PORTLAND HARBOR RI

APPENDIX G
BASELINE ECOLOGICAL RISK ASSESSMENT

ATTACHMENT 9
TISSUE-RESIDUE TRVS

DRAFT

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Prepared for
The Lower Willamette Group

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1.0 INTRODUCTION

The US Environmental Protection Agency (EPA) provided the Lower Willamette Group (LWG) with the aquatic biota tissue toxicity reference value (TRV) methodology to be used in the baseline ecological risk assessment (BERA) on June 13, 2008 (EPA 2008e), and a revised version on August 5, 2008 (EPA 2008d). Based on this methodology, EPA developed tissue TRVs for 10 benthic chemicals of potential concern (COPCs) (i.e., arsenic, cadmium, copper, zinc, tributyltin [TBT], bis(2-ethylhexyl) phthalate [BEHP], dibutyl phthalate, total polychlorinated biphenyls [PCBs], DDD, and total DDx [sum of all six DDT isomers (2,4′-DDD, 2,4′-DDE, 2,4′-DDT, 4,4′-DDD, 4,4′-DDE, and 4,4′-DDT)]) and 10 fish COPCs (i.e., cadmium, chromium, copper, lead, mercury, BEHP, total PCBs, lindane, and total DDx). The tissue TRVs were provided to LWG between August 8 and October 9, 2008. The methodology and tissue TRVs were reviewed by Windward Environmental LLC (Windward) and, following negotiations and several reconciliation meetings, revisions were made to the methodology and tissue TRVs. This attachment presents a summary of these revisions. EPA's tissue TRV methodology is provided as a supplement to this attachment.

2.0 REVISIONS TO EPA'S METHODOLOGY

This section presents the overall revisions made to the methodology (Section 2.1) and revisions made to the derivation of specific benthic invertebrate tissue TRVs (Section 2.2) and fish tissue TRVs (Section 2.3).

2.1 OVERALL REVISIONS

Three revisions were made to the aquatic biota tissue TRV methodology, and the revised methodology was applied to both the benthic invertebrate and the fish TRVs. These revisions included a review of all papers for acceptability and to identify appropriate lowest-observed-effect levels (LOAELs), changing the acute-chronic ratio (ACR) from a non-specific value to chemical-specific value when possible, and providing an approach for the inclusion of PCB congener studies in the derivation of total PCB TRVs. The three revisions are described in greater detail in the following subsections.

2.1.1 Review of All Papers Included in the Species Sensitivity Distributions

The EPA methods indicated that LOAELs were derived from those presented in the Environmental Residue Effects Database (ERED) or the Tissue Residue Effects Association Database (TREAD) maintained by EPA. The acceptability of all studies included in the species sensitivity distributions (SSDs) and the LOAELs established in each study were determined by independently reviewing each study. Windward reviewed each study relative to acceptability criteria detailed in EPA's TRV derivation methods (EPA 2008d) and against subsequent revisions agreed upon by LWG and EPA, which are discussed in the following sections. EPA independently reviewed a subset of the studies. In cases where Windward and EPA disagreed on the interpretation of studies, the studies were discussed between LWG and EPA, whereupon EPA provided the final determination of study acceptability and LOAEL values.

2.1.2 Chemical-Specific ACRs

In the methodology, EPA provided an ACR of 8.3 to be applied to all mortality LOAELs as an uncertainty factor. Per EPA, this uncertainty factor was applied to convert an acute mortality LOAEL into a LOAEL or NOAEL for effects on reproduction and growth because concentrations required to elicit acute mortality are generally higher than the concentrations that reduce growth and/or reproduction (EPA 2008e). After the October 17, 2008, meeting, EPA provided LWG with a list of chemical-specific ACRs (Parametrix 2006). The ACRs used to derive the final tissue TRVs are presented in Table 2-1.

Table 2-1. Acute-Chronic Ratios Provided by EPA

Chemical	ACR
Metals	
Arsenic	3.803
Cadmium	8.3
Chromium	8.3

Table 2-1. Acute-Chronic Ratios Provided by EPA

Chemical	ACR
Copper	3.23
Mercury	3.731
Lead	8.3
Zinc	2
TBT	
Tributyltin ion	12.69
Phthalates	
Di-n-butylphthalate	8.3
PCBs	
PCBs	8.6
Pesticides	
DDD	8.3
Lindane	25
Total DDx	8.3

ARC – acute-chronic ratio
EPA – US Environmental Protection Agency
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
PCB – polychlorinated biphenyl
Total DDx – sum of all six DDT isomers (2,4′-DDD; 4,4′-DDD; 2,4′-DDE; 4,4′-DDE; 2,4′-DDT; and 4,4′-DDT)
TBT – tributyltin

2.1.3 PCB Congener Studies

During the review of EPA's TRV for total PCBs, LWG questioned the validity of including studies that exposed aquatic organisms to single PCB congeners. In the October 17, 2008, meeting, EPA and LWG agreed to the following approach for using PCB congener studies in the derivation of the total PCBs TRV.

