope for each toxicity test endpoint for each species. Because substantial inter-batch and inter-study variability was observed for both the control and reference samples in some of the studies, all of the response data was either reference- or control-normalized prior to conducting subsequent data analyses.

9.1.3 Evaluation of the Slag Content of Sediment Samples

Characterization of slag content of sediments is an important step in the evaluation of sediment chemistry and toxicity within the UCR study area. Slag contains elevated levels of metals, which may be differentially available compared to typical riverine sediments or sediments impacted by effluent wastes within the UCR, and may act as a confounding factor in the evaluation and interpretation of sediment chemistry and toxicity.

Slag content was characterized based on the normalization of the concentrations of indicator metals to the concentrations of a reference metal (i.e., the UCR study area). The characterization of slag content in UCR sediments included selection of reference metals, selection of indicator metals, development of slag identification models, and, model evaluation.

Three models were developed to aid in characterizing the slag content of sediments in the UCR: the Cu:Al model (Figure 5.3), based on the ratio of copper to aluminum concentrations in surficial sediments of the UCR; the Cu:Al and Zn:Cd model (Figure 5.4), which incorporated the ratio of zinc to cadmium in surficial sediments; and, the Fe:Al and Zn:Cd model (Figure 5.5), which was based on the ratio of iron to aluminum and the ratio of zinc to cadmium in surficial sediments. The three slag characterization models were evaluated to determine their applicability for characterizing sediment samples from the UCR.

Of the three models evaluated, only the Cu:Al ratio model met all four of the selection criteria. In addition, classifications of sediment samples relative to slag content using this model generally agreed with visual observations. Therefore, the Cu:Al ratio model is recommended for assisting the classification of sediment samples from the UCR as typical (i.e., non slag-affected), slag-influenced (i.e., potentially slag-affected), or slag-dominated (i.e., slag-affected) sediment samples. Other techniques for evaluating the nature and quantity of slag in UCR sediment samples should also be collected in future studies to help calibrate slag classification models based on geochemical data.

9.1.4 Sediment Toxicity

A reference-envelope approach was used to support identification of sediment samples that are toxic to benthic invertebrates on a site-wide basis. The reference-envelope approach is a procedure for assessing sediment toxicity that was developed to overcome the limitations associated with the use of control sediments for this purpose, including accounting for differences in the non-contaminant characteristics of test sediments and for overcoming the low statistical power associated with comparing many test results to a single control. This procedure involved identification of reference sediment samples, normalizing the toxicity data to reflect reference or control responses, developing a reference envelope for each toxicity test endpoint, and designating each sediment sample as toxic (i.e., effect value is lower than the normal range of responses for reference sediment samples) or not toxic (i.e., effect value is within or higher than the normal range of responses for reference sediment samples) for each toxicity test endpoint, for each toxicity test, and for all toxicity tests combined. The results of 28-d whole-sediment toxicity tests with amphipods (*H. azteca*; Endpoints: Survival, growth, and biomass) indicated that 19 to 53% of the sediment samples from the UCR (n = 57) were toxic, depending on the endpoints that were considered. By comparison, 18 to 81% of the sediment samples from the UCR (n = 57) were found to be toxic to midges ©. *dilutus*) in 10-d whole-sediment toxicity tests, depending on the endpoints considered. UCR sediments tended to be less toxic to the cladoceran, *C. dubia*, in 7-d whole-sediment toxicity tests, 16 to 25% of the sediment samples from the UCR (n = 64) were designated as toxic to this species (depending on the endpoints considered). Overall, 58 of the 71 (82%) sediment samples from the UCR that were evaluated using the reference envelope approach were found to be toxic to amphipods, midges, or cladocerans. When sediment samples are designated as toxic or not toxic based on any of the eight toxicity test endpoints, the incidence of toxicity (IOT) was similar in

Reach 1 (89%; n = 19), Reach 3 (86%; n = 7), Reach 4 (95%; n = 19), Reach 5 (86%; n = 7), and Reach 6 (86%; n = 7). The IOT was lower in Reach 2, within which 5 of the 12 sediment samples were designated as toxic to benthic invertebrates (42%; Table 6.8).

Somewhat different results were obtained when IOT was determined based on further classification of toxic sediment samples into two categories, including moderately impacted (i.e., < 10% reduction in survival, growth, or reproduction relative to lower limit of the reference envelope) and highly impacted (i.e., > 10% reduction in survival, growth, or reproduction relative to lower limit of the reference envelope) sediment samples. When only highly-impacted sediment samples were considered, the highest IOT was observed in Reach 1 (84%; n = 19). By comparison, the IOT ranged from 57% to 71% in Reaches 3, 4, 5, and 6. In Reach 2, the IOT was 25% (n = 12) when only highly-impacted samples were considered (Table 6.9).

9.1.5 Concentration-Response Model Development

A step-wise approach was used to develop site-specific CRMs using the sediment chemistry, pore-water chemistry, and/or sediment toxicity data for the UCR. First, a series of preliminary analyses were conducted to identify the COPCs, COPC mixtures, and slag indicators that were most likely to be correlated with the responses to toxicity test organisms (e.g., frequency of detection, comparison to conservative sediment quality guidelines; SQGs). In the next step of the process, potential relationships between the concentrations of COPCs and the responses of toxicity test organisms were identified by conducting Spearman-Rank correlation analysis on the underlying data. To support this analysis, the underlying data were divided into three groups based on estimated slag content. The results of this analyses showed that the relationships between concentration and response tended to be strongest for the slag-affected samples and, to a lesser extent, for all samples combined. Concentration-response models were developed for each of the COPCs, COPC mixtures, and slag indicators in sediment that were retained following these initial analyses. Following their development, these CRMs were examined to identify the COPC/COPC mixture/slag indicator-toxicity test endpoint pairs that would be most relevant for derivation of TPSTs (i.e., $r^2 > 0.4$; $p < 0.05$; MacDonald *et al.* 2002; 2003; 2005a; 2005b; 2009; 2010).

9.1.6 Development and Evaluation of Preliminary Thresholds for Predicting Sediment Toxicity

Overall, 61 COPC/COPC mixture/slag indicator-endpoint pairs were selected for deriving TPSTs (Figures A6.1 to A6.61). As none of the COPC/COPC mixture/slag indicator-pairs for pore water met the selection criteria for identifying potential risk drivers, TPSTs for pore water were not developed in this investigation. Two types of TPSTs, including low-impact ($TPST_{LI}$s) and high-impact ($TPST_{HI}$s), were developed using the CRMs for whole sediment. The low-impact TPSTs were established at the concentrations of COPCs/COPC mixtures/slag indicators that corresponded to the lower limit of the reference envelope for the selected toxicity test endpoint. The high-impact TPSTs were established as the concentrations of COPCs/COPC mixtures/slag indicators that corresponded to a 10% reduction in survival, growth, biomass, or reproduction, compared to the lower limit of the reference envelope.

The reliability and predictive ability of these TPSTs were evaluated using the available sediment chemistry and sediment toxicity data from the UCR. The TPSTs were considered to be reliable and/or predictive of sediment toxicity if the IOT was <20% below the TPST, the IOT was >50% above the TPST, and the rate of correct classification of sediment samples as toxic and not toxic was 80%.

The results of this evaluation indicated that most of the site-specific TPSTs developed in this investigation provide a reliable basis for identifying toxic and not toxic slag-affected sediment samples in the UCR (i.e., for correctly classifying the sediment samples used to derive the TPSTs as toxic or not toxic, for the endpoint used to derive the TPSTs; i.e., TPST based on midge biomass typically did a good job of predicting impacts on midge biomass associated with exposure to UCR sediments). The TPSTs developed using data on the measurement endpoints for the cladoceran toxicity test tended to be the most reliable, with the TPSTs for 10 of 13 COPCs/COPC mixtures/slag indicators based on survival and for 11 of 15 COPCs/COPC mixtures/slag indicators based on reproduction exhibiting high reliability. By comparison, the TPSTs for only one of the COPCs/COPC mixtures/slag indicators (i.e., Cu:Al ratio) based on midge growth or biomass were shown to be reliable. The TPSTs for several of the COPCs/COPC mixtures/slag indicators based on amphipod growth or biomass were reliable, with the TPSTs for metal mixtures performing better than the TPSTs for individual metals.

The site-specific TPSTs were also evaluated to determine their predictive ability. The results of this evaluation indicate that none of the TPSTs derived using sediment chemistry and sediment toxicity data from the UCR provide an accurate basis for classifying all types of sediment samples as toxic or not toxic for all of the endpoints measured. That is, the TPST correctly classified sediment samples relative to their toxicity to benthic invertebrates or some toxicity test endpoints, but not others. This result is not surprising considering the results of the sediment toxicity tests, which showed that the various species and endpoints exhibited differential sensitivity to the COPCs, COPC mixtures, and slag indicators in UCR sediments, and the variability of the fate and transport of smelter waste-associated contaminants in the system. It is also likely that the conditions maintained during toxicity testing were only marginally suitable for midges and/or amphipods. This factor may have contributed to the high IOT for the low chemistry sediment samples. It is also possibly that unmeasured COPCs contributed to the variability in the CRMs.

The results of this investigation indicate that slag content is an important determinant of sediment toxicity in the UCR. For this reason, a sediment assessment framework was developed that relies on:

- Classification of sediment samples based on slag content; and,

- Application of numerical TPSTs.

When used together, such assessment tools provide a reliable basis for classifying sediment samples from the UCR as toxic or not toxic. Additional data should be collected to support validation and/or refinement of the recommended framework.

9.2 Conclusions

This investigation was conducted to provide an independent interpretation of the sediment chemistry and sediment toxicity data collected by USEPA in 2005 to support the RI and by other investigators to support evaluations of sediment quality conditions in the UCR. The principal conclusions that emerged from this investigation include:

- Sediments from the UCR are primarily contaminated by metals. However, UCR sediments are also known to contain other COPCs, such as polycyclic aromatic hydrocarbons, PCBs, organochlorine pesticides, and polychlorinated dibenzo-*p*-dioxins/polychlorinated dibenzofurans. The highest concentrations of metals were typically observed in Reach 1 of the study area;
- The results of chemical analyses and visual observations of sediment samples show that discharges of smelter slag have contaminated sediments within the UCR. Several procedures for classifying sediment samples from the UCR relative to slag content were developed and evaluated. Sediments located within Reach 1 had the highest accumulation of coarse-grained slag in the samples analyzed, as indicated by Cu:Al ratios and logged visual observations;
- Adverse effects on the survival, growth, biomass, and reproduction of aquatic invertebrates, including sediment-dwelling organisms, are associated with exposure to sediments from the UCR. Sediment toxicity was observed throughout the study area. Based on available data, the

highest IOT was observed in Reach 1 for amphipods, Reaches 4 and 5 for midges, and Reach 5 for cladocerans. Reach 4 had the highest IOT when any endpoint for any species was considered, however, the differences in IOT among the upper reaches were generally relatively small. Therefore, exposure to contaminated sediments poses potential risks to benthic communities utilizing habitats in the UCR;

- The highest IOT was observed in slag-affected sediment samples for most of the toxicity test endpoints considered (i.e., when slag-affected sediment samples were identified using the Cu:Al model). However, non slag-affected sediment samples had the highest IOT when midge survival was evaluated. These results emphasize the importance of accurately identifying and considering slag content in future evaluations of sediment toxicity in the UCR;

- Among the three species tested, sediment samples from the UCR were most toxic to midge, with the biomass endpoint being the most sensitive for this species (based on IOT). Amphipods exhibited intermediate sensitivity, with survival being the most sensitive endpoint. Cladocerans appeared to be less sensitive than either of the other two species. While midge exhibited the highest frequency of toxicity, the magnitude of toxicity (MOT) tended to be highest for amphipods in the most contaminated sediment samples;

- None of the species tested responded consistently across chemical gradients, generally resulting in weak relationships between the concentrations of COPCs or slag indicators and organism responses. The strongest modeled correlations between concentration and response were observed for: aluminum and beryllium vs. midge biomass; Mean PEC-Q and Mean $PEC\text{-}Q_{METALS(1\%OC)}$ (i.e., normalized to 1% organic carbon) vs. amphipod survival; and, beryllium, chromium, cobalt, and iron vs. amphipod growth or biomass;

- The data that were used in this investigation have certain limitations that influence their applicability for comprehensively assessing site-wide sediment quality conditions and fully resolving CRMs in the UCR. In particular, the sediment toxicity and pore-water chemistry data from the 2005 USEPA study were generated using co-located sediment samples from the UCR, rather than from splits of composite samples collected at each sampling location. Accordingly, the pore-water chemistry data do not provide a reliable basis for assessing exposure of toxicity test organisms to COPCs. In addition, pore-water chemistry data obtained by analysis of pore-water samples generated by centrifugation of UCR sediments do not provide an adequate basis for determining exposure of benthic invertebrates to COPCs in pore water. Inherent challenges and limitations in obtaining consistent and comparable pore-water samples in the field is a limiting factor. Controlled laboratory methods for obtaining pore-water samples in association with toxicity tests are preferred (e.g., through the use of peepers). Furthermore, it appears that at least some of the toxicity test results may have been influenced by the use of marginally suitable overlying water and/or toxicity test organisms may have responded to nutritional challenges during toxicity testing;

- The available sediment chemistry and sediment toxicity data do not support the development of robust CRMs that apply throughout the UCR or site-specific TPSTs that provide a consistently accurate basis for comprehensively classifying the sediment samples from the study area as toxic or not toxic (i.e., for predicting the presence and absence of sediment toxicity). Therefore, it is essential that sufficient quantities of high quality data be generated in the near term to support model development and validation;

- Generic SQGs do not always provide an accurate basis for classifying all sediment samples from the study area as toxic or not toxic (i.e., based on the concentrations of COPCs). The sediment quality standards (mean PEC-Q of 0.1) established by the Confederated Tribes of the Colville

Reservation (MacDonald and Ingersoll 2002) are adequately protective against sediment toxicity in the UCR (i.e., sediment toxicity is only infrequently observed at mean PEC-Qs of ≤ 0.1). However, they may not be consistently predictive of sediment toxicity, when used alone (i.e., the IOT to benthic invertebrates is variable at mean PEC-Qs of >0.1). Their applicability in this regard is likely to be enhanced by applying them selectively to non slag-affected and possibly slag-affected sediments from the study area (i.e., the IOT to benthic invertebrates is likely to be higher when the slag-affected samples are eliminated from the analyses);

- The Phase 1 sediment sampling program data set has limitations that constrain its use for establishing site-wide CRMs for predicting sediment toxicity in the UCR. The underlying sediment chemistry or sediment toxicity data can be used separately in evaluations of sediment quality conditions in the UCR. These conclusions also emphasize the need to establish clear expectations for the Phase 2 Sediment Sampling Program that provide detailed descriptions of requirements relative to:

  1. Site-wide study design, including (but not limited to) the selection of representative sampling sites, selection of reference sites, types of samples to be collected, and timing of the sampling program;
  2. Methods for collecting, handling, processing and preparing whole-sediment and pore-water samples, including sieving of sediment samples to optimize collection of the <2.00 mm size fraction for toxicity testing and pore-water sampling using peepers during laboratory toxicity testing;
  3. Chemical analytes that need to be measured in each media type;
  4. Independent classification of sediment samples relative to slag content and effluent-impacted aquatic environments over a range of spatial locations along the system;
  5. Toxicity testing, including, species (e.g., amphipods, midges, mussels), endpoints (e.g., survival, growth, biomass, reproduction), holding times, and associated methods;

6. Bioaccumulation testing that may be important in support of toxicity assessment, including species and associated methods;
7. Collection and analysis for invertebrate-tissue samples from hard-bottom and soft-bottom areas within the UCR, including freshwater mussels;
8. Toxicity identification evaluation procedures, which might be appropriate for selected sediment samples that are found to be toxic, but whose responses cannot be adequately understood; and,
9. Systematic toxicity testing to ensure that the selected toxicity testing laboratories have the capability to conduct the required toxicity tests successfully (e.g., to demonstrate the quality of overlying water and control sediments).

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Tables

Table 3.1. Listing and classification of chemicals of potential concern in the Upper Columbia River study area, based on physical and chemical properties.

Chemical of Potential Concern (COPC)	Substances that Partition into			Bioaccumulative Substances
	Water	Sediments	Floodplain/ Terrestrial Soils	
Metals and Metalloids				
Aluminum (Al)	✓	✓	✓	
Antimony (Sb)	✓	✓	✓	
Arsenic (As)	✓	✓	✓	
Barium (Ba)	✓	✓	✓	
Beryllium (Be)	✓	✓	✓	
Bismuth (Bi)	✓	✓	✓	
Cadmium (Cd)	✓	✓	✓	✓
Chromium (Cr)	✓	✓	✓	
Cobalt (Co)	✓	✓	✓	
Copper (Cu)	✓	✓	✓	✓
Germanium (Ge)	✓	✓	✓	
Gold (Au)	✓	✓	✓	
Indium (In)	✓	✓	✓	
Iron (Fe)	✓	✓	✓	
Lead (Pb)	✓	✓	✓	✓
Lithium (Li)	✓	✓	✓	
Manganese (Mn)	✓	✓	✓	
Mercury (Hg) and Methyl mercury (m-Hg)	✓	✓	✓	✓
Nickel (Ni)	✓	✓	✓	
Selenium (Se)	✓	✓	✓	✓
Silver (Ag)	✓	✓	✓	
Thallium (Tl)	✓	✓	✓	✓
Tin (Sn)	✓	✓	✓	
Vanadium (V)	✓	✓	✓	
Zinc (Zn)	✓	✓	✓	✓
Major Ions				
Calcium (Ca)	✓			
Potassium (K)	✓			
Sodium (Na)	✓			
Sulfate (SO^{4-})	✓			
Nutrients				
Ammonia (NH_3 and NH_4^+)	✓			
Nitrite (NO_2)	✓			
Nitrate (NO_3)	✓			
Phosphorus (P)	✓			
Chlorine (Cl_2)	✓			

Table 3.1. Listing and classification of chemicals of potential concern in the Upper Columbia River study area, based on physical and chemical properties.