1. Studies of single dioxin-like congeners were excluded.
2. All other studies of single PCB congeners were reviewed on a case-by-case basis, and the concentrations and detection frequency of the specific PCB congener in Portland Harbor were evaluated. If the specific PCB congener was found to be significant in Portland Harbor, the study was included in the derivation of the total PCB TRV. Significance was defined as follows: PCB congener study was included in the SSD if the detection frequency of the PCB congener was > 5% and the congener made up > 5% of the mean PCB (sum of PCB congeners) tissue residue across all benthic invertebrate tissue samples. Specifically, EPA requested that PCBs 1, 47, 101, and 153 be evaluated for significance in the harbor. Only one invertebrate study with PCB 153 met the significance criteria (Fisher et al. 1999). Two fish studies, one with PCB 153 (Broyles and Noveck 1979) and one with a

mixture of PCBs 133 and 197 (Opperhuizen and Schrap 1988) met the significance criteria.

3. Single congener studies were subjected to all other study acceptability criteria as well and only accepted if they passed these criteria.

4. One invertebrate study was rejected because the congener did not have significant presence in Portland Harbor (Dillon et al. 1990), and another invertebrate study was rejected because the effect data were weak (Fowler et al. 1978). One fish study (Broyles and Noveck 1979) was rejected because the study used eggs from fish with an estimated background PCB exposure of 3 to 11 µg/g. All three studies were included because of EPA directives[1] (EPA 2009b, a).

2.2 REVISIONS TO BENTHIC INVERTEBRATE TISSUE TRVS

Revisions to the benthic invertebrate tissue TRV methodology included changes in the chemical list for which TRVs were derived, elimination of studies with tissue concentrations below nutritional values for copper and zinc, omission of the ACR used for mortality studies of longer duration, and omission of behavioral studies that lacked a clear link to adverse effects on the three assessment endpoints. Each of these four revisions are described in greater details in the following subsections.

2.2.1 Chemical List

In the June 13, 2008, methodology (EPA 2008e), EPA provided a list of COPCs based on the *Comprehensive Round 2 Site Characterization Summary and Data Gaps Analysis Report* (Integral et al. 2007) for which benthic invertebrate tissue TRVs should be derived (Table 2-2). This list of COPCs was changed to include chemicals identified as COPCs in the screening-level ecological risk assessment (SLERA) and refined screening process. Aluminum was identified as a COPC through this process, but EPA agreed that a benthic invertebrate tissue TRV should not be derived and that potential adverse effects of aluminum should be discussed as an uncertainty.

Table 2-2. Benthic Invertebrate Tissue COPCs

COPC	COPC per EPA June 13, 2008?	Final COPC for BERA?
Antimony	X	
Arsenic	X	X
Cadmium	X	X
Copper	X	X
Zinc	X	X

[1] If the two invertebrate studies had been excluded the PCB TRV would have been 1.13 µg/kg ww. If the single fish study had been excluded the PCB TRV would have been 0.77 and 1.6 µg/kg ww for the 5th and 10th percentile, respectively.

Table 2-2. Benthic Invertebrate Tissue COPCs

COPC	COPC per EPA June 13, 2008?	Final COPC for BERA?
TBT	X	X
BEHP	X	X
Butylbenzyl phthalate	X	X
Total PCBs	X	X
beta-Hexachlorocyclohexane	X	
DDD	X	X
DDE	X	
DDT	X	
Total DDx	X	X
Endrin	X	

Source: EPA (2008e)
BEHP – bis(2-ethylhexyl) phthalate
COPC – chemical of potential concern
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
PCB – polychlorinated biphenyl
Total DDx – sum of all six DDT isomers (2,4′-DDD; 4,4′-DDD; 2,4′-DDE; 4,4′-DDE; 2,4′-DDT; and 4,4′-DDT)
TBT – tributyltin

2.2.2 Nutritional Values

EPA reviewed the literature on nutritional deficiency and sufficiency of copper and zinc to aquatic invertebrates and provided LWG with the following values to be used in the derivation of TRVs for copper and zinc (EPA 2008b). All final species LOAEL concentrations below these values were omitted from TRV derivation process.

- Zinc – all invertebrate taxa: 20 mg/kg wet weight (ww)
- Copper – crustaceans and mollusks: 5 mg/kg ww
- Copper – remaining invertebrate taxa: 2.2 mg/kg ww

2.2.3 Use of ACR

In the June 13, 2008 TRV methodology (EPA 2008e), the ACR was applied to all benthic mortality studies. For the final benthic TRVs, the ACR was applied only to mortality studies with a duration of ≤ 21 days (EPA 2008c).

2.2.4 Benthic Invertebrate Behavioral Studies

During the review of EPA's benthic invertebrate tissue TRVs, LWG rejected behavioral studies because of the lack of a direct link to adverse effects on benthic invertebrate

populations. In the October 17, 2008, meeting, LWG agreed to re-evaluate the behavioral studies that EPA believed established direct links to reductions in growth, reproduction, or survival. The behavioral endpoints that EPA asked LWG to reconsider were related to feeding ability (reduced prey capture efficiency and filtration rate) and predator avoidance (decreased locomotion and burrowing). LWG agreed in principle that effects on feeding ability and predator avoidance might be directly linked to reductions in growth, reproduction, and/or survival of the test organisms in particular cases. The LWG did not agree with the generalized assumption that effects on feeding ability and predator avoidance are directly linked to reductions in growth, reproduction, or survival; or to adverse effects on benthic invertebrate populations; or to adverse effects on the benthic community. Each of the 10 benthic behavioral studies was re-evaluated, and five LOAELs were accepted by LWG based on a plausible link between the behavioral endpoint reported and reductions in growth, reproduction, or survival of the test organisms.

One BEHP study (Woin and Larsson 1987) and one cadmium study (Wallace et al. 2000) yielded LOAELs based on reduced ability to capture prey. The BEHP study was accepted, whereas the cadmium study was rejected because the decrease in ability to capture prey was small (5% reduction compared to 3% reduction in the control) and based on observations taken over a very short period of time (2 hours). There is abundant information in the literature to suggest that aquatic organisms acclimatize to changes in metals exposure levels that initially cause low-level effects, such as were reported in this paper, so the Wallace et al. (2000) LOAEL did not meet the standard of being directly linked to survival, growth, or reproduction.

Three studies that evaluated feeding rate as a reduction in filtration rate were accepted. In the paper by Duquesne et al. (2004), a LOAEL was derived and included in the TRV derivation because it directly linked reduction in filtration to growth (based on a condition index). The other two papers were written by the same group (Kraak et al. 1994a; 1994b). In the first paper, long-term studies evaluating filtration rate and mortality were performed with zinc and lead. The studies reported that bivalves that had reduced filtration rates had an increase in mortality after 10 weeks of exposure. In the other paper, short-term studies (48 hours) evaluating filtration rates with zinc, cadmium, and copper were performed. Because the first paper provided a link between reduced filtration rate in their 48-hour test and mortality after 10 weeks' exposure (using the same test species), the three LOAELs were accepted.

For the other two behavior endpoints (delay in burrowing and reduction in locomotor activity), LWG did not agree that the specific studies (Amiard and Amiard-Triquet 1986; Gerhardt 1990; Olla et al. 1988; Thuren and Woin 1991) linked the observed behaviors to effects on survival, growth, or reproduction. In the subsequent negotiations, EPA directed (Toll 2009b) the inclusion of the Olla et al. (1988) study, which reported a delay in polychaete burrowing behavior after exposure to cadmium.

2.3 REVISIONS TO FISH TISSUE TRVS

Revisions to the fish tissue TRV methodology included changes in chemicals for which TRVs were derived, elimination of studies with tissue concentrations below nutritional values for copper, omission of the use of an ACR in mortality studies of longer duration, and omission of behavioral studies that lacked a clear link to adverse effects on survival, growth, or reproduction. Each of these four revisions is described in greater detail in the following subsections.

2.3.1 Chemical List

In the June 13, 2008 TRV methodology (EPA 2008e), EPA provided a list of COPCs based on the *Comprehensive Round 2 Site Characterization Summary and Data Gaps Analysis Report* (Integral et al. 2007) for which fish tissue TRVs should be derived (Table 2-3). This list of COPCs was changed to include chemicals identified as COPCs in the SLERA and refined screening process. Aluminum was identified as a COPC in this process but EPA agreed that a fish tissue TRV should not be derived and that potential adverse effects of aluminum should be discussed as an uncertainty.