Chemical of Potential Concern (COPC)	Substances that Partition into			Bioaccumulative Substances
	Water	Sediments	Floodplain/ Terrestrial Soils	
Conventional variables				
Total suspended solids (TSS)	✓			
Total gas pressure (TGP or TDG)	✓			
Microbiological variables				
Fecal coliforms	✓			
E. coli	✓			
Enterococci	✓			
Polycyclic Aromatic Hydrocarbons (PAHs) [1]				
Low Molecular Weight PAHs				
2-Methylnaphthalene		✓	✓	
Acenaphthene*		✓	✓	
Acenaphthylene*		✓	✓	
Anthracene*		✓	✓	
Fluorene*		✓	✓	
Naphthalene*		✓	✓	
Phenanthrene*		✓	✓	
High Molecular Weight PAHs				
Benz(a)anthracene*		✓	✓	✓
Benzo(a)pyrene*		✓	✓	✓
Benzo(b)fluoranthene*		✓	✓	
Benzo(e)pyrene*		✓	✓	
Benzo(b+k)fluoranthene		✓	✓	
Benzo(g,h,i)perylene*		✓	✓	
Benzo(k)fluoranthene*		✓	✓	
Chrysene*		✓	✓	✓
Dibenz(a,h)anthracene*		✓	✓	✓
Fluoranthene*		✓	✓	✓
Indeno(1,2,3-c,d)pyrene*		✓	✓	
Perylene*		✓	✓	
Pyrene*		✓	✓	✓
*Alkylated PAHs**				
C1-Benz(a)anthracenes/chrysenes		✓	✓	
C1-Fluoranthenes/pyrenes		✓	✓	
C1-Fluorenes		✓	✓	
C1-Naphthalenes		✓	✓	
C1-Phenanthrenes/anthracenes		✓	✓	
C2-Benz(a)anthracenes/chrysenes		✓	✓	
C2-Fluorenes		✓	✓	
C2-Naphthalenes		✓	✓	

Table 3.1. Listing and classification of chemicals of potential concern in the Upper Columbia River study area, based on physical and chemical properties.

Chemical of Potential Concern (COPC)	Substances that Partition into			Bioaccumulative Substances
	Water	Sediments	Floodplain/ Terrestrial Soils	
Alkylated PAHs (cont.)*				
C2-Phenanthrenes/anthracenes		✓	✓	
C3-Benz(a)anthracenes/chrysenes		✓	✓	
C3-Fluorenes		✓	✓	
C3-Naphthalenes		✓	✓	
C3-Phenanthrenes/anthracenes		✓	✓	
C4-Benz(a)anthracenes/chrysenes		✓	✓	
C4-Naphthalenes		✓	✓	
C4-Phenanthrenes/anthracenes		✓	✓	
Total PAHs		✓	✓	
ΣESB-TU_{FCV}[2]				
Pesticides [3]				
2,4'-DDD	✓	✓	✓	✓
2,4'-DDE	✓	✓	✓	✓
2,4'-DDT	✓	✓	✓	✓
4,4'-DDD	✓	✓	✓	✓
4,4'-DDE	✓	✓	✓	✓
4,4'-DDT	✓	✓	✓	✓
Aldrin	✓	✓	✓	✓
Atrazine	✓	✓	✓	✓
BHC (alpha)	✓	✓	✓	✓
BHC (beta)	✓	✓	✓	✓
BHC (delta)	✓	✓	✓	✓
BHC (gamma) - Lindane	✓	✓	✓	✓
Chlordane (alpha)	✓	✓	✓	✓
Chlordane (gamma)	✓	✓	✓	✓
Dieldrin	✓	✓	✓	✓
Endosulfan I	✓	✓	✓	✓
Endosulfan II	✓	✓	✓	✓
Endosulfan sulfate	✓	✓	✓	✓
Endrin	✓	✓	✓	✓
Endrin aldehyde	✓	✓	✓	✓
Endrin ketone	✓	✓	✓	✓
Heptachlor	✓	✓	✓	✓
Heptachlor epoxide	✓	✓	✓	✓
Hexachlorobenzene	✓	✓	✓	✓
Hexachlorobutadiene	✓	✓	✓	✓
Methoxychlor	✓	✓	✓	✓
Nonachlor (cis-)	✓	✓	✓	✓
Nonachlor (trans-)	✓	✓	✓	✓
Oxychlordane	✓	✓	✓	✓

Table 3.1. Listing and classification of chemicals of potential concern in the Upper Columbia River study area, based on physical and chemical properties.

Chemical of Potential Concern (COPC)	Substances that Partition into			Bioaccumulative Substances
	Water	Sediments	Floodplain/ Terrestrial Soils	
Chlorinated organic compounds				
Toxaphene	✓	✓	✓	✓
2,3,4,5-tetrachlorophenol		✓	✓	✓
2,3,4,6-tetrachlorophenol		✓	✓	✓
2,3,4-trichlorophenol		✓	✓	✓
2,3,5,6-tetrachlorophenol		✓	✓	✓
2,3,5-trichlorophenol		✓	✓	✓
2,3,6-trichlorophenol		✓	✓	✓
2,3-dichlorophenol		✓	✓	✓
2,4,5-trichlorophenol		✓	✓	✓
2,4,6-trichlorophenol		✓	✓	✓
2,4/2,5-dichlorophenol		✓	✓	✓
2,6-dichlorophenol		✓	✓	✓
3,4,5,6-tetrachlorocatechol		✓	✓	
3,4,5,6-tetrachloroguaiacol		✓	✓	
3,4,5,6-tetrachloroveratrole		✓	✓	
3,4,5-trichlorocatechol		✓	✓	
3,4,5-trichloroguaiacol		✓	✓	
3,4,5-trichlorophenol		✓	✓	✓
3,4,5-trichlorosyringol		✓	✓	
3,4,5-trichloroveratrole		✓	✓	
3,4,6-trichloroveratrole		✓	✓	
3,4-dichlorocatechol		✓	✓	
3,4-dichloroguaicol		✓	✓	
3,4-dichlorophenol		✓	✓	✓
3,5-dichlorocatechol		✓	✓	
3,5-dichlorophenol		✓	✓	✓
3,5-dichlorosyringol		✓	✓	
3,6-dichlorocatechol		✓	✓	
3-chlorocatechol		✓	✓	
3-chlorosyringol		✓	✓	
4,5,6-trichloroguaiacol		✓	✓	
4,5-dichlorocatechol		✓	✓	
4,5-dichloroguaicol		✓	✓	
4,5-dichloroveratrole		✓	✓	
4,6-dichloroguaicol		✓	✓	
4-chlorocatechol		✓	✓	
4-chloroguaiacol		✓	✓	
4-chlorophenol		✓	✓	✓
5,6-dichlorovanillin		✓	✓	
5-chloroguaiacol		✓	✓	
5-chlorovanillin		✓	✓	
6-chloroguaiacol		✓	✓	

Table 3.1. Listing and classification of chemicals of potential concern in the Upper Columbia River study area, based on physical and chemical properties.

Chemical of Potential Concern (COPC)	Substances that Partition into			Bioaccumulative Substances
	Water	Sediments	Floodplain/ Terrestrial Soils	
Chlorinated organic compounds (continued)				
6-chlorovanillin		✓	✓	
Pentachlorophenol		✓	✓	✓
Polychlorinated Biphenyls (PCBs)				
Aroclors				
Aroclor 1016		✓	✓	✓
Aroclor 1221		✓	✓	✓
Aroclor 1232		✓	✓	✓
Aroclor 1242		✓	✓	✓
Aroclor 1248		✓	✓	✓
Aroclor 1254		✓	✓	✓
Aroclor 1260		✓	✓	✓
Aroclor 1262		✓	✓	✓
Aroclor 1268		✓	✓	✓
PCB Homologs				
Monochlorobiphenyl		✓	✓	✓
Dichlorobiphenyl		✓	✓	✓
Trichlorobiphenyl		✓	✓	✓
Tetrachlorobiphenyl		✓	✓	✓
Pentachlorobiphenyl		✓	✓	✓
Hexachlorobiphenyl		✓	✓	✓
Heptachlorobiphenyl		✓	✓	✓
Octachlorobiphenyl		✓	✓	✓
Nonachlorobiphenyl		✓	✓	✓
Decachlorobiphenyl		✓	✓	✓
PCB Congeners		✓	✓	✓
Total PCBs		✓	✓	✓
Resin Acids				
Abietic Acid		✓	✓	
Chlorodehydroabietic Acid		✓	✓	
Dehydroabietic Acid		✓	✓	
Dehydroisopimaric Acid		✓	✓	
Dichlorodehydroabietic Acid		✓	✓	
Isopimaric Acid		✓	✓	
Neoabietic Acid		✓	✓	
Palustric Acid		✓	✓	
Pimaric Acid		✓	✓	
Sandaracopimaric Acid		✓	✓	

Table 3.1. Listing and classification of chemicals of potential concern in the Upper Columbia River study area, based on physical and chemical properties.

Chemical of Potential Concern (COPC)	Substances that Partition into			Bioaccumulative Substances
	Water	Sediments	Floodplain/ Terrestrial Soils	
Fatty Acids				
Arachidic Acid		✓	✓	
Behenic Acid		✓	✓	
Lauric Acid		✓	✓	
Lignoceric Acid		✓	✓	
Linoleic Acid		✓	✓	
Linolenic Acid		✓	✓	
Myristic Acid		✓	✓	
Oleic Acid		✓	✓	
Palmitric Acid		✓	✓	
Stearic Acid		✓	✓	
Polychlorinated Dibenzo-p-dioxins (PCDDs)				
2,3,7,8-TetraCDD		✓	✓	✓
1,2,3,7,8-PentaCDD		✓	✓	✓
1,2,3,4,7,8-HexaCDD		✓	✓	✓
1,2,3,6,7,8-HexaCDD		✓	✓	✓
1,2,3,7,8,9-HexaCDD		✓	✓	✓
1,2,3,4,6,7,8-HeptaCDD		✓	✓	✓
OctaCDD		✓	✓	✓
Polychlorinated Dibenzofurans (PCDFs)				
2,3,7,8-TetraCDF		✓	✓	✓
1,2,3,7,8-PentaCDF		✓	✓	✓
2,3,4,7,8-PentaCDF		✓	✓	✓
1,2,3,4,7,8-HexaCDF		✓	✓	✓
1,2,3,6,7,8-HexaCDF		✓	✓	✓
1,2,3,7,8,9-HexaCDF		✓	✓	✓
2,3,4,6,7,8-HexaCDF		✓	✓	✓
1,2,3,4,6,7,8-HeptaCDF		✓	✓	✓
1,2,3,4,7,8,9-HeptaCDF		✓	✓	✓
OctaCDF		✓	✓	✓
2,3,7,8-TCDD TEQs				✓

BHC = hexachlorocyclohexane; CB = chlorinated biphenyls; CDD = chlorinated dibenzodioxins; CDF = chlorinated dibenzofurans; ESB-TU_{FCV} = equilibrium partitioning sediment benchmark toxic units, final chronic value; TEQ = toxic equivalents.

[1]PAHs indicated with an asterisk (*) contribute to the ΣESB-TU_{FCV} calculation.

[2]ΣESB-TU_{FCV} calculated according to the methods described in USEPA (2003b).

[3]Additional herbicides, insecticides, and fungicides man be identified pending a pesticide use survey.

Table 4.1. Summary of sediment sample types and number of sample locations for the Upper Columbia River remedial investigation/feasibility study (modified from CEE 2004).

Sample Type	Number of Sample Locations
Baseline Sediment Samples	132
Focus-Area Sediment Samples	122
Beach Sediment Samples	16
Tributary Sediment Samples	11
Sediment Core Samples	11
Bioassay Sediment Samples[1]	50 (49 overlap with baseline samples)
Reference Area Sediment Samples	6
Total Sediment Samples [2]	***298***

[1] Bioassay sediment sample locations overlap with the Baseline sediment sample locations, except in one location (there is an additional Bioassay sample location at RM 687).

[2] Total number of samples expected to be collected.

Table 4.2. Summary of the number of sample locations assigned to various sediment sample types and analytical suites for the Upper Columbia River remedial investigation/feasibility study (from CEE 2004).

Sample Type	Analytical Suite 1 Bioassays, Metals, PCBs, Dioxin/Furans, Ammonia, Total Sulfides, AVS/SEM, TOC, Particle Size	Analytical Suite 2 Metals, PCBs, Dioxin/Furans, TOC, Particle Size	Analytical Suite 3 Metals, TOC, Particle Size
Baseline Samples Along Select Transects in Sediment Focus Areas and Fish Sampling Areas[a]		62	
Other Baseline Samples			143
Beach Samples[b]		48	
Tributary Samples		11	
Core Samples		11	
Bioassay Samples[c]	50		
Total	***50***	***132***	***143***

AVS/SEM = acid volatile sulfides/simultaneously extracted metals; PCBs = polychlorinated biphenyls; TOC = total organic carbon.

Notes:

[a] Samples collected from transect locations at River Miles 605 (9 locations), 633 (3 locations), 637 (7 locations), 642 (7 locations), 661 (3 locations), 678 (7 locations), 692 (3 locations), 706 (7 locations), 715 (3 locations), 723 (5 locations), 732 (3 locations), 742 (5 locations). These transects correlate with the 11 designated river/reservoir areas where Phase I fish sampling activities will be conducted, six of which overlap with the sediment focus areas described herein.

[b] Assumes three samples per beach area, representing elevation 1285’, 1270’ and 1255’. Each will be collected from a discrete elevation horizon, and will consist of a composite of three grab samples collected over a lateral area of 400 to 600 feet.

[c] In all instances, a bioassay sample location will co-locate with a baseline transect sample location, and will be collected at a depth of approximately 1-3 feet below the water surface at the time of sampling.

Table 4.3. Listing of the data sets utilized in the evaluation of sediment toxicity data in the Upper Columbia River study area, summarizing control and reference toxicant test results.

Study / Toxicity Test / Endpoint Measured	# Reps per Treatment	Laboratory	Source of Control Sediment	Batch Number	Control Number	Control Response (SD)	Test Acceptability Criteria Met?	Reference Toxicant	Reference Toxicant Test Results
Stefanoff *et al.* 2006; Schut and Stefanoff 2007									
7-day WS *Ceriodaphnia dubia*									
Survival	10	CH2M HILL ASL	20 mesh washed silica sand	1	1	80% (42.2)	Yes	Sodium chloride	1.42 g/L (7-day IC_{25}); 1.03-2.00 g/L (Control Chart Limits)
				2	1	90% (31.6)	Yes	ND	ND
Reproduction	10	CH2M HILL ASL	20 mesh washed silica sand	1	1	22.8 offspring (11.5)	Yes	Sodium chloride	0.42 g/L (7-day IC_{25}); 0.21-0.90 g/L (Control Chart Limits)
				2	1	24 offspring (8.96)	Yes	ND	ND
10-day WS *Chironomus dilutus*									
Survival	8	CH2M HILL ASL	Beaver Creek sediment (Oregon)	1	1	83.8% (15.1)	Yes	Potassium chloride	6.6 g/L (48-hr LC_{50}); 0.7-7.4 g/L (95% Confidence Interval)
				2	1	88.8% (13.6)	Yes	Potassium chloride	5.1 g/L (48-hr LC_{50}); 1.6-7.4 µg/L (95% Confidence Interval)
Growth (weight)	8	CH2M HILL ASL	Beaver Creek sediment (Oregon)	1	1	1.51 mg/ (0.40)	Yes	NA	NA
				2	1	1.97 mg/L (0.18)	Yes	NA	NA
28-day WS *Hyalella azteca*									
Survival	8	NAS	Beaver Creek sediment (Oregon)	1	1	9.63% (7.4)	Yes	Cadmium chloride	7.89 µg/L (96-hr LC_{50}); 3.26-10.7 µg/L (Control Chart Limits)
				2	1	97.5% (4.6)	Yes	Cadmium chloride	4.40 µg/L (96-hr LC_{50}); 3.34-10.8 µg/L (Control Chart Limits)
Growth (weight)	8	NAS	Beaver Creek sediment (Oregon)	1	1	0.41 mg	Yes[1,2]	NA	NA
				2	1	0.38 mg	Yes[1,2]	NA	NA

Table 4.3. Listing of the data sets utilized in the evaluation of sediment toxicity data in the Upper Columbia River study area, summarizing control and reference toxicant test results.

Study / Toxicity Test / Endpoint Measured	# Reps per Treatment	Laboratory	Source of Control Sediment	Batch Number	Control Number	Control Response (SD)	Test Acceptability Criteria Met?	Reference Toxicant	Reference Toxicant Test Results
Besser *et al.* 2008									
12-day WS *Chironomus dilutus*									
Survival	8	USGS/CERC	West Bearskin (Minnesota)[3]	1	1	91.3% (4)	Yes	ND	ND
Growth (weight)	8	USGS/CERC	West Bearskin (Minnesota)[3]	1	1	0.894 mg/individual (0.02)	Yes	ND	ND
28-day WS *Hyalella azteca*									
Survival	8	USGS/CERC	West Bearskin (Minnesota)[3]	1	1	95% (10.7)	Yes	ND	ND
Growth (length)	8	USGS/CERC	West Bearskin (Minnesota)[3]	1	1	3.85 mm/individual (0.059)	NA[4]	ND	ND
Bortleson *et al.* 1994									
7-day WS *Ceriodaphnia dubia*									
Survival	10	WSU (Dayton, Ohio)	ND	1	1	90% (ND)	Yes[5]	ND	ND
				1	2	90% (ND)	Yes	ND	ND
Reproduction	10	WSU (Dayton, Ohio)	ND	1	1	14.8 young/F (10.2)	No	ND	ND
				1	2	33.3 young/F (12.8)	Yes	ND	ND

WS = whole sediment; NA = not applicable; ND = No data; SD = standard deviation; F = Female.
ASL = Applied Science Laboratory; NAS = Northwestern Aquatic Sciences; USGS/CERC = US Geological Survey/Columbia Environmental Research Center; WAS = Wright State University.

[1] ASTM test acceptability criterion for *Hyalella azteca* growth is "measurable growth of test organisms in the control sediment."

[2] The testing laboratory indicated that the *H. azteca* growth test acceptability criterion was met based on an initial average dry weight measurement of 0.03mg/individual.

[3] For this study, two control materials were tested. The results for West Bearskin Lake were not reported in the journal publication, but were obtained directly from the USGS/CERC laboratory.