Table 2-3. Fish Tissue COPCs

COPC	COPC per EPA June 13, 2008?	Final COPC for BERA?
Antimony		X
Cadmium		X
Chromium	X	X
Copper		X
Lead	X	X
Mercury	X	X
Selenium	X	
Zinc	X	X
BEHP	X	X
Di-n-butyl-phthalate	X	
Total PCBs	X	X
beta-Hexachlorocyclohexane	X	
DDD	X	
DDE	X	
DDT	X	
Total DDx	X	X
gamma-Hexachlorocyclohexane	X	
beta-Hexachlorocyclohexane	X	
Hexachlorobutadiene	X	
Butylbenzyl phthalate	X	

Source: EPA (2008e)
BEHP – bis(2-ethylhexyl) phthalate
COPC – chemical of potential concern
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
PCB – polychlorinated biphenyl
Total DDx – sum of all six DDT isomers (2,4′-DDD; 4,4′-DDD; 2,4′-DDE; 4,4′-DDE; 2,4′-DDT; and 4,4′-DDT)
TBT – tributyltin

2.3.2 Copper Nutritional Sufficiency/Deficiency

Based on a review of fish whole-body copper residues associated with nutrient deficiency and sufficiency, EPA concluded that the tissue TRV for Portland Harbor should be no lower than 2.2 mg/kg ww for any fish species citation. All final species LOAEL tissue-residue concentrations below this value were omitted from TRV derivation process.

2.3.3 Use of ACR

In the June 13, 2008, TRV methodology (EPA 2008e), the ACR was applied to all fish mortality studies. For the final fish TRVs, the ACR was applied only to mortality studies with a duration of ≤ 30 days.

2.3.4 Fish Behavioral Studies

During the review of EPA's fish tissue TRVs, LWG rejected behavioral studies because of the lack of a direct link to adverse effects on fish. In a memo dated December 22, 2008 (EPA 2008a), EPA provided evidence linking behavior endpoints to adverse effects at the population or community level. Following this communication LWG reevaluated all behavioral studies included in EPA's original TRV derivations for acceptability.

In its January 14, 2009, communication to EPA (Toll 2009a), LWG agreed to use the following three behavioral studies[2] in the development of fish tissue-residue TRVs for use in the Portland Harbor BERA:

- Gakstatter & Weiss (1967) – goldfish and bluegill equilibrium loss when exposed to DDTs
- Weber et al. (1991) – reduced fathead minnow feeding and prey capture when exposed to lead.
- Kania & O'Hara (1974) – reduced mosquitofish feeding and prey capture when exposed to mercury.

[2] Note that the behavioral data in the study by Bengtsson (1980) were rejected for TRV development because significant effects on minnow swimming ability were not found, but the data on reproductive effects were accepted for use in deriving TRVs.

In a subsequent memo dated January 23, 2009 (EPA 2009b), EPA directed LWG to also include the following four studies reporting behavior endpoints:

- Hollis et al. (2000) – impaired rainbow trout swimming and reduced survival when exposed to cadmium
- Webber and Haines (2003) – altered golden shiner predator avoidance behavior when exposed to mercury
- Fisher et al. (1994) – retarded photoperiodism and reduced growth of Atlantic salmon exposed to PCBs
- Scott et al. (2003) – eliminated predator avoidance behavior of rainbow trout exposed to cadmium

3.0 EXAMPLE OF SSD CALCULATION

In accordance with EPA's Revised Aquatic Biota Tissue TRV Derivation (supplement to this attachment) tissue TRVs were derived using an SSD if a minimum of five data points were available. This section presents the calculation process using the benthic invertebrates studies for TBTs and the @Risk software.

The @Risk software was used to fit different distributions to the final species LOAEL based on the selected TBT studies (Table 3-1; the complete information on all TBTs studies are presented in the attached Excel table). The best fitted distribution was selected based on the Chi-Squared, Anderson-Darling, and Kolmogorov-Smirnov statistics.

Table 3-1. Final Species LOAELs Based on Benthic Invertebrate TBT Studies

Analyte	Species	Endpoint	Final Species LOAEL (mg/kg ww)
TBT	Armandia brevis (polychaete)	Mortality	0.54
TBT	Crassostrea gigas (Pacific oyster)	Mortality	1.30
TBT	Eohaustorius estuarius (amphipod)	Mortality	0.55
TBT	Eohaustorius washingtonianus (amphipod)	Mortality	2.3
TBT	Hinia reticulata (netted dogwhelk)	Reproduction	0.045
TBT	Hyalella azteca (amphipod)	Mortality	0.28
TBT	Mya arenaria (soft shell clam)	Growth	2.90
TBT	Mytilus edulis (mussel)	Growth	1.40
TBT	Neanthes arenaceodentata (neanthes)	Reproduction	1.25
TBT	Nucella lapillus (Atlantic dogwinkle)	Reproduction	0.10
TBT	Rhepoxynius abronius (amphipod)	Mortality	1.01
TBT	Scrobicularia plana (clam)	Mortality	4.8

LOAEL – lowest-observed-apparent-effects level
TBT – tributyltin
ww – wet weight

For each of the possible distributions @Risk calculated the 10th percentile and the percentile for the best fitted distribution was selected as the TRV. Table 3-2 presents a summary of the @Risk information. For TBT the Weibull distribution was selected and the TRV of 1.15 mg/kg ww based on the 10th percentile. A similar process was performed for calculation the fish TRVs with the exception that both the 5th and the 10th percentiles were selected.

Table 3-2. TBT Example of @Risk Statistical Information and Calculated Percentiles

	Input	Weibull	Expon	Log-Logistic	Lognorm	Beta-General	Triang	InvGauss	Uniform
Distribution Statistics									
Minimum	0.045	0	0	0	0	0	0	0	0
Maximum	4.8	+Infinity	+Infinity	+Infinity	+Infinity	4.8773	5.3599	+Infinity	5.2364
Mean	1.3996	1.3996	1.3996	2.779	1.8198	1.6594	1.8016	1.3996	2.6182
Mode	1.3167 [est]	0	0	0.2284	0.1382	0	0.045	0.1153	0
Median	1.13	0.9692	0.9701	0.8986	0.7706	1.3091	1.5858	0.4872	2.6182
Standard deviation	1.3684	1.4013	1.3996	+Infinity	3.8934	1.4137	1.2581	2.8059	1.5116
Skewness	1.3527	2.0035	2	+Infinity	16.2109	0.6005	0.5655	6.0145	0
Kurtosis	4.1811	9.0235	9	+Infinity	1404.788	2.1408	2.4	63.2909	1.8
Percentiles									
5%	0.045	0.0715	0.0718	0.1039	0.0892	0.0224	0.1577	0.0819	0.2618
10%	0.1	**0.147**	0.1475	0.1796	0.1436	0.0759	0.2964	0.1125	0.5236
15%	0.1	0.2269	0.2275	0.2521	0.198	0.155	0.4391	0.1425	0.7855
20%	0.28	0.3116	0.3123	0.3254	0.2556	0.2573	0.586	0.1743	1.0473
25%	0.28	0.4019	0.4026	0.4018	0.3183	0.3816	0.7376	0.2093	1.3091
30%	0.55	0.4984	0.4992	0.483	0.3875	0.5269	0.8944	0.249	1.5709
35%	0.86	0.602	0.6029	0.5709	0.465	0.6926	1.0568	0.2945	1.8327
40%	0.86	0.714	0.7149	0.6677	0.5528	0.8784	1.2256	0.3478	2.0945
45%	1.01	0.8358	0.8367	0.7758	0.6536	1.0839	1.4016	0.411	2.3564
50%	1.01	0.9692	0.9701	0.8986	0.7706	1.3091	1.5858	0.4872	2.6182
55%	1.25	1.1168	1.1176	1.041	0.9086	1.5541	1.7795	0.5808	2.88
60%	1.3	1.2817	1.2824	1.2095	1.0742	1.8192	1.9843	0.6981	3.1418
65%	1.3	1.4687	1.4693	1.4144	1.2771	2.1049	2.2023	0.8485	3.4036
70%	1.4	1.6846	1.6851	1.6719	1.5325	2.4118	2.4365	1.0471	3.6655
75%	1.4	1.9401	1.9402	2.01	1.8657	2.741	2.6912	1.3194	3.9273
80%	2.3	2.2527	2.2525	2.4816	2.3228	3.0942	2.973	1.7121	4.1891
85%	2.9	2.6559	2.6552	3.2031	2.9986	3.474	3.2928	2.3217	4.4509
90%	2.9	3.2243	3.2227	4.4957	4.1351	3.8848	3.6721	3.3893	4.7127
95%	4.8	4.1962	4.1928	7.7728	6.6578	4.3363	4.1664	5.7905	4.9745

Bold identifies TBT TRV selected for benthic invertebrates.

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EPA. 2008b. EPA e-mail dated November 3, 2008 (Burt Shephard to Helle Andersen, Windward Environmental) regarding nutritional deficiency levels of zinc and copper in aquatic invertebrates. Risk Evaluation Unit, US Environmental Protection Agency Region 10, Oregon Operations Office, Portland, OR.

EPA. 2008c. EPA e-mail dated November 10, 2008 (Burt Shephard to John Toll, Windward Environmental) regarding benthic ACR time limit. Risk Evaluation Unit, US Environmental Protection Agency Region 10, Oregon Operations Office, Portland, OR.