[4] Initial measurements of *H. azteca* growth were not available. However, the ASTM test acceptability criterion (measurable growth) is not numerically defined. In addition, there were no growth measurements significantly < the study's reference station (ANOVA; Besser *et al.* 2008). Therefore, these data were considered to have met the *H. azteca* growth ASTM test acceptability criterion.

[5] Control 1 did not meet the test acceptability criterion for the *C. dubia* reproduction endpoint. Therefore, Control 1 was used for neither the survival endpoint nor the reproduction endpoint.

Table 5.1. Concentration of metals in slag samples collected from the Trail B.C. smelter (Nener 1992).

Chemical of Potential Concern	Sample			Mean	Standard Deviation
	Tap 1/2	Tap 3	Tap 4		
Metal (mg/kg DW)					
Aluminum	26,700	31,700	28,800	29,067	2,510
Antimony	< 25	< 25	< 25	NA	NA
Cadmium	10.7	9.1	8.2	9.3	1.3
Copper	4100	3490	2780	3460	661
Iron	279,000	339,000	321,000	313,000	30800
Lead	16	32	14	21	9.9
Manganese	5330	6670	6020	6010	670
Zinc	25,500	26,100	19,900	23,800	3420

DW = dry weight; NA = not applicable.

Table 5.2. Classification of slag content in surficial sediments collected from the Upper Columbia River.

Station	Slag Identification Model		
	Cu:Al	Cu:Al and Zn:Cd	Fe:Al and Zn:Cd
RM744A2(X3)	S	S	S
RM744A1(X1)	S	S	S
RM743A2(X3)	S	S	S
RM743A1(X1)	S	S	S
RM742A2(X5)	S	S	S
RM742A1(X1)	S	S	S
RM741A1(X3)	S	S	S
RM740A1(X1)	S	PS	PS
RM739A1(X3)	S	S	S
RM738A1(X3)	S	S	S
RM737A1(X3)	S	S	S
RM736A1(X1)	S	PS	PS
RM734A1	S	S	S
RM733A1(X1)	S	S	S
RM732R1	REF (NS)	REF (NS)	REF (NS)
RM730A1	S	S	S
RM729A1(X1)	S	S	S
RM727A1(X1)	S	PS	PS
RM726R1	REF (NS)	REF (NS)	REF (NS)
RM724A2(X3)	S	S	S
RM724A1(X1)	NS	PS	PS
RM723A2(X3)	S	S	S
RM723A1(X1)	PS	PS	PS
RM721R1	REF (NS)	REF (NS)	REF (NS)
RM713A1(X3)	PS	PS	PS
RM708A1(X3)	PS	PS	PS
RM706A2(X7)	PS	PS	PS
RM706A1(X1)	PS	PS	PS
RM705R1	REF (NS)	REF (NS)	REF (NS)
RM704A1(X1)	PS	PS	NS
RM698A1(X1)	PS	PS	PS
RM692A1(X1)	NS	NS	NS
RM689A1(X3)	NS	PS	PS
RM687A1	PS	PS	NS
RM686R1	REF (NS)	REF (NS)	REF (NS)
RM686A1(X3)	NS	PS	PS
RM685R1	REF (NS)	REF (NS)	REF (NS)
RM680A1(X1)	NS	PS	PS
RM678A1(X1)	NS	PS	PS
RM677A1(X3)	NS	NS	NS
RM676A1(X3)	NS	PS	PS
RM661A1(X1)	NS	PS	PS
RM658A1(X3)	NS	PS	PS
RM644A1(X3)	NS	PS	PS
RM642A1(X1)	NS	NS	NS

Table 5.2. Classification of slag content in surficial sediments collected from the Upper Columbia River.

Station	Slag Identification Model		
	Cu:Al	Cu:Al and Zn:Cd	Fe:Al and Zn:Cd
RM641A1(X1)	NS	NS	NS
RM640A1(X3)	NS	PS	PS
RM637A1(X1)	NS	NS	PS
RM634A1(X1)	NS	PS	PS
RM628A1(X1)	NS	PS	PS
RM622A1(X3)	NS	PS	PS
RM616A1(X3)	NS	PS	PS
RM606A1(X3)	NS	PS	PS
RM605A2(X8)	NS	PS	PS
RM605A1(X1)	NS	NS	PS
RM603A1(X1)	NS	PS	PS
Non Slag-Affected (n)	29	12	12
Potentially Slag-Affected (n)	8	28	28
Slag-Affected (n)	19	16	16

NS = non slag-affected; PS = potentially slag-affected; REF = reference station; S = slag-affected.
Cu:Al = slag identification model based on the copper to aluminum ratio in surficial sediments.
Cu:Al and Zn:Cd = slag identification model based on the copper to aluminum and zinc to cadmium ratios in surficial sediments.
Fe:Al and Zn:Cd = slag identification model based on the iron to aluminum and zinc to cadmium ratios in surficial sediments.

Table 5.3. Similarity between classifications of slag content using three slag identification models developed for the Upper Columbia River study area[1].

Pairs of Slag Identification Models	Percent Agreement Between Models[2]			
	Non Slag-Affected (n)	Potentially Slag-Affected (n)	Slag-Affected (n)	Overall Classification (n)[3]
Cu:Al; Cu:Al and Zn:Cd	26.1% (6 of 23)	28.6% (8 of 28)	84.2% (16 of 19)	60% (30 of 50)
Cu:Al; Fe:Al and Zn:Cd	16% (4 of 25)	20% (6 of 30)	84.2% (16 of 19)	52% (26 of 50)
Cu:Al and Zn:Cd; Fe:Al and Zn:Cd	50% (4 of 8)	86.7% (26 of 30)	100% (16 of 16)	92% (46 of 50)

n = number of samples.
Cu:Al = slag identification model based on the copper to aluminum ratio in surficial sediments.
Cu:Al/Zn:Cd = slag identification model based on the copper to aluminum and zinc to cadmium ratios in surficial sediments.
Fe:Al/Zn:Cd = slag identification model based on the iron to aluminum and zinc to cadmium ratios in surficial sediments.

[1] The geographic reference stations (i.e., RM685R1, RM686R1, RM705R1, RM721R1, RM726R1, RM732R1) were not classified using the slag identification models.
[2] The percent agreement is calculated using the number of stations similarly classified for a slag designation and the number of unique stations between the two models classified as the same slag designation.
[3] Overall classification rate is calculated using the number of stations similarly classified for each slag designation and the overall number of stations classified (i.e., 50).

Table 5.4. Comparison of sediment sample classification using the three slag identification models and visual observations of slag in the surficial sediments of the Upper Columbia River.

Station	Cu:Al	Cu:Al and Zn:Cd	Fe:Al and Zn:Cd	Slag Observations
RM744A2(X3)	S	S	S	40% Possible Slag
RM744A1(X1)	S	S	S	60%-65% Possible Slag
RM743A2(X3)	S	S	S	15% Possible Slag
RM743A1(X1)	S	S	S	Approximately 30% Possible Slag
RM742A2(X5)	S	S	S	40%-50% Possible Slag
RM742A1(X1)	S	S	S	20%-30% Possible Slag
RM741A1(X3)	S	S	S	30% Possible Slag
RM740A1(X1)	S	PS	PS	10% Possible Slag
RM739A1(X3)	S	S	S	NA
RM738A1(X3)	S	S	S	30%-40% Possible Slag
RM737A1(X3)	S	S	S	Approximately 30% Possible Slag
RM736A1(X1)	S	PS	PS	Approximately 10% Possible Slag
RM734A1	S	S	S	Approximately 30% Possible Slag
RM733A1(X1)	S	S	S	Approximately 15% Possible Slag
RM732R1	REF (NS)	REF (NS)	REF (NS)	NA
RM730A1	S	S	S	Approximately 20% Possible Slag
RM729A1(X1)	S	S	S	NA
RM727A1(X1)	S	PS	PS	NA
RM726R1	REF (NS)	REF (NS)	REF (NS)	NA
RM724A2(X3)	S	S	S	Approximately 20% - 25% Slag
RM724A1(X1)	NS	PS	PS	NA
RM723A2(X3)	S	S	S	Approximately 30% - 50% Slag
RM723A1(X1)	PS	PS	PS	NA
RM721R1	REF (NS)	REF (NS)	REF (NS)	NA
RM713A1(X3)	PS	PS	PS	NA
RM708A1(X3)	PS	PS	PS	0%
RM706A2(X7)	PS	PS	PS	Approximately 10% - 20% Slag
RM706A1(X1)	PS	PS	PS	Approximately 20% Slag
RM705R1	REF (NS)	REF (NS)	REF (NS)	NA
RM704A1(X1)	PS	PS	NS	NA
RM698A1(X1)	PS	PS	PS	NA
RM692A1(X1)	NS	NS	NS	NA
RM689A1(X3)	NS	PS	PS	NA
RM687A1	PS	PS	NS	NA
RM686R1	REF (NS)	REF (NS)	REF (NS)	NA
RM686A1(X3)	NS	PS	PS	NA
RM685R1	REF (NS)	REF (NS)	REF (NS)	NA
RM680A1(X1)	NS	PS	PS	NA
RM678A1(X1)	NS	PS	PS	NA
RM677A1(X3)	NS	NS	NS	NA
RM676A1(X3)	NS	PS	PS	NA
RM661A1(X1)	NS	PS	PS	NA
RM658A1(X3)	NS	PS	PS	NA

Table 5.4. Comparison of sediment sample classification using the three slag identification models and visual observations of slag in the surficial sediments of the Upper Columbia River.

Station	Cu:Al	Cu:Al and Zn:Cd	Fe:Al and Zn:Cd	Slag Observations
RM644A1(X3)	NS	PS	PS	Few black particles (i.e., <5%)
RM642A1(X1)	NS	NS	NS	Some black sand present in the sample (i.e., <5%)
RM641A1(X1)	NS	NS	NS	NA
RM640A1(X3)	NS	PS	PS	NA
RM637A1(X1)	NS	NS	PS	0% Slag
RM634A1(X1)	NS	PS	PS	0% Slag
RM628A1(X1)	NS	PS	PS	0% Slag
RM622A1(X3)	NS	PS	PS	0% Slag
RM616A1(X3)	NS	PS	PS	NA
RM606A1(X3)	NS	PS	PS	NA
RM605A2(X8)	NS	PS	PS	NA
RM605A1(X1)	NS	NS	PS	NA
RM603A1(X1)	NS	PS	PS	NA

NA = not available; NS = non slag-affected; PS = potentially slag-affected; REF = reference station; S = slag-affected.
Cu:Al = slag identification model based on the copper to aluminum ratio in surficial sediments.
Cu:Al and Zn:Cd = slag identification model based on the copper to aluminum and zinc to cadmium ratios in surficial sediments.
Fe:Al and Zn:Cd = slag identification model based on the iron to aluminum and zinc to cadmium ratios in surficial sediments.

Table 5.5. Evaluation of agreement between visual observations of slag and sediment sample classification using all three slag identification models for surficial sediments of the Upper Columbia River study area.

Sample Classification	n	Number of Samples with Observations of Slag Content	Number of Samples Observed to Contain ≤ 5% Slag	Number of Samples Observed to Contain ≥ 5% Slag	Agreement Between Visual Observations and Classification (n)
Cu:Al					
Non Slag-Affected	23	6	6	0	100% (6 of 6)
Potentially Slag-Affected	8	3	1	2	33% (1 of 3)
Slag-Affected	19	16	0	16	100% (16 of 16)
Reference[1]	6	0	0	0	NA
All Sample Types	**56**	**25**	**7**	**18**	**92%**
Cu:Al and Zn:Cd					
Non Slag-Affected	6	2	2	0	100% (2 of 2)
Potentially Slag-Affected	28	9	5	4	44% (5 of 9)
Slag-Affected	16	14	0	14	100% (14 of 14)
Reference[1]	6	0	0	0	NA
All Sample Types	**56**	**25**	**7**	**18**	**84%**
Fe:Al and Zn:Cd					
Non Slag-Affected	6	1	1	0	100% (1 of 1)
Potentially Slag-Affected	28	10	6	4	60% (6 of 10)
Slag-Affected	26	14	0	14	100% (14 of 14)
Reference[1]	6	0	0	0	NA
All Sample Types	**56**	**25**	**7**	**18**	**84%**

n = number of samples; NA = not available.

Cu:Al = slag identification model based on the copper to aluminum ratio in surficial sediments.
Cu:Al and Zn:Cd = slag identification model based on the copper to aluminum and zinc to cadmium ratios in surficial sediments.
Fe:Al and Zn:Cd = slag identification model based on the iron to aluminum and zinc to cadmium ratios in surficial sediments.

[1]There were no visual observations recorded for the reference samples.

Table 6.1. Advantages and limitations of selected approaches to interpreting the results of whole-sediment toxicity tests.

Approach	Advantages	Limitations
Control Comparison Approach	• Simple, easy to implement • Understandable	• Control sediment characteristics may not be representative of that for test sediments (can influence chronic or sublethal endpoints) • Substantial numbers of replicates needed to achieve necessary statistical power • Most studies have too few replicates to provide necessary statistical power
Minimum Significant Difference (MSD) Approach	• Designations of toxicity can be made with consistent level of statistical rigor (i.e., α and β can be defined explicitly)	• MSDs have not been published for any freshwater toxicity test species • Doesn't work well for endpoints with moderate to high variability
Reference Envelope Approach	• Accounts for influence of site-specific factors on sediment toxicity (e.g., grain size, TOC, background contamination) • Application is not dependent on control results • Applicable to all toxicity tests and endpoints regardless of variability	• Requires additional samples to be collected and tested • Requires chemical and biological criteria for qualifying reference samples
Multiple Category Approach	• Provides information on the magnitude of toxicity • Useful as communication tool	• Not statistically based • May not be biologically relevant

Table 6.2. Summary of selected reference stations for development of the toxicity test reference envelopes for the Upper Columbia River.

Reference Station	Meets Reference Criteria?						
	Chemistry	Cladoceran, *Ceriodaphnia dubia*		Midge, *Chironomus dilutus*		Amphipod, *Hyalella azteca*	
		Survival	Reproduction	Survival	Growth	Survival	Growth
Stefanoff *et al.* 2006; Schut and Stefanoff 2007							
RM685R1	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
RM686R1	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
RM705R1	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
RM721R1	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
RM726R1	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
RM732R1	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
RM706A2(X7)	**Y**	**Y**	**Y**	N	**Y**	**Y**	**Y**
Besser *et al.* 2008[1]							
SA8	**Y**	ND	ND	**Y**	**Y**	**Y**	**Y**
Bortleson *et al.* 1994[1]							
2	**Y**	**Y**	**Y**	ND	ND	ND	ND
62	**Y**	**Y**	**Y**	ND	ND	ND	ND
Number of Reference Stations:		**9**		**7**		**8**	

Y = yes; N = no; ND = no data.

[1] No data were available on organochlorine pesticides, polycyclic aromatic hydrocarbons, or polychlorinated biphenyls.

Table 6.3. Summary of the response data for control treatments for the three studies and associated batches of samples tested.

Study	Batch	Amphipod, *Hyalella azteca*				Midge, *Chironomus dilutus*			Cladoceran, *Ceriodaphnia dubia*		
		Percent Survival (%)	Biomass (mg)	Growth (length) (mm)	Growth (weight) (mg)	Percent Survival (%)	Biomass (mg)	Growth (weight) (mg)	Percent Survival (%)	Reproduction (Count)	Reproduction (Number of Offspring)
Stefanoff *et al.* 2006; Schut and Stefanoff 2007	1	96	3.90	NR	0.41	84	11.2	1.51	80	22.8	NR
Stefanoff *et al.* 2006; Schut and Stefanoff 2007	2	98	3.72	NR	0.38	89	13.3	1.97	90	24.0	NR
Besser *et al.* 2008	1	95	2.63	3.85	0.277	91	8.21	0.894	NA	NA	NA
Bortleson *et al.* 1994	1	NA	NA	NA	NA	NA	NA	NA	90	NA	33.3

NR = not reported; NA = not applicable.

Table 6.4. Median reference values and control values used to normalize toxicity data in each study from the Upper Columbia River.

Study	Batch	Normalization type	*Ceriodaphnia dubia*		*Chironomus dilutus*			*Hyalella azteca*		
			% Survival	Reproduction (Number of Offspring)	% Survival	Growth (mg)[2]	Total Biomass (mg)[3]	% Survival	Growth (mg)[1]	Total Biomass (mg)[2]
Stefanoff *et al.* 2006;	1	Median Reference	100	23.3	70	1.99	12.5	96	0.530	5.24
Schut and Stefanoff 2007	2	Median Reference	90	22.0	80	1.97	12.0	96	0.483	4.58
Besser *et al.* 2008	NA	Control	ND	ND	91	0.894	8.21	95	3.85 mm	2.77
Bortleson *et al.* 1994	NA	Control	90	33.3	ND	ND	ND	ND	ND	ND

ND = no data; NA = not applicable.

[1] Growth (mg) is measured as the average individual organism weight per treatment, except for *H. azteca* in Study 02, in which growth is measured as the average individual organism length per treatment.

[2] Biomass (mg) is measured as the average biomass of surviving individuals per replicate. Each treatment (for *C. dilutus* and *H. azteca*) consisted of eight replicates, each seeded with ten organisms).

Table 6.5. Summary of physical characteristics in the Upper Columbia River study area by reach.

Physical Characteristic/ Statistic	Stefanoff *et al.* 2006; Schut and Stefanoff 2007										Besser *et al.* 2008						
	Reference Stations[1]				Test Stations						Reference Station[1]	Test Stations					
	Reach 1	Reach 2	Reach 3	Reach 4	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Sanpoil River	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
< 200 µm																	
n	1	2	2	2	14	8	3	15	4	5	ND	ND	ND	ND	ND	ND	ND
Min	41.6	25.2	15.6	32	2.3	5.7	43.4	3.35	2.7	2.2	ND	ND	ND	ND	ND	ND	ND
Max	41.6	35.9	64.4	39	19.5	34	77.4	93	15.8	48.9	ND	ND	ND	ND	ND	ND	ND
Mean	41.6	30.6	40	35.5	8.32	18.4	57.3	48.2	9.25	22.8	ND	ND	ND	ND	ND	ND	ND
Median	41.6	30.6	40	35.5	8.35	18	51	50.2	9.25	19.5	ND	ND	ND	ND	ND	ND	ND
St. Dev.	NA	7.57	34.5	4.95	4.87	10.1	17.8	28	6.91	17.6	ND	ND	ND	ND	ND	ND	ND
CV (%)	NA	24.8	86.3	13.9	58.5	55	31.2	58	74.7	77.5	ND	ND	ND	ND	ND	ND	ND
% Clay																	
n	1	2	2	2	14	8	3	15	4	5	1	1	1	1	2	1	1
Min	4.99	2.27	0.312	0.96	0.046	0.057	3.47	0.0335	0.0405	0.022	44	0.5	5	44	7	27	3
Max	4.99	2.87	7.08	2.34	0.78	2.79	9.29	15.5	0.711	9.05	44	0.5	5	44	54	27	3
Mean	4.99	2.57	3.7	1.65	0.216	0.914	6.63	5.75	0.367	2.41	44	0.5	5	44	30.5	27	3
Median	4.99	2.57	3.7	1.65	0.131	0.737	7.14	4.25	0.358	0.78	44	0.5	5	44	30.5	27	3
St. Dev.	NA	0.427	4.79	0.976	0.238	0.895	2.94	5.28	0.367	3.77	NA	NA	NA	NA	33.2	NA	NA
CV (%)	NA	16.6	129	59.1	110	97.9	44.3	91.7	100	157	NA	NA	NA	NA	109	NA	NA
% Colloid																	
n	1	2	2	2	14	8	3	15	4	5	ND	ND	ND	ND	ND	ND	ND
Min	2.5	0.926	0.234	0.8	0	0.0285	3.47	0	0.0135	0.011	ND	ND	ND	ND	ND	ND	ND
Max	2.5	1.01	5.15	1.56	0.319	0.96	5.42	13	0.395	2.93	ND	ND	ND	ND	ND	ND	ND
Mean	2.5	0.967	2.69	1.18	0.137	0.357	4.15	4.16	0.18	1.03	ND	ND	ND	ND	ND	ND	ND
Median	2.5	0.967	2.69	1.18	0.148	0.191	3.57	4.08	0.156	0.293	ND	ND	ND	ND	ND	ND	ND
St. Dev.	NA	0.058	3.48	0.537	0.101	0.347	1.1	3.92	0.193	1.28	ND	ND	ND	ND	ND	ND	ND
CV (%)	NA	6	129	45.5	74.1	97.1	26.4	94.3	107	124	ND	ND	ND	ND	ND	ND	ND

Table 6.5. Summary of physical characteristics in the Upper Columbia River study area by reach.

Physical Characteristic/ Statistic	Stefanoff *et al.* 2006; Schut and Stefanoff 2007										Besser *et al.* 2008						
	Reference Stations[1]				Test Stations						Reference Station[1]	Test Stations					
	Reach 1	Reach 2	Reach 3	Reach 4	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Sanpoil River	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
% Fines																	
n	1	2	2	2	14	8	3	15	4	5	1	1	1	1	2	1	1
Min	39.1	24.2	15.4	31.2	2.29	5.67	39.9	3.31	2.69	2.19	76	9.5	18	58	20	66	18
Max	39.1	35	59.2	37.4	19.3	33.3	72	80.3	15.4	46	76	9.5	18	58	93	66	18
Mean	39.1	29.6	37.3	34.3	8.18	18	53.1	44.1	9.07	21.7	76	9.5	18	58	56.5	66	18
Median	39.1	29.6	37.3	34.3	8.14	17.4	47.4	46.2	9.09	19.2	76	9.5	18	58	56.5	66	18
St. Dev.	NA	7.62	31	4.41	4.8	9.87	16.8	24.7	6.71	16.4	NA	NA	NA	NA	51.6	NA	NA
CV (%)	NA	25.8	83.2	12.9	58.7	54.7	31.6	56	74	75.5	NA	NA	NA	NA	91.4	NA	NA
% Gravel																	
n	1	2	2	2	14	8	3	15	4	5	ND	ND	ND	ND	ND	ND	ND
Min	8.4	5.2	0.4	0	0	0	0	0	0	0	ND	ND	ND	ND	ND	ND	ND
Max	8.4	7.4	7.4	4.4	20.6	6.5	0	9.2	14.7	19.5	ND	ND	ND	ND	ND	ND	ND
Mean	8.4	6.3	3.9	2.2	2.79	1.08	0	2.11	4.08	5.66	ND	ND	ND	ND	ND	ND	ND
Median	8.4	6.3	3.9	2.2	0.1	0	0	0.6	0.8	3.1	ND	ND	ND	ND	ND	ND	ND
St. Dev.	NA	1.56	4.95	3.11	5.79	2.27	NA	3.13	7.11	7.88	ND	ND	ND	ND	ND	ND	ND
CV (%)	NA	24.7	127	141	208	210	NA	148	174	139	ND	ND	ND	ND	ND	ND	ND
% TOC																	
n	1	2	2	2	14	8	3	15	4	5	1	1	1	1	2	1	1
Min	2.52	2.44	2.14	1.52	0.0609	0.154	0.8	0.0372	0.0366	0.0641	1.9	0.28	1.5	1.6	0.23	2.7	0.33
Max	2.52	3.91	2.91	3.18	0.702	1.44	1.96	2.17	0.121	0.413	1.9	0.28	1.5	1.6	1.8	2.7	0.33
Mean	2.52	3.18	2.53	2.35	0.339	0.686	1.41	0.549	0.0856	0.194	1.9	0.28	1.5	1.6	1.02	2.7	0.33
Median	2.52	3.18	2.53	2.35	0.354	0.646	1.47	0.25	0.0924	0.121	1.9	0.28	1.5	1.6	1.02	2.7	0.33
St. Dev.	NA	1.04	0.544	1.17	0.214	0.434	0.582	0.663	0.0415	0.146	NA	NA	NA	NA	1.11	NA	NA
CV (%)	NA	32.7	21.6	49.9	63.1	63.3	41.3	121	48.5	75.2	NA	NA	NA	NA	109	NA	NA

Table 6.5. Summary of physical characteristics in the Upper Columbia River study area by reach.

Physical Characteristic/ Statistic	Stefanoff *et al.* 2006; Schut and Stefanoff 2007										Besser *et al.* 2008						
	Reference Stations[1]				Test Stations						Reference Station[1]	Test Stations					
	Reach 1	Reach 2	Reach 3	Reach 4	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Sanpoil River	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
% Coarse Sand																	
n	1	2	2	2	14	8	3	15	4	5	ND	ND	ND	ND	ND	ND	ND
Min	2.8	3.6	0.6	0.3	0	0	0	0	1.7	0	ND	ND	ND	ND	ND	ND	ND
Max	2.8	4.4	4.7	6	4.7	8.2	0.2	7.2	6.3	12.9	ND	ND	ND	ND	ND	ND	ND
Mean	2.8	4	2.65	3.15	0.743	1.43	0.0667	1.88	4.05	4.38	ND	ND	ND	ND	ND	ND	ND
Median	2.8	4	2.65	3.15	0.25	0.35	0	1.2	4.1	2.6	ND	ND	ND	ND	ND	ND	ND
St. Dev.	NA	0.566	2.9	4.03	1.26	2.79	0.115	2.35	2.44	5.02	ND	ND	ND	ND	ND	ND	ND
CV (%)	NA	14.1	109	128	170	195	173	125	60.2	115	ND	ND	ND	ND	ND	ND	ND
% Fine Sand																	
n	1	2	2	2	14	8	3	15	4	5	ND	ND	ND	ND	ND	ND	ND
Min	38	39.2	32.4	34.2	39.9	37.9	21.8	6.6	6.9	5.6	ND	ND	ND	ND	ND	ND	ND
Max	38	45.5	51.3	65.9	92.8	88	56.2	67.2	55.8	63.8	ND	ND	ND	ND	ND	ND	ND
Mean	38	42.4	41.9	50.1	72.8	61.7	42.1	39.5	29.6	37.7	ND	ND	ND	ND	ND	ND	ND
Median	38	42.4	41.9	50.1	78.8	59.6	48.2	45.2	27.9	42.2	ND	ND	ND	ND	ND	ND	ND
St. Dev.	NA	4.45	13.4	22.4	17.6	18.8	18	19.2	20.6	21.3	ND	ND	ND	ND	ND	ND	ND
CV (%)	NA	10.5	31.9	44.8	24.1	30.4	42.8	48.6	69.6	56.4	ND	ND	ND	ND	ND	ND	ND
% Medium Sand																	
n	1	2	2	2	14	8	3	15	4	5	ND	ND	ND	ND	ND	ND	ND
Min	9.2	7.6	2.2	1.8	0.8	1.1	0.4	0.4	25.3	10.4	ND	ND	ND	ND	ND	ND	ND
Max	9.2	26	21	16.4	57.8	47.9	0.8	36.3	82.7	59.8	ND	ND	ND	ND	ND	ND	ND
Mean	9.2	16.8	11.6	9.1	15.3	17.4	0.6	8.33	53	29.5	ND	ND	ND	ND	ND	ND	ND
Median	9.2	16.8	11.6	9.1	6.15	7.5	0.6	2.4	52	28.2	ND	ND	ND	ND	ND	ND	ND
St. Dev.	NA	13	13.3	10.3	19.4	19.6	0.2	10.7	24.6	18.8	ND	ND	ND	ND	ND	ND	ND
CV (%)	NA	77.4	115	113	127	113	33.3	128	46.5	63.8	ND	ND	ND	ND	ND	ND	ND

Table 6.5. Summary of physical characteristics in the Upper Columbia River study area by reach.

Physical Characteristic/ Statistic	Stefanoff *et al.* 2006; Schut and Stefanoff 2007										Besser *et al.* 2008						
	Reference Stations[1]				Test Stations						Reference Station[1]	Test Stations					
	Reach 1	Reach 2	Reach 3	Reach 4	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Sanpoil River	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
% Sand																	
n	1	2	2	2	14	8	3	15	4	5	1	1	1	1	2	1	1
Min	50	56.7	35.2	56.6	59.9	64.3	22.6	7	82.6	47.1	24	92	82	43	7	34	82
Max	50	69.6	77	68	97.7	93	56.6	94.7	95.9	84.6	24	92	82	43	80	34	82
Mean	50	63.2	56.1	62.3	88.9	80.5	42.7	49.7	86.7	71.6	24	92	82	43	43.5	34	82
Median	50	63.2	56.1	62.3	91.4	82.1	49	49.8	84.1	77.4	24	92	82	43	43.5	34	82
St. Dev.	NA	9.12	29.6	8.06	10.1	9.56	17.8	27	6.28	14.6	NA	NA	NA	NA	51.6	NA	NA
CV (%)	NA	14.4	52.7	12.9	11.3	11.9	41.8	54.3	7.25	20.4	NA	NA	NA	NA	119	NA	NA
% Silt																	
n	1	2	2	2	14	8	3	15	4	5	1	1	1	1	2	1	1
Min	34.1	21.9	15.1	30.2	2.21	5.61	36.5	3.27	2.65	2.17	32	9	13	14	13	39	15
Max	34.1	32.1	52.2	35.1	18.5	31.8	62.7	67.9	14.7	36.9	32	9	13	14	39	39	15
Mean	34.1	27	33.6	32.7	7.97	17.1	46.5	38.3	8.7	19.3	32	9	13	14	26	39	15
Median	34.1	27	33.6	32.7	8	16.8	40.3	37.2	8.74	18.4	32	9	13	14	26	39	15
St. Dev.	NA	7.2	26.2	3.44	4.6	9.1	14.2	20.2	6.35	13.1	NA	NA	NA	NA	18.4	NA	NA
CV (%)	NA	26.6	78.1	10.5	57.7	53.2	30.5	52.8	72.9	67.8	NA	NA	NA	NA	70.7	NA	NA

Table 6.5. Summary of physical characteristics in the Upper Columbia River study area by reach.

Physical Characteristic/ Statistic	Bortleson *et al.* 1994									
	Reference Stations[1]		Test Stations							
	Reach 6	Upstream of Trail	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Spokane River	Upstream of Trail
< 200 µm										
n	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Max	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mean	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
St. Dev.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CV (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
% Clay										
n	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Max	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mean	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
St. Dev.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CV (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
% Colloid										
n	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Max	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mean	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
St. Dev.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CV (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 6.5. Summary of physical characteristics in the Upper Columbia River study area by reach.

Physical Characteristic/ Statistic	Bortleson *et al.* 1994									
	Reference Stations[1]		Test Stations							
	Reach 6	Upstream of Trail	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Spokane River	Upstream of Trail
% Fines										
n	1	1	5	3	3	3	2	1	1	2
Min	85	9	0	22	44	54	48	95	53	10
Max	85	9	25	41	82	97	99	95	53	38
Mean	85	9	7.8	32	69.3	81.7	73.5	95	53	24
Median	85	9	5	33	82	94	73.5	95	53	24
St. Dev.	NA	NA	10.1	9.54	21.9	24	36.1	NA	NA	19.8
CV (%)	NA	NA	130	29.8	31.6	29.4	49.1	NA	NA	82.5
% Gravel										
n	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Max	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mean	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
St. Dev.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CV (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
% TOC										
n	1	1	5	3	3	3	2	1	1	2
Min	2.3	0.8	0.1	1.9	1.3	1.4	0.6	1.3	1.4	0.7
Max	2.3	0.8	0.4	2.9	3.3	2.6	1.6	1.3	1.4	3.4
Mean	2.3	0.8	0.18	2.33	2.37	2.17	1.1	1.3	1.4	2.05
Median	2.3	0.8	0.1	2.2	2.5	2.5	1.1	1.3	1.4	2.05
St. Dev.	NA	NA	0.13	0.513	1.01	0.666	0.707	NA	NA	1.91
CV (%)	NA	NA	72.4	22	42.5	30.7	64.3	NA	NA	93.1

Table 6.5. Summary of physical characteristics in the Upper Columbia River study area by reach.

Physical Characteristic/ Statistic	Bortleson *et al.* 1994									
	Reference Stations[1]		Test Stations							
	Reach 6	Upstream of Trail	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Spokane River	Upstream of Trail
% Coarse Sand										
n	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Max	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mean	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
St. Dev.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CV (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
% Fine Sand										
n	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Max	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mean	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
St. Dev.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CV (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
% Medium Sand										
n	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Max	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mean	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
St. Dev.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CV (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 6.5. Summary of physical characteristics in the Upper Columbia River study area by reach.

Physical Characteristic/ Statistic	Bortleson *et al.* 1994									
	Reference Stations[1]		Test Stations							
	Reach 6	Upstream of Trail	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Spokane River	Upstream of Trail
% Sand										
n	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Max	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mean	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
St. Dev.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CV (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
% Silt										
n	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Max	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mean	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
St. Dev.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CV (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = no data; NA = not applicable; n = number of stations; min = minimum; max = maximum; St. Dev. = standard deviation; CV = coefficient of variation; TOC = total organic carbon.

[1] Reference Stations defined by chemical and biological criteria: see text for description of reference station selection criteria.

Table 6.6. Calculation of the reference envelope using normalized data (control-normalized or reference-normalized) for the eight sediment toxicity test endpoints measured in the Upper Columbia River.

Endpoint (%)[1]	n	Mean	Standard Deviation	Reference Envelope		Percentiles							Shapiro-Wilk Test of Normality	
				Minimum	Maximum	5th	10th	25th	50th	75th	90th	95th	W	*p*
Ceriodaphnia dubia														
Survival	9	97.9	8.15	80	111	85.8	91.6	95.5	100	100	102	107	0.825	**0.0389**
Reproduction	9	95.9	11.7	67	108	77.2	87.4	95.9	98.4	100	105	106	0.757	**0.007**
Chironomus dilutus														
Survival	7	98.7	5.67	88.8	108	91.2	93.6	96.9	99.2	101	104	106	0.943	0.667
Growth	7	104	6.01	98.5	114	98.6	98.7	99.1	101	106.4	111	113	0.837	0.0925
Biomass	7	103	6.67	96.4	113	96.5	96.5	98.3	102	107	112	113	0.875	0.206
Hyalella azteca														
Survival	8	100	1.6	98.7	103	98.7	98.7	99.2	100	101	103	103	0.912	0.369
Growth	8	88.3	20.9	56.0	110	58.52	61.0	76.8	90.5	107	109	109	0.892	0.242
Biomass	8	88.4	20.1	60.7	111	60.7	60.8	76.4	90.7	106	108	109	0.877	0.176

n = number of stations

[1] Toxicity test response data were all normalized and expressed as a percentage of either the control or the median reference value for calculation of the reference envelopes.

Table 6.7. Sediment chemistry data for stations with the minimum value of the reference envelope.

Chemical of Potential Concern	Reference Criteria	Endpoint							
		Ceriodaphia dubia		*Chironomus dilutus*			*Hyalella azteca*		
		% Survival RM706A2(X7)[1]	Young/Female 62[1]	% Survival SA8[1]	Growth RM721R1[1]	Biomass RM686R1[1]	% Survival RM686R1[1]	Growth SA8[1]	Biomass RM706A2(X7)[1]
Metals (mg/kg dw)									
Arsenic	9.79	1.4	3.7	8.4	2.25	<1.4	<1.4	8.4	1.4
Cadmium	0.99	0.42	**HND**	0.48	0.415	0.19	0.19	0.48	0.42
Chromium	43.4	24.9	ND	ND	22.2	8.9	8.9	ND	24.9
Copper	31.6	26.2	25	22	15.1	5.5	5.5	22	26.2
Lead	35.8	14.7	15	16	12.5	3.8	3.8	16	14.7
Mercury	0.18	0.044	0.03	0.03	0.035	0.008	0.008	0.03	0.044
Nickel	22.7	15.9	ND	ND	14.5	5.8	5.8	ND	15.9
Zinc	121	97.5	120	120	54.8	26.1	26.1	120	97.5
Meets Reference Criteria?		NA	NA	NA	NA	NA	NA	NA	NA
Simultaneously Extracted Metals (SEM; µmol/g)									
(ΣSEM - AVS)/ƒoc	130	2.58	ND	25.5	-176	9.52	9.52	25.5	2.58
Meets Reference Criteria?		Yes	**Yes**	Yes	Yes	Yes	Yes	Yes	Yes
Polycyclic Aromatic Hydrocarbons (PAHs; µg/kg DW)									
Anthracene	57.2	<9	ND	ND	<7	<9	<9	ND	<9
Benz[a]anthracene	108	<9	ND	ND	<7	1	1	ND	<9
Dibenzo[a,h]anthracene	33	<9	ND	ND	<7	<9	<9	ND	<9
Benzo[a]pyrene	150	<9	ND	ND	<7	<9	<9	ND	<9
Chrysene	166	1	ND	ND	<7	2	2	ND	1
Fluoranthene	423	2	<6.9	ND	<7	3	3	ND	2
Fluorene	77.4	<9	ND	ND	<7	<9	<9	ND	<9
Naphthalene	176	7.7	ND	ND	1	3	3	ND	7.7
Phenanthrene	204	0.8	<13	ND	<7	1	1	ND	0.8
Pyrene	195	2	ND	ND	<7	3	3	ND	2
ΣPAH_{13}	1610	49.5	<19.9	ND	39.8	40.7	40.7	ND	49.5
$\Sigma ESB\text{-}TU\ FCV_{13}$	0.1	0.00779	0.001887434	ND	0.0073	0.0128	0.0128	ND	0.00779
Meets Reference Criteria?		Yes	**Yes**	Yes	Yes	Yes	Yes	Yes	Yes

Table 6.7. Sediment chemistry data for stations with the minimum value of the reference envelope.