EPA. 2008d. EPA letter dated August 5, 2008 to Lower Willamette Group (from E. Blischke and C. Humphrey to J. McKenna and R. Wyatt) regarding Portland Harbor RI/FS tissue TRV methodology, with attachments titled "Aquatic Tissue TRV response." Aquatic Biota Tissue TRV Derivation, and LWG Tissue TRV Response. US Environmental Protection Agency Region 10, Oregon Operations Office, Portland, OR.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
OREGON OPERATIONS OFFICE
805 SW Broadway, Suite 500
Portland, Oregon 97205

August 5, 2008

Mr. Robert Wyatt
Northwest Natural & Co-Chairman, Lower Willamette Group
220 Northwest Second Avenue
Portland, Oregon 97209

Re: Portland Harbor Superfund Site; Administrative Order on Consent for Remedial Investigation and Feasibility Study; Docket No. CERCLA-10-2001-0240 - Toxicity Reference Value Methodology – Aquatic Biota Tissue

Dear Mr. Wyatt:

On June 30, 2008, the Lower Willamette Group (LWG) identified seven issues associated with the Toxicity Reference Value Methodology – Aquatic Biota Tissue developed by EPA. EPA has reviewed each of the seven points raised in your June 30th letter. A summary of EPA's response to each point is summarized in Attachment 1 to this letter. A revised Toxicity Reference Value Methodology – Aquatic Biota Tissue is included as Attachment 2 to this letter.

EPA believes that we have fairly considered each of the points in your letter. The tissue residue toxicity reference values (TRVs) currently under development by EPA will reflect the changes made to the methodology in response to your concerns.

If you have any questions, please contact Chip Humphrey at (503) 326-2678 or Eric Blischke (503) 326-4006. All legal inquiries should be directed to Lori Cora at (206) 553-1115.

Sincerely,

Chip Humphrey
Eric Blischke
Remedial Project Managers

cc: Greg Ulirsch, ATSDR
Rob Neely, NOAA
Ted Buerger, US Fish and Wildlife Service
Preston Sleeger, Department of Interior
Jim Anderson, DEQ
Kurt Burkholder, Oregon DOJ
David Farrer, Oregon Environmental Health Assessment Program
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Michael Karnosh, Confederated Tribes of Grand Ronde
Tom Downey, Confederated Tribes of Siletz
Audie Huber, Confederated Tribes of Umatilla
Brian Cunninghame, Confederated Tribes of Warm Springs
Erin Madden, Nez Perce Tribe
Rose Longoria, Confederated Tribes of Yakama Nation

Attachment 2
Revised Aquatic Biota Tissue TRV Derivation

Introduction

Unlike the case where several published sources of screening level aquatic biota tissue benchmarks are available (e.g. Dyer et al. 2000, Shephard 1998), EPA is unaware of any published source of widely available aquatic biota tissue TRVs for use in baseline ecological risk assessments. This means that the aquatic biota tissue TRVs for the BERA will have to be derived from the original residue-effects literature. The two primary compendia of residue-effects literature for aquatic species are the Environmental Residue Effects Database (ERED), found online at http://el.erdc.usace.army.mil/ered/, and the review by Jarvinen and Ankley (1999), most of which was later incorporated into the ERED. EPA has also shared with the LWG an updated (January 2008) version of the residue-effects database described in Shephard (1998), which was the original source for most of the literature originally incorporated in the ERED. Combined with additional studies identified by LWG and other interested parties during the Portland Harbor RI/FS process, these data sources will be used to obtain studies to be used during TRV derivation. All of these sources contain primarily whole body residue-effects information.

Without a compendium of baseline ecological risk assessment aquatic biota tissue TRVs from which tissue TRVs for the Portland Harbor BERA can be selected, a TRV derivation methodology or hierarchy will have to be defined. The primary purpose of any baseline ecological risk assessment at a Superfund site is to determine risks associated with current site conditions, and to assist risk management decisions regarding the need for site remediation. Given that the tissue TRVs will be used in a baseline ecological risk assessment, EPA believes that the TRV derivation methodology must be consistent with EPA's ecological risk assessment paradigm. A paradigm is a philosophical and theoretical framework of a scientific discipline. As such, it differs from a specific protocol or guidance. The intent of the EPA (1997) ecological risk assessment paradigm is to provide a general conceptual framework for organizing problems and risk assessment approaches. Consistency of the tissue TRV derivation methodology with the EPA risk assessment paradigm was a major consideration in EPA's selection of a TRV derivation methodology.