Chemical of Potential Concern	Reference Criteria	Endpoint							
		Ceriodaphia dubia		*Chironomus dilutus*			*Hyalella azteca*		
		% Survival RM706A2(X7)[1]	Young/Female 62[1]	% Survival SA8[1]	Growth RM721R1[1]	Biomass RM686R1[1]	% Survival RM686R1[1]	Growth SA8[1]	Biomass RM706A2(X7)[1]
Polychlorinated Biphenyls (PCBs; µg/kg DW)									
ΣPCBs	59.8	12.4	ND		9.1	11.7	11.7		12.4
Meets Reference Criteria?		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Organochlorine Pesticides (µg/kg DW)									
Chlordane (Total)	3.24	<1.5	**ND**	ND	<1.09	<1.42	<1.42	ND	<1.5
Dieldrin	1.9	<1.6	**ND**	ND	<1.1	<1.4	<1.4	ND	<1.6
ΣDDD[2]	4.88	<3.2	**ND**	ND	<2.2	<2.8	<2.8	ND	<3.2
ΣDDE[3]	3.16	HND	**ND**	ND	<2.2	<2.8	<2.8	ND	HND
ΣDDT[4]	4.16	<3.2	**ND**	ND	<2.2	<2.8	<2.8	ND	<3.2
DDTs (Total)[5]	5.28	HND	**ND**	ND	HND	HND	HND	ND	HND
Endrin	2.22	<1.6	**ND**	ND	<1.1	<1.4	<1.4	ND	<1.6
Endrin Aldehyde	2.22	<1.6	**ND**	ND	<1.1	<1.4	<1.4	ND	<1.6
Endrin Ketone	2.22	<1.6	**ND**	ND	<1.1	<1.4	<1.4	ND	<1.6
Lindane	2.37	<0.75	**ND**	ND	<0.545	<0.71	<0.71	ND	<0.75
Heptachlor Epoxide	2.47	<0.75	**ND**	ND	<0.545	<0.71	<0.71	ND	<0.75
Meets Reference Criteria?		Yes	**Yes**	Yes	Yes	Yes	Yes	Yes	Yes
COPC Mixtures[6]									
Mean PEC-$Q_{METALS, PAHs, PCBs}$	0.1	0.0631	0.080127612	ND	0.0511	0.0246	0.0246	ND	0.0631
Mean PEC-Q_{METALS}		0.169	0.159818821	0.177	0.138	0.0546	0.0546	0.177	0.169
Mean PEC-$Q_{METALS(1\%OC)}$	0.1	0.058	0.069486444	0.0932	0.0566	0.0359	0.0359	0.0932	0.058
Meets Reference Criteria?		Yes		Yes	Yes	Yes	Yes	Yes	Yes
Conventionals									
TOC (%)		2.91	2.3	1.9	2.44	1.52	1.52	1.9	2.91
Station Meets Reference Criteria?		Yes	YES	Yes	Yes	Yes	Yes	Yes	Yes

…footnotes continued on next page

Table 6.7. Sediment chemistry data for stations with the minimum value of the reference envelope.

Chemical of Potential Concern	Reference Criteria	Endpoint							
		Ceriodaphia dubia		*Chironomus dilutus*			*Hyalella azteca*		
		% Survival	Young/Female	% Survival	Growth	Biomass	% Survival	Growth	Biomass
		RM706A2(X7)[1]	62[1]	SA8[1]	RM721R1[1]	RM686R1[1]	RM686R1[1]	SA8[1]	RM706A2(X7)[1]

NA = not applicable as metals were assessed using ΣSEM-AVS and Mean PEC-Q_{METALS}.
ND = no data; HND = high non-detect (i.e., value reported as less than the detection limit (DL), and the DL was greater than the threshold effect concentration).
ΣESB-TU FCV_{13} = equilibrium partitioning sediment benchmark toxic unit calculated with the final chronic value for 13 PAHs.
AVS = acid-volatile sulfide; PEC-Q = probable effect concentration quotient; OC = organic carbon; foc = fraction organic carbon; TOC = total organic carbon.

[1] Selected Reference Station: See text for description of reference station selection criteria.
[2] Sum DDDs is calculated as the p,p'-DDD and o,p'-DDD congeners.

Table 6.8. Toxicity designations for toxicity tests for all samples evaluated for the Upper Columbia River study area.

Station	Reach	Amphipod, *Hyalella azteca*					Midge, *Chironomus dilutus*					Cladoceran, *Ceriodaphnia dubia*				Overall Toxicity	# of Toxic Endpoints
		Surv.	Growth	Biomass	Overall	Ref.	Surv.	Growth	Biomass	Overall	Ref.	Surv.	Repr.	Overall	Ref.		
Reference Sites																	
RM732R1	Fivemile Creek	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM721R1	Flat Creek	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM726R1	Crown Creek	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM705R1	Nancy Creek	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM685R1	Cheweka Creek	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM686R1	Barnaby Creek	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM706A2(X7)	3	NT	NT	NT	NT	YES	T	NT	T	T	NO	NT	NT	NT	YES	T	2
02	Canada	*ND*	*ND*	*ND*	*ND*	NO	*ND*	*ND*	*ND*	*ND*	NO	NT	NT	NT	YES	NT	0
62	Sanpoil River	*ND*	*ND*	*ND*	*ND*	NO	*ND*	*ND*	*ND*	*ND*	NO	NT	NT	NT	YES	NT	0
SA8	Sanpoil River	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	*ND*	*ND*	*ND*	*ND*	NT	0
Total - Toxic		***0***	***0***	***0***	***0***	NA	***1***	***0***	***1***	***1***	NA	***0***	***0***	***0***	NA	***1***	NA
Total - Not Toxic		***8***	***8***	***8***	***8***	NA	***7***	***8***	***7***	***7***	NA	***9***	***9***	***9***	NA	***9***	NA
All Other Sites																	
RM733A1(X1)	1	T	NT	NT	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	3
RM734A1	1	T	T	T	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	5
RM736A1(X1)	1	T	NT	NT	T	*NA*	NT	NT	NT	NT	*NA*	T	NT	T	*NA*	T	2
RM737A1(X3)	1	T	T	T	T	*NA*	NT	T	T	T	*NA*	T	T	T	*NA*	T	7
RM738A1(X3)	1	T	T	T	T	*NA*	NT	T	T	T	*NA*	T	T	T	*NA*	T	7
RM739A1(X3)	1	T	NT	NT	T	*NA*	NT	NT	NT	NT	*NA*	NT	NT	NT	*NA*	T	1
RM740A1(X1)	1	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	NT	NT	NT	*NA*	NT	0
RM741A1(X3)	1	T	NT	NT	T	*NA*	NT	NT	T	T	*NA*	NT	NT	NT	*NA*	T	2
RM742A1(X1)	1	T	T	T	T	*NA*	NT	T	T	T	*NA*	NT	T	T	*NA*	T	6
RM742A2(X5)	1	NT	NT	T	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	3
RM743A1(X1)	1	T	NT	NT	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	3
RM743A2(X3)	1	T	NT	T	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	4
RM744A1(X1)	1	T	NT	T	T	*NA*	T	NT	T	T	*NA*	NT	NT	NT	*NA*	T	4
RM744A2(X3)	1	T	T	T	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	5
LR7	1	T	NT	T	T	*NA*	NT	T	T	T	*NA*	*ND*	*ND*	*ND*	*NA*	T	4
8	1	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	T	T	T	*NA*	T	2

Table 6.8. Toxicity designations for toxicity tests for all samples evaluated for the Upper Columbia River study area.

Station	Reach	Amphipod, *Hyalella azteca*					Midge, *Chironomus dilutus*					Cladoceran, *Ceriodaphnia dubia*				Overall	# of Toxic
		Surv.	Growth	Biomass	Overall	Ref.	Surv.	Growth	Biomass	Overall	Ref.	Surv.	Repr.	Overall	Ref.	Toxicity	Endpoints
All Other Sites (continued)																	
10	1	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	T	T	T	*NA*	T	2
11	1	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	T	T	*NA*	T	1
14	1	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
RM713A1(X3)	2	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	NT	NT	NT	*NA*	NT	0
RM723A1(X1)	2	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	NT	NT	NT	*NA*	NT	0
RM723A2(X3)	2	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	NT	NT	NT	*NA*	NT	0
RM724A1(X1)	2	NT	NT	NT	NT	*NA*	T	NT	T	T	*NA*	NT	NT	NT	*NA*	T	2
RM724A2(X3)	2	NT	NT	NT	NT	*NA*	NT	NT	T	T	*NA*	NT	NT	NT	*NA*	T	1
RM727A1(X1)	2	NT	NT	NT	NT	*NA*	NT	T	NT	T	*NA*	NT	NT	NT	*NA*	T	1
RM729A1(X1)	2	T	NT	NT	T	*NA*	NT	NT	T	T	*NA*	NT	NT	NT	*NA*	T	2
RM730A1	2	T	NT	NT	T	*NA*	NT	NT	T	T	*NA*	NT	NT	NT	*NA*	T	2
LR6	2	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	*ND*	*ND*	*ND*	*NA*	NT	0
15	2	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
17	2	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
19	2	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
RM704A1(X1)	3	NT	NT	NT	NT	*NA*	NT	NT	T	T	*NA*	NT	NT	NT	*NA*	T	1
RM706A1(X1)	3	NT	NT	T	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	3
RM708A1(X3)	3	T	NT	T	T	*NA*	NT	T	T	T	*NA*	T	NT	T	*NA*	T	5
RM706A2(X7)	3	NT	NT	NT	NT	YES	T	NT	T	T	NO	NT	NT	NT	YES	T	2
LR5	3	T	NT	T	T	*NA*	NT	NT	NT	NT	*NA*	*ND*	*ND*	*ND*	*NA*	T	2
20	3	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
22	3	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	T	NT	T	*NA*	T	1
RM640A1(X3)	4	NT	NT	NT	NT	*NA*	T	NT	T	T	*NA*	NT	T	T	*NA*	T	3
RM641A1(X1)	4	NT	NT	NT	NT	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	2
RM642A1(X1)	4	NT	NT	NT	NT	*NA*	T	NT	T	T	*NA*	NT	NT	NT	*NA*	T	2
RM644A1(X3)	4	T	NT	NT	T	*NA*	T	T	T	T	*NA*	NT	NT	NT	*NA*	T	4
RM658A1(X3)	4	NT	NT	NT	NT	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	2
RM661A1(X1)	4	NT	NT	NT	NT	*NA*	NT	T	NT	T	*NA*	NT	NT	NT	*NA*	T	1
RM676A1(X3)	4	T	NT	NT	T	*NA*	T	NT	T	T	*NA*	NT	NT	NT	*NA*	T	3
RM677A1(X3)	4	T	T	T	T	*NA*	T	NT	T	T	*NA*	NT	NT	NT	*NA*	T	5

Table 6.8. Toxicity designations for toxicity tests for all samples evaluated for the Upper Columbia River study area.

Station	Reach	Amphipod, *Hyalella azteca*					Midge, *Chironomus dilutus*					Cladoceran, *Ceriodaphnia dubia*				Overall Toxicity	# of Toxic Endpoints
		Surv.	Growth	Biomass	Overall	Ref.	Surv.	Growth	Biomass	Overall	Ref.	Surv.	Repr.	Overall	Ref.		
All Other Sites (continued)																	
RM678A1(X1)	4	NT	NT	NT	NT	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	2
RM680A1(X1)	4	NT	NT	T	T	*NA*	T	NT	T	T	*NA*	NT	NT	NT	*NA*	T	3
RM686A1(X3)	4	T	NT	NT	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	3
RM687A1	4	T	T	T	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	5
RM689A1(X3)	4	T	NT	NT	T	*NA*	T	NT	T	T	*NA*	NT	NT	NT	*NA*	T	3
RM692A1(X1)	4	NT	NT	NT	NT	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	2
RM698A1(X1)	4	NT	T	T	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	4
LR3	4	T	NT	NT	T	*NA*	NT	T	T	T	*NA*	*ND*	*ND*	*ND*	*NA*	T	3
LR4	4	T	NT	NT	T	*NA*	NT	T	T	T	*NA*	*ND*	*ND*	*ND*	*NA*	T	3
38	4	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	T	NT	T	*NA*	T	1
46	4	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
RM622A1(X3)	5	NT	NT	NT	NT	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	2
RM628A1(X1)	5	T	NT	NT	T	*NA*	NT	T	T	T	*NA*	T	NT	T	*NA*	T	4
RM634A1(X1)	5	T	NT	NT	T	*NA*	NT	T	T	T	*NA*	T	T	T	*NA*	T	5
RM637A1(X1)	5	NT	NT	NT	NT	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	2
LR2	5	NT	NT	NT	NT	*NA*	NT	T	T	T	*NA*	*ND*	*ND*	*ND*	*NA*	T	2
57	5	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
61	5	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	T	T	*NA*	T	1
RM603A1(X1)	6	NT	NT	NT	NT	*NA*	NT	T	T	T	*NA*	NT	T	T	*NA*	T	3
RM605A1(X1)	6	T	NT	NT	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	3
RM605A2(X8)	6	T	NT	NT	T	*NA*	NT	T	T	T	*NA*	NT	NT	NT	*NA*	T	3
RM606A1(X3)	6	T	NT	NT	T	*NA*	NT	NT	T	T	*NA*	NT	NT	NT	*NA*	T	2
RM616A1(X3)	6	NT	NT	NT	NT	*NA*	NT	NT	T	T	*NA*	NT	NT	NT	*NA*	T	1
LR1	6	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	*ND*	*ND*	*ND*	*NA*	NT	0
71	6	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	T	T	*NA*	T	1
Total - Toxic		***30***	***8***	***16***	***34***	*NA*	***10***	***32***	***46***	***48***	*NA*	***10***	***11***	***16***	*NA*	***58***	*NA*
Total - Not Toxic		***27***	***49***	***41***	***23***	*NA*	***47***	***25***	***11***	***9***	*NA*	***54***	***53***	***48***	*NA*	***13***	*NA*
Total Count		***57***	***57***	***57***	***57***	*NA*	***57***	***57***	***57***	***57***	*NA*	***64***	***64***	***64***	*NA*	***71***	*NA*

Surv. = survival; Ref. = reference station; Repr = reproduction; ND = no data; NA = not applicable; NT = not toxic (unlikely to cause injury or death based on the reference envelope approach); T = toxic (capable of causing injury or death; based on the reference envelope approach).

Table 6.9. Incidence of toxicity for all samples evaluated for the Upper Columbia River study area (including not toxic, moderately impacted, and highly impacted samples).

Station	Reach	Amphipod, *Hyalella azteca*					Midge, *Chironomus dilutus*					Cladoceran, Ceriodaphnia dubia				Overall Toxicity	# of HI Endpoints
		Surv.	Growth	Biomass	Overall	Ref.	Surv.	Growth	Biomass	Overall	Ref.	Surv.	Repr.	Overall	Ref.		
Reference Sites																	
RM732R1	Fivemile Cr.	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM721R1	Flat Cr.	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM726R1	Crown Cr.	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM705R1	Nancy Cr.	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM685R1	Cheweka Cr.	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM686R1	Barnaby Cr.	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	NT	NT	NT	YES	NT	0
RM706A2(X7)	3	NT	NT	NT	NT	YES	**HI**	NT	**HI**	**HI**	NO	NT	NT	NT	YES	**HI**	2
2	Canada	*ND*	*ND*	*ND*	*ND*	NO	*ND*	*ND*	*ND*	*ND*	NO	NT	NT	NT	YES	NT	0
62	Sanpoil R.	*ND*	*ND*	*ND*	*ND*	NO	*ND*	*ND*	*ND*	*ND*	NO	NT	NT	NT	YES	NT	0
SA8	Sanpoil R.	NT	NT	NT	NT	YES	NT	NT	NT	NT	YES	*ND*	*ND*	*ND*	NO	NT	0
Total - Highly Impacted		***0***	***0***	***0***	***0***	NA	***1***	***0***	***1***	***1***	NA	***0***	***0***	***0***	NA	***1***	NA
Total - Moderately Impacted		***0***	***0***	***0***	***0***	NA	***0***	***0***	***0***	***0***	NA	***0***	***0***	***0***	NA	***0***	NA
Total - Not Toxic		***8***	***8***	***8***	***8***	NA	***7***	***8***	***7***	***7***	NA	***9***	***9***	***9***	NA	***9***	NA
Total Count		***8***	***8***	***8***	***8***	NA	***8***	***8***	***8***	***8***	NA	***9***	***9***	***9***	NA	***10***	NA
All Other Sites																	
RM733A1(X1)	1	**MI**	NT	NT	**MI**	*NA*	NT	**MI**	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	1
RM734A1	1	**MI**	**HI**	**HI**	**HI**	*NA*	NT	**HI**	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	4
RM736A1(X1)	1	**MI**	NT	NT	**MI**	*NA*	NT	NT	NT	NT	*NA*	**HI**	NT	**HI**	*NA*	**HI**	1
RM737A1(X3)	1	**MI**	**HI**	**HI**	**HI**	*NA*	NT	**HI**	**HI**	**HI**	*NA*	**HI**	**HI**	**HI**	*NA*	**HI**	6
RM738A1(X3)	1	**MI**	**HI**	**HI**	**HI**	*NA*	NT	**HI**	**HI**	**HI**	*NA*	**HI**	**HI**	**HI**	*NA*	**HI**	6
RM739A1(X3)	1	**MI**	NT	NT	**MI**	*NA*	NT	NT	NT	NT	*NA*	NT	NT	NT	*NA*	**MI**	0
RM740A1(X1)	1	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	NT	NT	NT	*NA*	NT	0
RM741A1(X3)	1	**HI**	NT	NT	**HI**	*NA*	NT	NT	**MI**	**MI**	*NA*	NT	NT	NT	*NA*	**HI**	1
RM742A1(X1)	1	**MI**	**MI**	**HI**	**HI**	*NA*	NT	**HI**	**HI**	**HI**	*NA*	NT	**HI**	**HI**	*NA*	**HI**	4
RM742A2(X5)	1	NT	NT	**MI**	**MI**	*NA*	NT	**HI**	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	2
RM743A1(X1)	1	**MI**	NT	NT	**MI**	*NA*	NT	**HI**	**MI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	1
RM743A2(X3)	1	**HI**	NT	**HI**	**HI**	*NA*	NT	**HI**	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	4
RM744A1(X1)	1	**HI**	NT	**MI**	**HI**	*NA*	**MI**	NT	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	2
RM744A2(X3)	1	**HI**	**HI**	**HI**	**HI**	*NA*	NT	**HI**	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	5

Table 6.9. Incidence of toxicity for all samples evaluated for the Upper Columbia River study area (including not toxic, moderately impacted, and highly impacted samples).