EPA's desired outcome from the aquatic biota tissue TRV derivation process is to develop TRVs that are based on measured tissue residues from various aquatic species that are associated with adverse ecological effects or unacceptable ecological risks to the assessment endpoints for various categories of ecological receptors at Portland Harbor. This is consistent with EPA (1997) ecological risk assessment guidance, which calls for BERA risk characterizations to identify thresholds for effects on the assessment endpoints as a range between contamination levels identified as posing no ecological risk and the lowest contamination levels identified as likely to produce adverse ecological effects. To meet this goal, the tissue TRVs to be derived for the BERA will be LOER (lowest observed effect residue) based, and thus will likely be higher than the screening level benchmarks used in the SLERA.

Derivation Methodologies for Aquatic Biota Tissue TRVs

EPA has identified two primary approaches using the existing scientific literature to derive baseline ecological risk assessment aquatic biota tissue TRVs. Although other approaches may be available, EPA suggests that the following two approaches are the most appropriate for aquatic biota tissue TRV derivation at Portland Harbor. These were selected based on increasing data availability, complexity of calculation, TRV reliability, consistency with the ecological risk assessment paradigm, and ecological realism. Therefore, the two baseline tissue TRV derivation approaches EPA is recommending are:

1. Lowest Value Approach
2. Species Sensitivity Distribution (SSD) approach.

Both of these methodologies will be used to derive tissue TRVs for the Portland Harbor BERA. The strengths, weaknesses and application of these two tissue TRV derivation approaches in the BERA are discussed in the following section. Given that there are no available compendia of aquatic biota tissue TRVs for use in baseline ecological risk assessments for Superfund, EPA believes an extended discussion of both methodologies is necessary to justify the hierarchy of TRV derivation methods presented at the end of this section.

Lowest Value Approach

The lowest value approach evaluates all available toxicity data for a contaminant. After the data are compiled, the lowest relevant toxicity value (i.e. the lowest residue-effects LOER [lowest observed effect residue] concentration) is selected as the TRV. So long as the LOER is based on an acceptable endpoint for an appropriate species, no further adjustments to the value may be required. However, the LOER may also have to be divided by one or more uncertainty factors to obtain the final TRV. Although many types of uncertainty factors can be considered, the factors applied to the literature-based LOER generally fall into one of three broad categories:

- Acute to chronic adjustment
- Interspecies extrapolation
- Laboratory to field extrapolation

Most residue-effects literature associates a measured residue with reductions in survival using acute (i.e., short-term) exposure periods. Although survival is part of most assessment endpoints in the Portland Harbor BERA, TRVs are often based on reproduction and growth to ensure they are appropriately protective of the most sensitive portion of the assessment endpoint. An uncertainty factor can thus be applied to a literature-based mortality LOER to convert an acute mortality LOER into a LOER or NOER for effects on reproduction and growth. This acute to chronic uncertainty factor (more commonly called an acute-chronic ratio or ACR) is applied because concentrations required to elicit acute mortality are generally higher than the concentrations that reduce growth and/or reproduction.

Unless a species specific acute to chronic ratio is available for residues in the particular study under review, a default acute to chronic ratio is required for TRV derivation. The default acute to chronic ratio for use in the Portland Harbor BERA tissue TRV derivation will be 8.3, based on

the study of Raimondo et al. (2007). The Raimondo et al. (2007) study is the geometric mean acute-chronic ratio of 456 same-species pairs of acute and maximum acceptable toxicant concentrations for metals, narcotics, pesticides, and other organic chemicals. The default 8.3 acute to chronic ratio (uncertainty factor) will only be applied to LOER values for which mortality was the measured toxicological endpoint.

This uncertainty factor is, strictly speaking, most appropriate for use with acute (i.e., relatively short study exposure times) mortality as opposed to chronic (i.e., relatively long study exposure times) mortality. However, most of the tissue toxicity literature studies in which mortality was measured used acute exposure periods, using as the definition of acute an exposure duration less than 10% of the lifespan of the test organism (Rand 1980). The 8.3 uncertainty factor will be applied to all mortality LOERs unless other information is available to suggest it is not necessary (e.g., specific test duration data or presence of other sublethal endpoints from the same study).

Interspecies extrapolations and laboratory to field uncertainty factor both account for the assumption that laboratory studies underestimate adverse effect concentrations in the field. Reasons for applying an interspecies uncertainty factor include the life stage tested in the laboratory may be less sensitive than another life stage; laboratory test species are often selected because of their ease of handling and culture in the laboratory, and are not representative of the taxonomic diversity found in the field; and concerns that commonly uses laboratory test species may be more tolerant to contamination than are other species. Concerns regarding the use of interspecies extrapolation and laboratory to field uncertainty factors include the possibility that laboratory species and/or test conditions overestimate toxicity under field exposure conditions. Since the objective of tissue TRV derivation for the BERA is to derive a LOER based TRV, interspecies extrapolation and laboratory to field uncertainty factors will not be used during the derivation of Portland Harbor BERA tissue TRVs.