Station	Reach	Amphipod, *Hyalella azteca*					Midge, *Chironomus dilutus*					Cladoceran, Ceriodaphnia dubia				Overall Toxicity	# of HI Endpoints
		Surv.	Growth	Biomass	Overall	Ref.	Surv.	Growth	Biomass	Overall	Ref.	Surv.	Repr.	Overall	Ref.		
LR7	1	**HI**	NT	**HI**	**HI**	*NA*	NT	**HI**	**HI**	**HI**	*NA*	*ND*	*ND*	*ND*	*NA*	**HI**	4
8	1	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	**HI**	**HI**	**HI**	*NA*	**HI**	2
10	1	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	**HI**	**HI**	**HI**	*NA*	**HI**	2
11	1	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	**HI**	**HI**	*NA*	**HI**	1
14	1	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
RM713A1(X3)	2	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	NT	NT	NT	*NA*	NT	0
RM723A1(X1)	2	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	NT	NT	NT	*NA*	NT	0
RM723A2(X3)	2	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	NT	NT	NT	*NA*	NT	0
RM724A1(X1)	2	NT	NT	NT	NT	*NA*	**MI**	NT	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	1
RM724A2(X3)	2	NT	NT	NT	NT	*NA*	NT	NT	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	1
RM727A1(X1)	2	NT	NT	NT	NT	*NA*	NT	**HI**	NT	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	1
RM729A1(X1)	2	**MI**	NT	NT	**MI**	*NA*	NT	NT	**MI**	**MI**	*NA*	NT	NT	NT	*NA*	**MI**	0
RM730A1	2	**MI**	NT	NT	**MI**	*NA*	NT	NT	**MI**	**MI**	*NA*	NT	NT	NT	*NA*	**MI**	0
LR6	2	NT	NT	NT	NT	*NA*	NT	NT	NT	NT	*NA*	*ND*	*ND*	*ND*	*NA*	NT	0
15	2	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
17	2	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
19	2	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
RM704A1(X1)	3	NT	NT	NT	NT	*NA*	NT	NT	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	1
RM706A1(X1)	3	NT	NT	**MI**	**MI**	*NA*	NT	**HI**	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	2
RM708A1(X3)	3	**MI**	NT	**MI**	**MI**	*NA*	NT	**HI**	**HI**	**HI**	*NA*	**HI**	NT	**HI**	*NA*	**HI**	3
RM706A2(X7)	3	NT	NT	NT	NT	YES	**HI**	NT	**HI**	**HI**	NO	NT	NT	NT	YES	**HI**	2
LR5	3	**MI**	NT	**HI**	**HI**	*NA*	NT	NT	NT	NT	*NA*	*ND*	*ND*	*ND*	*NA*	**HI**	1
20	3	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	NT	NT	NT	*NA*	NT	0
22	3	*ND*	*ND*	*ND*	*ND*	*NA*	*ND*	*ND*	*ND*	*ND*	*NA*	**MI**	NT	**MI**	*NA*	**MI**	0
RM640A1(X3)	4	NT	NT	NT	NT	*NA*	**HI**	NT	**HI**	**HI**	*NA*	NT	**HI**	**HI**	*NA*	**HI**	3
RM641A1(X1)	4	NT	NT	NT	NT	*NA*	NT	**MI**	**MI**	**MI**	*NA*	NT	NT	NT	*NA*	**MI**	0
RM642A1(X1)	4	NT	NT	NT	NT	*NA*	**MI**	NT	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	1
RM644A1(X3)	4	**MI**	NT	NT	**MI**	*NA*	**MI**	**MI**	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	1
RM658A1(X3)	4	NT	NT	NT	NT	*NA*	NT	**MI**	**MI**	**MI**	*NA*	NT	NT	NT	*NA*	**MI**	0
RM661A1(X1)	4	NT	NT	NT	NT	*NA*	NT	**MI**	NT	**MI**	*NA*	NT	NT	NT	*NA*	**MI**	0
RM676A1(X3)	4	**MI**	NT	NT	**MI**	*NA*	**HI**	NT	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	2
RM677A1(X3)	4	**MI**	**MI**	**HI**	**HI**	*NA*	**HI**	NT	**HI**	**HI**	*NA*	NT	NT	NT	*NA*	**HI**	3

Table 6.9. Incidence of toxicity for all samples evaluated for the Upper Columbia River study area (including not toxic, moderately impacted, and highly impacted samples).

Station	Reach	Amphipod, *Hyalella azteca*					Midge, *Chironomus dilutus*					Cladoceran, Ceriodaphnia dubia				Overall	# of HI
		Surv.	Growth	Biomass	Overall	Ref.	Surv.	Growth	Biomass	Overall	Ref.	Surv.	Repr.	Overall	Ref.	Toxicity	Endpoints
RM678A1(X1)	4	NT	NT	NT	NT	NA	NT	MI	HI	HI	NA	NT	NT	NT	NA	HI	1
RM680A1(X1)	4	NT	NT	MI	MI	NA	HI	NT	HI	HI	NA	NT	NT	NT	NA	HI	2
RM686A1(X3)	4	MI	NT	NT	MI	NA	NT	MI	HI	HI	NA	NT	NT	NT	NA	HI	1
RM687A1	4	MI	MI	HI	HI	NA	NT	HI	MI	HI	NA	NT	NT	NT	NA	HI	2
RM689A1(X3)	4	MI	NT	NT	MI	NA	HI	NT	HI	HI	NA	NT	NT	NT	NA	HI	2
RM692A1(X1)	4	NT	NT	NT	NT	NA	NT	MI	MI	MI	NA	NT	NT	NT	NA	MI	0
RM698A1(X1)	4	NT	MI	HI	HI	NA	NT	HI	HI	HI	NA	NT	NT	NT	NA	HI	3
LR3	4	MI	NT	NT	MI	NA	NT	MI	HI	HI	NA	ND	ND	ND	NA	HI	1
LR4	4	MI	NT	NT	MI	NA	NT	HI	HI	HI	NA	ND	ND	ND	NA	HI	2
38	4	ND	ND	ND	ND	NA	ND	ND	ND	ND	NA	MI	NT	MI	NA	MI	0
46	4	ND	ND	ND	ND	NA	ND	ND	ND	ND	NA	NT	NT	NT	NA	NT	0
RM622A1(X3)	5	NT	NT	NT	NT	NA	NT	MI	HI	HI	NA	NT	NT	NT	NA	HI	1
RM628A1(X1)	5	HI	NT	NT	HI	NA	NT	MI	MI	MI	NA	MI	NT	MI	NA	HI	1
RM634A1(X1)	5	MI	NT	NT	MI	NA	NT	MI	HI	HI	NA	HI	HI	HI	NA	HI	3
RM637A1(X1)	5	NT	NT	NT	NT	NA	NT	MI	HI	HI	NA	NT	NT	NT	NA	HI	1
LR2	5	NT	NT	NT	NT	NA	NT	MI	MI	MI	NA	ND	ND	ND	NA	MI	0
57	5	ND	ND	ND	ND	NA	ND	ND	ND	ND	NA	NT	NT	NT	NA	NT	0
61	5	ND	ND	ND	ND	NA	ND	ND	ND	ND	NA	NT	HI	HI	NA	HI	1
RM603A1(X1)	6	NT	NT	NT	NT	NA	NT	MI	MI	MI	NA	NT	HI	HI	NA	HI	1
RM605A1(X1)	6	MI	NT	NT	MI	NA	NT	MI	MI	MI	NA	NT	NT	NT	NA	MI	0
RM605A2(X8)	6	MI	NT	NT	MI	NA	NT	MI	MI	MI	NA	NT	NT	NT	NA	MI	0
RM606A1(X3)	6	MI	NT	NT	MI	NA	NT	NT	HI	HI	NA	NT	NT	NT	NA	HI	1
RM616A1(X3)	6	NT	NT	NT	NT	NA	NT	NT	HI	HI	NA	NT	NT	NT	NA	HI	1
LR1	6	NT	NT	NT	NT	NA	NT	NT	NT	NT	NA	ND	ND	ND	NA	NT	0
71	6	ND	ND	ND	ND	NA	ND	ND	ND	ND	NA	NT	HI	HI	NA	HI	1
Total - Highly Impacted		6	4	11	14	NA	6	15	33	36	NA	7	11	13	NA	46	NA
Total - Moderately Impacted		24	4	5	20	NA	4	17	13	12	NA	3	0	3	NA	12	NA
Total - Not Toxic		27	49	41	23	NA	47	25	11	9	NA	54	53	48	NA	13	NA
Total Count		57	57	57	57	NA	57	57	57	57	NA	64	64	64	NA	71	NA

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Table 6.9. Incidence of toxicity for all samples evaluated for the Upper Columbia River study area (including not toxic, moderately impacted, and highly impacted samples).

Station	Reach	Amphipod, *Hyalella azteca*					Midge, *Chironomus dilutus*					Cladoceran, Ceriodaphnia dubia				Overall Toxicity	# of HI Endpoints
		Surv.	Growth	Biomass	Overall	Ref.	Surv.	Growth	Biomass	Overall	Ref.	Surv.	Repr.	Overall	Ref.		

Cr. = creek; R. = river; Surv. = survival; Ref. = reference station; Repr. = reproduction; ND = no data; NA = not applicable.
HI = highly impacted; sediment samples with >10% reduction in survival, growth, biomass, or reproduction relative to the lower limit of the reference envelope.
MI = moderately impacted; sediment samples with survival, growth, biomass, or reproduction <10% below the lower limit of the reference envelope.
NT = not toxic; sediment samples with survival, growth, biomass, or reproduction > or = the minimum value of the reference envelope.
T = toxic; sediment samples with survival, growth, biomass, or reproduction lower than the minimum value of the reference envelope (includes both the MI and HI categories).

Table 6.10. Observed incidence of toxicity to amphipods, midges, and cladoceran exposed to sediment samples from the Upper Columbia River study area (including both moderately impacted and highly impacted sediment samples).

Reach	Incidence of Toxicity to Amphipod, *Hyalella azteca,* Midge, *Chironomus dilutus,* and Cladoceran, *Ceriodaphnia dubia*			
	Amphipod[1]	**Midge[1]**	**Cladoceran[2]**	**Overall Toxicity for Amphipod, Midge, or Cladoceran[3]**
Upper Columbia River Reaches[4]				
Reach 1	93% (14 of 15)	80% (12 of 15)	39% (7 of 18)	89% (17 of 19)
Reach 2	22% (2 of 9)	56% (5 of 9)	0% (0 of 11)	42% (5 of 12)
Reach 3	60% (3 of 5)	80% (4 of 5)	33% (2 of 6)	86% (6 of 7)
Reach 4	59% (10 of 17)	100% (17 of 17)	12% (2 of 17)	95% (18 of 19)
Reach 5	40% (2 of 5)	100% (5 of 5)	50% (3 of 6)	86% (6 of 7)
Reach 6	50% (3 of 6)	83% (5 of 6)	33% (2 of 6)	86% (6 of 7)
All Six Reaches Combined	*60% (34 of 57)*	*84% (48 of 57)*	*25% (16 of 64)*	*82% (58 of 71)*
Stations selected for the Reference Envelopes[5]				
C. dilutus Reference Envelope	0% (0 of 7)	0% (0 of 7)	0% (0 of 6)	0% (0 of 7)
H. azteca Reference Envelope	0% (0 of 8)	13% (1 of 8)	0% (0 of 7)	13% (1 of 8)
C. dubia Reference Envelope	0% (0 of 7)	14% (1 of 7)	0% (0 of 9)	11% (1 of 9)
All Reference Stations	*0% (0 of 8)*	*13% (1 of 8)*	*0% (0 of 9)*	*10% (1 of 10)*
All Stations (In and Out of Study Area)	*53% (34 of 64)*	*75% (48 of 64)*	*22% (16 of 72)*	*73% (58 of 80)*

[1] Sediment samples were designated as toxic if the sample was designated as toxic based on the survival, growth or biomass endpoints.

[2] Sediment samples were designated as toxic if the sample was designated as toxic based on the survival, or reproduction endpoints.

[3] Sediment samples were designated as toxic if the sample was designated as toxic for one or more endpoints (survival or biomass) for any species.

[4] Only reference envelope stations that were located on the Upper Columbia River mainstem were included in these reach-specific summaries.

[5] Includes all stations selected for the reference envelope (i.e., includes stations on the Upper Columbia River mainstem, as well as stations on tributaries, the Sanpoil River, and in Canada).

Table 6.11. Observed incidence of toxicity to amphipods, midges, and cladoceran exposed to sediment samples from the Upper Columbia River study area (including highly impacted sediment samples only).

Reach	Incidence of Toxicity to Amphipod, *Hyalella azteca*, Midge *Chironomus dilutus*, and Cladoceran, *Ceriodaphnia dubia*			
	Amphipod[1]	**Midge[1]**	**Cladoceran[2]**	**Overall Toxicity for Amphipod, Midge, or Daphnid[3]**
Upper Columbia River Reaches[4]				
Reach 1	60% (9 of 15)	73% (11 of 15)	39% (7 of 18)	84% (16 of 19)
Reach 2	0% (0 of 9)	33% (3 of 9)	0% (0 of 11)	25% (3 of 12)
Reach 3	20% (1 of 5)	80% (4 of 5)	17% (1 of 6)	71% (5 of 7)
Reach 4	18% (3 of 17)	76% (13 of 17)	6% (1 of 17)	68% (13 of 19)
Reach 5	20% (1 of 5)	60% (3 of 5)	33% (2 of 6)	71% (5 of 7)
Reach 6	0% (0 of 6)	33% (2 of 6)	33% (2 of 6)	57% (4 of 7)
All Six Reaches Combined	*25% (14 of 57)*	*63% (36 of 57)*	*20% (13 of 64)*	*65% (46 of 71)*
Stations selected for the Reference Envelopes[5]				
C. dilutus Reference Envelope	0% (0 of 8)	0% (0 of 7)	0% (0 of 6)	0% (0 of 7)
H. azteca Reference Envelope	0% (0 of 8)	13% (1 of 8)	0% (0 of 7)	13% (1 of 8)
C. dubia Reference Envelope	0% (0 of 7)	14% (1 of 7)	0% (0 of 9)	11% (1 of 9)
All Reference Stations	*0% (0 of 8)*	*13% (1 of 8)*	*0% (0 of 9)*	*10% (1 of 10)*
All Stations (In and Out of Study Area)	*22% (14 of 64)*	*56% (36 of 64)*	*18% (13 of 72)*	*58% (46 of 80)*

[1] Sediment samples were designated as highly impacted if the sample was designated as highly impacted based on the survival, growth or biomass endpoints.
[2] Sediment samples were designated as highly impacted if the sample was designated as highly impacted based on the survival, or reproduction endpoints.
[3] Sediment samples were designated as highly impacted if the sample was designated as highly impacted for one or more endpoints (survival or biomass) for any species.
[4] Only reference envelope stations that were located on the Upper Columbia River mainstem were included in these reach-specific summaries.
[5] Includes all stations selected for the reference envelope (i.e., includes stations on the Upper Columbia River mainstem, as well as stations on tributaries, the Sanpoil River, and in Canada).

Table 6.12. Observed incidence of toxicity to amphipod, *Hyalella azteca* exposed to sediment samples from the Upper Columbia River study area (including both moderately impacted and highly impacted sediment samples).

Reach	Incidence of Toxicity to Amphipod, *Hyalella azteca*			
	Survival	Growth	Biomass	Overall Toxicity for Amphipod[1]
Upper Columbia River Reaches[2]				
Reach 1	87% (13 of 15)	33% (5 of 15)	60% (9 of 15)	93% (14 of 15)
Reach 2	22% (2 of 9)	0% (0 of 9)	0% (0 of 9)	22% (2 of 9)
Reach 3	40% (2 of 5)	0% (0 of 5)	60% (3 of 5)	60% (3 of 5)
Reach 4	47% (8 of 17)	18% (3 of 17)	24% (4 of 17)	59% (10 of 17)
Reach 5	40% (2 of 5)	0% (0 of 5)	0% (0 of 5)	40% (2 of 5)
Reach 6	50% (3 of 6)	0% (0 of 6)	0% (0 of 6)	50% (3 of 6)
All Six Reaches Combined	*53% (30 of 57)*	*14% (8 of 57)*	*28% (16 of 57)*	*60% (34 of 57)*
Stations selected for the Reference Envelope[3]				
H. azteca Reference Envelope	0% (0 of 8)	0% (0 of 8)	0% (0 of 8)	0% (0 of 8)
All Stations (In and Out of Study Area)	47% (30 of 64)	13% (8 of 64)	25% (16 of 64)	53% (34 of 64)

[1] Sediment samples were designated as toxic if the sample was designated as toxic based on the survival, growth, or biomass endpoints.

[2] Only reference envelope stations that were located on the Upper Columbia River mainstem were included in these reach-specific summaries.

[3] Includes all stations selected for the reference envelope (i.e., includes reference envelope stations on the Upper Columbia River mainstem, as well as reference envelope stations on tributaries, the Sanpoil River, and in Canada).

Table 6.13. Observed incidence of toxicity to amphipod, *Hyalella azteca* exposed to sediment samples from the Upper Columbia River study area (including highly impacted sediment samples only).

Reach	Incidence of Toxicity to Amphipod, *Hyalella azteca*			
	Survival	**Growth**	**Biomass**	**Overall Toxicity for Amphipod[1]**
Upper Columbia River Reaches[2]				
Reach 1	33% (5 of 15)	27% (4 of 15)	47% (7 of 15)	60% (9 of 15)
Reach 2	0% (0 of 9)	0% (0 of 9)	0% (0 of 9)	0% (0 of 9)
Reach 3	0% (0 of 5)	0% (0 of 5)	20% (1 of 5)	20% (1 of 5)
Reach 4	0% (0 of 17)	0% (0 of 17)	18% (3 of 17)	18% (3 of 17)
Reach 5	20% (1 of 5)	0% (0 of 5)	0% (0 of 5)	20% (1 of 5)
Reach 6	0% (0 of 6)	0% (0 of 6)	0% (0 of 6)	0% (0 of 6)
All Six Reaches Combined	*11% (6 of 57)*	*7% (4 of 57)*	*19% (11 of 57)*	*25% (14 of 57)*
Stations selected for the Reference Envelope[3]				
H. azteca Reference Envelope	0% (0 of 8)	0% (0 of 8)	0% (0 of 8)	0% (0 of 8)
All Stations (In and Out of Study Area)	9% (6 of 64)	6% (4 of 64)	17% (11 of 64)	22% (14 of 64)

[1] Sediment samples were designated as highly impacted if the sample was designated as highly impacted based on the survival, growth, or biomass endpoints.

[2] Only reference envelope stations that were located on the Upper Columbia River mainstem were included in these reach-specific summaries.

[3] Includes all stations selected for the reference envelope (i.e., includes reference envelope stations on the Upper Columbia River mainstem, as well as reference envelope stations on tributaries, the Sanpoil River, and in Canada).

Table 6.14. Observed incidence of toxicity to midge, *Chironomus dilutus* exposed to sediment samples from the Upper Columbia River study area (including both moderately impacted and highly impacted sediment samples).

Reach	Incidence of Toxicity to Midge, *Chironomus dilutus*			
	Survival	**Growth**	**Biomass**	**Overall Toxicity for Midge**[1]
Upper Columbia River Reaches[2]				
Reach 1	7% (1 of 15)	67% (10 of 15)	80% (12 of 15)	80% (12 of 15)
Reach 2	11% (1 of 9)	11% (1 of 9)	44% (4 of 9)	56% (5 of 9)
Reach 3	20% (1 of 5)	40% (2 of 5)	80% (4 of 5)	80% (4 of 5)
Reach 4	41% (7 of 17)	65% (11 of 17)	94% (16 of 17)	100% (17 of 17)
Reach 5	0% (0 of 5)	100% (5 of 5)	100% (5 of 5)	100% (5 of 5)
Reach 6	0% (0 of 6)	50% (3 of 6)	83% (5 of 6)	83% (5 of 6)
All Six Reaches Combined	*18% (10 of 57)*	*56% (32 of 57)*	*81% (46 of 57)*	*84% (48 of 57)*
Stations selected for the Reference Envelope[3]				
C. dilutus Reference Envelope	0% (0 of 7)	0% (0 of 7)	0% (0 of 7)	0% (0 of 7)
All Stations (In and Out of Study Area)	16% (10 of 64)	50% (32 of 64)	72% (46 of 64)	75% (48 of 64)

[1] Sediment samples were designated as toxic if the sample was designated as toxic based on the survival, growth, or biomass endpoints.

[2] Only reference envelope stations that were located on the Upper Columbia River mainstem were included in these reach-specific summaries.

[3] Includes all stations selected for the reference envelope (i.e., includes reference envelope stations on the Upper Columbia River mainstem, as well as reference envelope stations on tributaries, the Sanpoil River, and in Canada).

Table 6.15. Observed incidence of toxicity to midge, *Chironomus dilutus* exposed to sediment samples from the Upper Columbia River study area (including highly impacted sediment samples only).

Reach	Incidence of Toxicity to Midge, *Chironomus dilutus*			
	Survival	Growth	Biomass	Overall Toxicity for Midge[1]
Upper Columbia River Reaches[2]				
Reach 1	0% (0 of 15)	60% (9 of 15)	67% (10 of 15)	73% (11 of 15)
Reach 2	0% (0 of 9)	11% (1 of 9)	22% (2 of 9)	33% (3 of 9)
Reach 3	20% (1 of 5)	40% (2 of 5)	80% (4 of 5)	80% (4 of 5)
Reach 4	29% (5 of 17)	18% (3 of 17)	71% (12 of 17)	76% (13 of 17)
Reach 5	0% (0 of 5)	0% (0 of 5)	60% (3 of 5)	60% (3 of 5)
Reach 6	0% (0 of 6)	0% (0 of 6)	33% (2 of 6)	33% (2 of 6)
All Six Reaches Combined	*11% (6 of 57)*	*26% (15 of 57)*	*58% (33 of 57)*	*63% (36 of 57)*
Stations selected for the Reference Envelope[3]				
C. dilutus Reference Envelope	0% (0 of 7)	0% (0 of 7)	0% (0 of 7)	0% (0 of 7)
All Stations (In and Out of Study Area)	9% (6 of 64)	23% (15 of 64)	52% (33 of 64)	56% (36 of 64)

[1] Sediment samples were designated as highly impacted if the sample was designated as highly impacted based on the survival, growth, or biomass endpoints.

[2] Only reference envelope stations that were located on the Upper Columbia River mainstem were included in these reach-specific summaries.

[3] Includes all stations selected for the reference envelope (i.e., includes reference envelope stations on the Upper Columbia River mainstem, as well as reference envelope stations on tributaries, the Sanpoil River, and in Canada).

Table 6.16. Observed incidence of toxicity to cladoceran, *Ceriodaphnia dubia* exposed to sediment samples from the Upper Columbia River study area (including both moderately impacted and highly impacted sediment samples).

Reach	Incidence of Toxicity (IOT) to Cladoceran, *Ceriodaphnia dubia*		
	Survival	**Reproduction**	**Overall Toxicity for Cladoceran[1]**
Upper Columbia River Reaches[2]			
Reach 1	28% (5 of 18)	33% (6 of 18)	39% (7 of 18)
Reach 2	0% (0 of 11)	0% (0 of 11)	0% (0 of 11)
Reach 3	33% (2 of 6)	0% (0 of 6)	33% (2 of 6)
Reach 4	6% (1 of 17)	6% (1 of 17)	12% (2 of 17)
Reach 5	33% (2 of 6)	33% (2 of 6)	50% (3 of 6)
Reach 6	0% (0 of 6)	33% (2 of 6)	33% (2 of 6)
All Six Reaches Combined	*16% (10 of 64)*	*17% (11 of 64)*	*25% (16 of 64)*
Stations selected for the Reference Envelope[3]			
C. dubia Reference Envelope	0% (0 of 9)	0% (0 of 9)	0% (0 of 9)
All Stations (In and Out of Study Area)	*14% (10 of 72)*	*15% (11 of 72)*	*22% (16 of 72)*

IOT = incidence of toxicity.

[1] Sediment samples were designated as toxic if the sample was designated as toxic based on the survival or reproduction endpoints.

[2] Only reference envelope stations that were located on the Upper Columbia River mainstem were included in these reach-specific summaries.

[3] Includes all stations selected for the reference envelope (i.e., includes reference envelope stations on the Upper Columbia River mainstem, as well as reference envelope stations on tributaries, the Sanpoil River, and in Canada).

Table 6.17. Observed incidence of toxicity to cladoceran, *Ceriodaphnia dubia* exposed to sediment samples from the Upper Columbia River study area (including highly impacted sediment samples only).

Reach	Incidence of Toxicity (IOT) to Cladoceran, *Ceriodaphnia dubia*		
	Survival	**Reproduction**	**Overall Toxicity for Cladoceran**[1]
Upper Columbia River Reaches[2]			
Reach 1	28% (5 of 18)	33% (6 of 18)	39% (7 of 18)
Reach 2	0% (0 of 11)	0% (0 of 11)	0% (0 of 11)
Reach 3	17% (1 of 6)	0% (0 of 6)	17% (1 of 6)
Reach 4	0% (0 of 17)	6% (1 of 17)	6% (1 of 17)
Reach 5	17% (1 of 6)	33% (2 of 6)	33% (2 of 6)
Reach 6	0% (0 of 6)	33% (2 of 6)	33% (2 of 6)
All Six Reaches Combined	*11% (7 of 64)*	*17% (11 of 64)*	*20% (13 of 64)*
Stations selected for the Reference Envelope[3]			
C. dubia Reference Envelope	0% (0 of 9)	0% (0 of 9)	0% (0 of 9)
All Stations (In and Out of Study Area)	*10% (7 of 72)*	*15% (11 of 72)*	*18% (13 of 72)*

IOT = incidence of toxicity.

[1] Sediment samples were designated as highly impacted if the sample was designated as highly impacted based on the survival or reproduction endpoints.

[2] Only reference envelope stations that were located on the Upper Columbia River mainstem were included in these reach-specific summaries.

[3] Includes all stations selected for the reference envelope (i.e., includes reference envelope stations on the Upper Columbia River mainstem, as well as reference envelope stations on tributaries, the Sanpoil River, and in Canada).

Table 6.18. Incidence of toxicity for non slag-affected, potentially slag-affected and slag-affected samples in the Upper Columbia River Watershed.

End Point	Non Slag-Affected Samples	Potentially Slag-Affected Samples	Slag-Affected Samples
Ceriodaphnia dubia			
Survival	3 of 36 (8%)	2 of 11 (18%)	5 of 25 (20%)
Reproduction	5 of 36 (14%)	0 of 11 (0%)	6 of 25 (24%)
Overall Toxicity for *C. dubia*	7 of 36 (19%)	2 of 11 (18%)	7 of 25 (28%)
Chironomus dilutus			
Survival	8 of 34 (24%)	1 of 9 (11%)	1 of 21 (5%)
Biomass	25 of 34 (74%)	6 of 9 (67%)	15 of 21 (71%)
Growth	17 of 34 (50%)	4 of 9 (44%)	11 of 21 (52%)
Overall Toxicity for *C. dilutus*	26 of 34 (76%)	6 of 9 (67%)	16 of 21 (76%)
Hyalella azteca			
Survival	12 of 34 (35%)	3 of 9 (33%)	15 of 21 (71%)
Biomass	2 of 34 (6%)	5 of 9 (56%)	9 of 21 (43%)
Growth	1 of 34 (3%)	2 of 9 (22%)	5 of 21 (24%)
Overall Toxicity for *H. azteca*	13 of 34 (38%)	5 of 9 (56%)	16 of 21 (76%)
Overall Toxicity for all Endpoints	**29 of 41 (71%)**	**8 of 12 (67%)**	**21 of 27 (78%)**

Table 8.1. Comparison of the incidence of toxicity (IOT) for three types of sediment samples identified using three methods of evaluating the slag content of sediments in the Upper Columbia River.

Sediment Sample Classification	*Ceriodaphnia dubia*			*Chironomus dilutus*				*Hyalella azteca*				All Species All Endpoints
	Survival	Reproduction	Survival and Reproduction	Survival	Biomass	Growth	Survival, Biomass, Growth	Survival	Biomass	Growth	Survival, Biomass, Growth	
Method Used to Classify Sediments - Cu:Al												
Non Slag												
n	36	36	36	34	34	34	34	34	34	34	34	41
Toxic	3	5	7	8	25	17	26	12	2	1	13	29
IoT (%)	**8.3**	**13.9**	**19.4**	**23.5**	**73.5**	**50.0**	**76.5**	**35.3**	**5.9**	**2.9**	**38.2**	**70.7**
Potential Slag												
n	11	11	11	9	9	9	9	9	9	9	9	12
Toxic	2	0	2	1	6	4	6	3	5	2	5	8
IoT (%)	**18.2**	**0.0**	**18.2**	**11.1**	**66.7**	**44.4**	**66.7**	**33.3**	**55.6**	**22.2**	**55.6**	**66.7**
Slag												
n	25	25	25	21	21	21	21	21	21	21	21	27
Toxic	5	6	7	1	15	11	16	15	9	5	16	21
IoT (%)	**20.0**	**24.0**	**28.0**	**4.8**	**71.4**	**52.4**	**76.2**	**71.4**	**42.9**	**23.8**	**76.2**	**77.8**
Method Used to Classify Sediments - Cu:Al/Zn:Cd												
Non Slag												
n	15	15	15	13	13	13	13	13	13	13	13	16
Toxic	1	0	1	2	6	4	6	2	1	1	2	7
IoT (%)	**6.7**	**0.0**	**6.7**	**15.4**	**46.2**	**30.8**	**46.2**	**15.4**	**7.7**	**7.7**	**15.4**	**43.8**
Potential Slag												
n	35	35	35	33	33	33	33	33	33	33	33	40
Toxic	5	5	9	7	25	18	27	14	6	2	17	32
IoT (%)	**14.3**	**14.3**	**25.7**	**21.2**	**75.8**	**54.5**	**81.8**	**42.4**	**18.2**	**6.1**	**51.5**	**80.0**
Slag												
n	22	22	22	18	18	18	18	18	18	18	18	24
Toxic	4	6	6	1	15	10	15	14	9	5	15	19
IoT (%)	**18.2**	**27.3**	**27.3**	**5.6**	**83.3**	**55.6**	**83.3**	**77.8**	**50.0**	**27.8**	**83.3**	**79.2**

Table 8.1. Comparison of the incidence of toxicity (IOT) for three types of sediment samples identified using three methods of evaluating the slag content of sediments in the Upper Columbia River.

Sediment Sample Classification	*Ceriodaphnia dubia*			*Chironomus dilutus*				*Hyalella azteca*				All Species All Endpoints
	Survival	Reproduction	Survival and Reproduction	Survival	Biomass	Growth	Survival, Biomass, Growth	Survival	Biomass	Growth	Survival, Biomass, Growth	
Method Used to Classify Sediments - Fe:Al/Zn:Cd												
Non Slag												
n	15	15	15	13	13	13	13	13	13	13	13	16
Toxic	1	0	1	2	6	3	6	2	2	2	2	7
IoT (%)	**6.7**	**0.0**	**6.7**	**15.4**	**46.2**	**23.1**	**46.2**	**15.4**	**15.4**	**15.4**	**15.4**	**43.8**
Potential Slag												
n	34	34	34	32	32	32	32	32	32	32	32	38
Toxic	5	5	9	7	25	19	27	13	4	1	16	31
IoT (%)	**14.7**	**14.7**	**26.5**	**21.9**	**78.1**	**59.4**	**84.4**	**40.6**	**12.5**	**3.1**	**50.0**	**81.6**
Slag												
n	23	23	23	19	19	19	19	19	19	19	19	26
Toxic	4	6	6	1	15	10	15	15	10	5	16	20
IoT (%)	**17.4**	**26.1**	**26.1**	**5.3**	**78.9**	**52.6**	**78.9**	**78.9**	**52.6**	**26.3**	**84.2**	**76.9**

n = number of samples; IoT = incidence of toxicity; Al = aluminum; Cd = cadmium; Cu = copper; Zn = zinc.

Table 8.2. Predictive ability of generic sediment quality guidelines when applied to non slag-affected sediment samples from the Upper Columbia River (based on the Cu:Al and Zn:Cd slag identification model).

COPC, COPC Mixture/ Sediment Toxicity Test	n	$TPST_{LI}$	$TPST_{HI}$	Incidence of Toxicity[1]						
				$<TPST_{LI}$	$\geq TPST_{LI}$	Correct Class. Rate for $TPST_{LI}$	$TPST_{LI}$-$TPST_{HI}$[2]	$\leq TPST_{HI}$	$>TPST_{HI}$	Correct Class. Rate for $TPST_{HI}$
(ΣSEM-AVS)/f_{OC} (µmol/g)										
Cladoceran 7-d Survival	12	130	3000	0% (0 of 7)	0% (0 of 5)	58%	0% (0 of 5)	0% (0 of 12)	No Data	100%
Cladoceran 7-d Reproduction	12	130	3000	0% (0 of 7)	0% (0 of 5)	58%	0% (0 of 5)	0% (0 of 12)	No Data	100%
Cladoceran 7-d All	12	130	3000	0% (0 of 7)	0% (0 of 5)	58%	0% (0 of 5)	0% (0 of 12)	No Data	100%
Midge 10-d Survival	13	130	3000	12% (1 of 8)	20% (1 of 5)	62%	20% (1 of 5)	15% (2 of 13)	No Data	85%
Midge 10-d Growth	13	130	3000	**0% (0 of 8)**	**80% (4 of 5)**	**92%**	80% (4 of 5)	31% (4 of 13)	No Data	69%
Midge 10-d Biomass	13	130	3000	**12% (1 of 8)**	**100% (5 of 5)**	**92%**	100% (5 of 5)	46% (6 of 13)	No Data	54%
Midge 10-d All	13	130	3000	**12% (1 of 8)**	**100% (5 of 5)**	**92%**	100% (5 of 5)	46% (6 of 13)	No Data	54%
Amphipod 28-d Survival	13	130	3000	12% (1 of 8)	20% (1 of 5)	62%	20% (1 of 5)	15% (2 of 13)	No Data	85%
Amphipod 28-d Growth	13	130	3000	12% (1 of 8)	0% (0 of 5)	54%	0% (0 of 5)	8% (1 of 13)	No Data	92%
Amphipod 28-d Biomass	13	130	3000	12% (1 of 8)	0% (0 of 5)	54%	0% (0 of 5)	8% (1 of 13)	No Data	92%
Amphipod 28-d All	13	130	3000	12% (1 of 8)	20% (1 of 5)	62%	20% (1 of 5)	15% (2 of 13)	No Data	85%
All Endpoints	13	130	3000	**12% (1 of 8)**	**100% (5 of 5)**	**92%**	100% (5 of 5)	46% (6 of 13)	No Data	54%
Mean PEC-Q										
Cladoceran 7-d Survival	14	0.1	1	0% (0 of 11)	33% (1 of 3)	86%	0% (0 of 2)	**0% (0 of 13)**	**100% (1 of 1)**	**100%**
Cladoceran 7-d Reproduction	14	0.1	1	0% (0 of 11)	0% (0 of 3)	79%	0% (0 of 2)	0% (0 of 13)	0% (0 of 1)	93%
Cladoceran 7-d All	14	0.1	1	0% (0 of 11)	33% (1 of 3)	86%	0% (0 of 2)	**0% (0 of 13)**	**100% (1 of 1)**	**100%**
Midge 10-d Survival	12	0.1	1	10% (1 of 10)	50% (1 of 2)	83%	50% (1 of 2)	17% (2 of 12)	No Data	83%
Midge 10-d Growth	12	0.1	1	30% (3 of 10)	50% (1 of 2)	67%	50% (1 of 2)	33% (4 of 12)	No Data	67%
Midge 10-d Biomass	12	0.1	1	40% (4 of 10)	100% (2 of 2)	67%	100% (2 of 2)	50% (6 of 12)	No Data	50%
Midge 10-d All	12	0.1	1	40% (4 of 10)	100% (2 of 2)	67%	100% (2 of 2)	50% (6 of 12)	No Data	50%
Amphipod 28-d Survival	12	0.1	1	20% (2 of 10)	0% (0 of 2)	67%	0% (0 of 2)	17% (2 of 12)	No Data	83%
Amphipod 28-d Growth	12	0.1	1	10% (1 of 10)	0% (0 of 2)	75%	0% (0 of 2)	8% (1 of 12)	No Data	92%
Amphipod 28-d Biomass	12	0.1	1	10% (1 of 10)	0% (0 of 2)	75%	0% (0 of 2)	8% (1 of 12)	No Data	92%
Amphipod 28-d All	12	0.1	1	20% (2 of 10)	0% (0 of 2)	67%	0% (0 of 2)	17% (2 of 12)	No Data	83%
All Endpoints	14	0.1	1	36% (4 of 11)	100% (3 of 3)	71%	100% (2 of 2)	46% (6 of 13)	100% (1 of 1)	57%

Table 8.2. Predictive ability of generic sediment quality guidelines when applied to non slag-affected sediment samples from the Upper Columbia River (based on the Cu:Al and Zn:Cd slag identification model).

COPC, COPC Mixture/ Sediment Toxicity Test	n	$TPST_{LI}$	$TPST_{HI}$	Incidence of Toxicity[1]						
				$<TPST_{LI}$	$\geq TPST_{LI}$	Correct Class. Rate for $TPST_{LI}$	$TPST_{LI}$-$TPST_{HI}$[2]	$\leq TPST_{HI}$	$>TPST_{HI}$	Correct Class. Rate for $TPST_{HI}$
***Mean PEC-Q** $_{METALS(1\%OC)}$*										
Cladoceran 7-d Survival	15	0.1	1	0% (0 of 8)	14% (1 of 7)	60%	25% (1 of 4)	8% (1 of 12)	0% (0 of 3)	73%
Cladoceran 7-d Reproduction	15	0.1	1	0% (0 of 8)	0% (0 of 7)	53%	0% (0 of 4)	0% (0 of 12)	0% (0 of 3)	80%
Cladoceran 7-d All	15	0.1	1	0% (0 of 8)	14% (1 of 7)	60%	25% (1 of 4)	8% (1 of 12)	0% (0 of 3)	73%
Midge 10-d Survival	13	0.1	1	0% (0 of 7)	33% (2 of 6)	69%	67% (2 of 3)	20% (2 of 10)	0% (0 of 3)	62%
Midge 10-d Growth	13	0.1	1	**0% (0 of 7)**	**67% (4 of 6)**	**85%**	33% (1 of 3)	**10% (1 of 10)**	**100% (3 of 3)**	**92%**
Midge 10-d Biomass	13	0.1	1	**0% (0 of 7)**	**100% (6 of 6)**	**100%**	100% (3 of 3)	30% (3 of 10)	100% (3 of 3)	77%
Midge 10-d All	13	0.1	1	**0% (0 of 7)**	**100% (6 of 6)**	**100%**	100% (3 of 3)	30% (3 of 10)	100% (3 of 3)	77%
Amphipod 28-d Survival	13	0.1	1	0% (0 of 7)	33% (2 of 6)	69%	33% (1 of 3)	10% (1 of 10)	33% (1 of 3)	77%
Amphipod 28-d Growth	13	0.1	1	0% (0 of 7)	17% (1 of 6)	62%	33% (1 of 3)	10% (1 of 10)	0% (0 of 3)	69%
Amphipod 28-d Biomass	13	0.1	1	0% (0 of 7)	17% (1 of 6)	62%	33% (1 of 3)	10% (1 of 10)	0% (0 of 3)	69%
Amphipod 28-d All	13	0.1	1	0% (0 of 7)	33% (2 of 6)	69%	33% (1 of 3)	10% (1 of 10)	33% (1 of 3)	77%
All Endpoints	16	0.1	1	**0% (0 of 9)**	**100% (7 of 7)**	**100%**	100% (4 of 4)	31% (4 of 13)	100% (3 of 3)	75%
***ΣPEC-Q** $_{METALS(1\%OC)}$*										
Cladoceran 7-d Survival	15	1	NA	0% (0 of 8)	14% (1 of 7)	60%	N/A	N/A	N/A	N/A
Cladoceran 7-d Reproduction	15	1	NA	0% (0 of 8)	0% (0 of 7)	53%	N/A	N/A	N/A	N/A
Cladoceran 7-d All	15	1	NA	0% (0 of 8)	14% (1 of 7)	60%	N/A	N/A	N/A	N/A
Midge 10-d Survival	13	1	NA	0% (0 of 7)	33% (2 of 6)	69%	N/A	N/A	N/A	N/A
Midge 10-d Growth	13	1	NA	**0% (0 of 7)**	**67% (4 of 6)**	**85%**	N/A	N/A	N/A	N/A
Midge 10-d Biomass	13	1	NA	**0% (0 of 7)**	**100% (6 of 6)**	**100%**	N/A	N/A	N/A	N/A
Midge 10-d All	13	1	NA	**0% (0 of 7)**	**100% (6 of 6)**	**100%**	N/A	N/A	N/A	N/A
Amphipod 28-d Survival	13	1	NA	0% (0 of 7)	33% (2 of 6)	69%	N/A	N/A	N/A	N/A
Amphipod 28-d Growth	13	1	NA	0% (0 of 7)	17% (1 of 6)	62%	N/A	N/A	N/A	N/A
Amphipod 28-d Biomass	13	1	NA	0% (0 of 7)	17% (1 of 6)	62%	N/A	N/A	N/A	N/A
Amphipod 28-d All	13	1	NA	0% (0 of 7)	33% (2 of 6)	69%	N/A	N/A	N/A	N/A
All Endpoints	16	1	NA	**0% (0 of 9)**	**100% (7 of 7)**	**100%**	N/A	N/A	N/A	N/A

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Table 8.2. Predictive ability of generic sediment quality guidelines when applied to non slag-affected sediment samples from the Upper Columbia River (based on the Cu:Al and Zn:Cd slag identification model).

COPC, COPC Mixture/ Sediment Toxicity Test	n	$TPST_{LI}$	$TPST_{HI}$	Incidence of Toxicity[1]						
				$<TPST_{LI}$	$\geq TPST_{LI}$	Correct Class. Rate for $TPST_{LI}$	$TPST_{LI}$-$TPST_{HI}$[2]	$\leq TPST_{HI}$	$>TPST_{HI}$	Correct Class. Rate for $TPST_{HI}$

COPC = chemical of potential concern; Class. = classification; LI = low impact; HI = high impact; OC = organic carbon; PEC-Q = probable effect concentration-quotients; TPST = threshold for predicting sediment toxicity; SEM-AVS = simultaneously extracted metals minus acid volatile sulfides; f_{OC} = fraction organic carbon; d = day; IOT = incidence of toxicity.
Mean PEC-Q was calculated based on the following metals: arsenic, cadmium, chromium, copper, nickel, lead, and zinc; total polycyclic aromatic hydrocarbons; and, total polychlorinated biphenyls (Ingersoll *et al.* 2001).
$PEC\text{-}Q_{METALS}$ = were calculated based on the following metals, arsenic, cadmium, chromium, copper, nickel, lead, zinc (Ingersoll *et al.* 2001); 1%OC = normalized to 1% organic carbon.

[1]Bolded results indicate that the TPST met all three evaluation criteria: IOT below the TPST <20%; IOT above the TPST >50%; and, correct classificiaton rate for the TPST ≥80%.
[2]$TPST_{LI}$-$TPST_{HI}$ includes those samples that are greater than or equal to the $TPST_{LI}$ and less than or equal to the $TPST_{HI}$.

Table 8.3. Mean control-adjusted response of the cladoceran (*Ceriodaphnia dubia*), the midge (*Chironomus dilutus*), and the amphipod (*Hyalella azteca*) in non and potentially slag-affected sediments in the Upper Columbia River (as identified based on Cu:Al ratio) that were classified using the threshold for predicting sediment toxicity for Mean PEC-Q based on *C. dilutus* biomass of 0.85.

Test Organism	Test Duration	Endpoint Measured	Mean Control or Reference-Adjusted Response (n)	
			Mean PEC-Q < 0.85	Mean PEC-Q ≥ 0.85
Ceriodaphnia dubia	7-d	Survival	98.6% ± 12.7% (38)	77.8 ± NA (1)
		Reproduction	96.1% ± 19.5% (38)	83.2 ± NA (1)
Chironomus dilutus	10-d	Survival	93.3%± 13.4% (37)	ND
		Growth	99.3% ± 9.82% (37)	ND
		Biomass	85.0% ± 14.0% (37)	ND
Hyalella azteca	28-d	Survival	98.8% ± 3.03% (37)	ND
		Growth	80.6% ± 20.3% 37)	ND
		Biomass	78.9% ± 20.7% (37)	ND

d = day; n = sample size

Mean PEC-Q was calculated based on the following metals: arsenic, cadmium, chromium, copper, nickel, lead, and zinc; total polycyclic aromatic hydrocarbons; and, total polychlorinated biphenyls (Ingersoll *et al.* 2001).

Table 8.4. Mean control-adjusted response of the cladoceran (*Ceriodaphnia dubia*), the midge (*Chironomus dilutus*), and the amphipod (*Hyalella azteca*) in slag-affected sediments in the Upper Columbia River that were classified using the Cu:Al slag identification tool.

Test Organism	Test Duration	Endpoint Measured	Mean Control or Reference-Adjusted Response (n)		
			5% ≤ Slag (%)[1] < 20%	20% ≤ Slag (%)[1] < 40%	Slag (%)[1] ≥ 40%
Ceriodaphnia dubia	7-d	Survival	97.8% ± 13.1% (8)	83.5% ± 40% (12)	70.7% ± 21.9% (5)
		Reproduction	102% ± 11.6% (8)	81.4% ± 43.1% (12)	47.6% ± 35.5% (5)
Chironomus dilutus	10-d	Survival	105% ± 7.27% (9)	103% ± 10.4% (9)	106% ± 3.06% (3)
		Growth	96.5% ± 20.5% (9)	90.1% ± 22.7% (9)	68.6% ± 5.02% (3)
		Biomass	99.9% ± 18.8% (9)	84.2% ± 11.6% (9)	70.5% ± 1.31% (3)
Hyalella azteca	28-d	Survival	94.4% ± 8.63% (9)	90.6% ± 5.31% (9)	90.0% ± 10.8% (3)
		Growth	78.1% ± 17% (9)	76.1% ± 27.3% (9)	44.0% ± 14.9% (3)
		Biomass	75% ± 19.6% (9)	68.4% ± 27.6% (9)	40.0% ± 17.1% (3)

d = day; n = sample size

[1] Estimated percent slag was calculated based on the Cu:Al slag identification tool.

Table 8.5. Mean control-adjusted response of the cladoceran (*Ceriodaphnia dubia*), the midge (*Chironomus dilutus*), and the amphipod (*Hyalella azteca*) in non slag-affected sediments in the Upper Columbia River (as identified based on Cu:Al and Zn:Cd ratio) that were classified using the toxicity threshold for Mean PEC-$Q_{METALS\ (1\%\ OC)}$ of 0.1.

Test Organism	Test Duration	Endpoint Measured	Mean Control or Reference-Adjusted Response (n)	
			Mean PEC-$Q_{METALS\ (1\%OC)} < 0.1$	Mean PEC-$Q_{METALS\ (1\%OC)} \geq 0.1$
Ceriodaphnia dubia	7-d	Survival	100% ± 4.96% (8)	103% ± 12.3% (7)
		Reproduction	95.5% ± 12.5% (8)	108% ± 16.4% (7)
Chironomus dilutus	10-d	Survival	98.7% ± 5.67% (7)	91.5% ± 17.4% (6)
		Growth	104% ± 6.01% (7)	95.1% ± 4.55% (6)
		Biomass	103% ± 6.67% (7)	83.3% ± 11% (6)
Hyalella azteca	28-d	Survival	101% ± 1.57% (7)	97.8% ± 2.56% (6)
		Growth	91.9% ± 19.8% (7)	76.5% ± 18.5% (6)
		Biomass	92.3% ± 18% (7)	75.1% ± 18.8% (6)

d = day; n = sample size

PEC-Q_{METALS} = were calculated based on the following metals, arsenic, cadmium, chromium, copper, nickel, lead, zinc (Ingersoll *et al.* 2001).

1%OC = normalized to 1% organic carbon.

Table 8.6. Mean control-adjusted response of the cladoceran (*Ceriodaphnia dubia*), the midge (*Chironomus dilutus*), and the amphipod (*Hyalella azteca*) in potential and slag-affected sediments in the Upper Columbia River that were classified using the Cu:Al and Zn:Cd slag identification tool.

Test Organism	Test Duration	Endpoint Measured	Mean Control or Reference-Adjusted Response (n)			
			Slag(%)[1] < 5%	5% ≤ Slag (%)[1] < 20%	20% ≤ Slag (%)[1] < 40%	Slag (%)[1] ≥ 40%
Ceriodaphnia dubia	7-d	Survival	96.6% ± 13.9% (32)	97.4% ± 14.1% (7)	100% ± 10.3% (7)	68.5% ± 39.4% (11)
		Reproduction	88.5% ± 22.2% (32)	102% ± 12.5% (7)	93.7% ± 24.4% (7)	60.1% ± 46.9% (11)
Chironomus dilutus	10-d	Survival	93.4% ± 13% (30)	107% ± 7.54% (7)	105% ± 11.7% (6)	101% ± 5.23% (8)
		Growth	99.5% ± 11.2% (30)	102% ± 19.5% (7)	90.2% ± 19.8% (6)	78.6% ± 20.5% (8)
		Biomass	83.7% ± 13.8% (30)	107% ± 13.7% (7)	87.9% ± 8.78% (6)	73.9% ± 9.03% (8)
Hyalella azteca	28-d	Survival	98.3% ± 3.61% (30)	97.9% ± 4.03% (7)	88.7% ± 4.91% (6)	89.7% ± 9.00% (8)
		Growth	77.0% ± 19.3% (30)	85.7% ± 8.69% (7)	71.2% ± 15.8% (6)	61.6% ± 33.1% (8)
		Biomass	74.9% ± 19.7% (30)	83.9% ± 9.89% (7)	62.2% ± 16.3% (6)	56.3% ± 32.8% (8)

d = day; n = sample size

[1] Estimated percent slag was calculated based on the Cu:Al and Zn:Cd slag identification tool.

Table 8.7. Evaluation of the framework for classifying toxicity of Upper Columbia River whole sediments to benthic invertebrates based on incidence of toxicity.

Species/ Endpoint	Incidence of Toxicity						
	Non and Potentially Slag-Affected[1]				Slag-Affected[1]		
	Not Toxic	Likely Not Toxic	Potentially Toxic	Likely Toxic	Potentially Toxic	Likely Toxic	Highly Toxic
Hyalella azteca							
Survival	0 of 7 (0%)	11 of 23 (48%)	2 of 9 (22%)	2 of 3 (67%)	5 of 9 (56%)	8 of 9 (89%)	2 of 3 (67%)
Biomass	0 of 8 (0%)	2 of 23 (9%)	4 of 9 (44%)	1 of 3 (33%)	2 of 9 (22%)	4 of 9 (44%)	3 of 3 (100%)
Chironomus dilutus							
Survival	1 of 8 (13%)	7 of 23 (30%)	1 of 9 (11%)	0 of 3 (0%)	0 of 9 (0%)	1 of 9 (11%)	0 of 3 (0%)
Biomass	1 of 8 (13%)	21 of 23 (91%)	7 of 9 (78%)	2 of 3 (67%)	3 of 9 (33%)	9 of 9 (100%)	3 of 3 (100%)
Ceriodaphnia dubia							
Survival	0 of 9 (0%)	3 of 23 (13%)	1 of 8 (13%)	1 of 4 (25%)	1 of 8 (13%)	2 of 11 (18%)	2 of 5 (40%)
Reproduction	0 of 9 (0%)	3 of 23 (13%)	0 of 8 (0%)	2 of 4 (50%)	0 of 8 (0%)	3 of 11 (27%)	3 of 5 (60%)

[1] Samples were classified as non slag-affected, potentially slag-affected, or slag-affected based on the Cu:Al method.

Table 8.8. Evaluation of the framework for classifying toxicity of Upper Columbia River whole sediments to benthic invertebrates based on magnitude of toxicity.

Species/ Endpoint	Mean Control-Adjusted Response[1]						
	Non and Potentially Slag-Affected[2]				Slag-Affected[2]		
	Not Toxic	Likely Not Toxic	Potentially Toxic	Likely Toxic	Potentially Toxic	Likely Toxic	Highly Toxic
Hyalella azteca							
Biomass	88.4 ± 20.1	81.1 ± 20.2	63.7 ± 12.3	66.3 ± 14.9	75.0 ± 19.6	68.4 ± 27.6	40.0 ± 17.1
Chironomus dilutus							
Biomass	99.0 ± 13.4	80.9 ± 12.9	88.4 ± 13.0	94.4 ± 8.65	99.9 ± 18.8	84.2 ± 11.6	70.5 ± 1.31

[1] Samples were classified as non slag-affected, potentially slag-affected, or slag-affected based on the Cu:Al method.