Concerns regarding the scientific basis and validity of the uncertainty factors include the magnitude of the factors, and whether or not the approach is consistent with the risk assessment paradigm. Specific criticisms include the often arbitrary nature of uncertainty factors, their largely empirical nature, and their lack of a theoretical scientific basis (Chapman et al. 1998, Rand et al. 1995, Calabrese and Baldwin 1993). The absence of universally accepted values for uncertainty factors (Calabrese and Baldwin 1993) confirms their often arbitrary nature.

As described herein, the lowest value approach ignores all data except the lowest effect concentration (i.e. the most conservative or worst case approach). This type of approach is more appropriate for a screening level benchmark as opposed to a baseline ecological risk assessment TRV. Ideally, a TRV used within a BERA is developed from multiple acceptable studies, which if desired permits estimation of the probability of risk or the probability of an adverse toxicological effect at a given exposure concentration. Ultimately, uncertainty factors applied to TRV derivation are used to address a lack of knowledge regarding the toxicity of a chemical. Use of the lowest value approach would require that, in addition to agreement on the toxicity value and study used to derive the TRV, agreement would have to be reached on the values of the uncertainty factors to be applied during BERA TRV development.

Given the amount of residue-effects literature available describing the effects of many bioaccumulated chemicals to aquatic life, EPA believes better approaches are available to derive aquatic biota tissue TRVs for the Portland Harbor BERA than the use of the lowest value approach. However, for chemicals with an insufficient amount of residue-effects literature to permit TRV derivation by other methods described in this section, EPA will use the lowest value approach as the last (lowest) rung on the hierarchy of TRV development methods acceptable for use in the Portland Harbor BERA.

The strengths and weaknesses of the lowest value approach to aquatic biota tissue TRV derivation are as follows:

- ***Strengths***
    - Simplicity of use
    - Ease of understanding
    - Minimal data requirements - as little as one toxicity value needed to derive a TRV
    - Uncertainty factors, if needed, become larger as toxicity data become more unreliable or uncertain, or if fewer studies are available
    - The magnitude of the uncertainty factor, if needed, can be changed as new toxicological information becomes available

- ***Weaknesses***
    - Largely empirical, no theoretical basis
    - Questions regarding the validity of acute to chronic ratios
    - Questions regarding the magnitude of the acute to chronic ratio
    - Not fully consistent with the risk assessment paradigm
    - Lack of transparency – the lowest value approach does not provide a consistent degree of protection to ecological receptors, and thus does not permit informed discussions between risk managers and other interested parties regarding the level of protection occurring

The specifics of the lowest value approach as applied to BERA tissue TRV derivation for Portland Harbor are presented in the aquatic biota tissue TRV derivation methodology presented later in this section.

Species Sensitivity Distribution (SSD) Approach

A species sensitivity distribution is a statistical model which calculates a chemical concentration protective of a predetermined proportion or percentage of a group of species from a defined adverse toxicological effect. In theory, SSDs are intended to provide an indication of both the total range and distribution of species sensitivities in natural communities, even when the actual range of sensitivities is unknown (Stephan 2002). In practice, SSDs are most commonly presented as a cumulative distribution function (CDF) of the toxicity of a chemical to a group of laboratory test species. Perhaps the best known application of SSDs to develop TRVs for ecological risk assessment is their use to derive EPA's ambient water quality criteria (AWQC) for the protection of aquatic life (Stephan et al., 1985).

The general approach to derive a SSD is to obtain the toxicity data for a number of species. In instances where multiple studies have evaluated the same toxicological endpoint on the same species, the data must undergo some preprocessing before it is incorporated into the SSD. Preprocessing procedures to be applied to TRV development for Portland Harbor will be given later in this section.

Several statistical models have been used to fit toxicity data to species sensitivity distributions. These include log-triangular distributions (Stephan et al. 1985), log-logistic distributions (Aldenberg and Slob 1993), lognormal distributions (Wagner and Lokke 1991) and Burr Type III distributions (Shao 2000). There is no known theoretical reason why a SSD for any given data set should conform to a specific statistical distribution. For example, most new approaches for water quality criteria derivation outside of the U.S. select specific SSD derivation models based on which best fit the underlying data distribution from a statistical point of view.

The largest single difference between the various published approaches to deriving SSDs is the statistical distribution fit to the toxicity data. In general, development of an SSD from toxicity data is as follows:

Each data point within an SSD is given equal weighting, i.e. no single study carries more weight within the SSD than does any other study. The SSD is calculated from a cumulative distribution frequency of the species sensitivity to contaminant data by ranking the effect concentration for each species from lowest to highest. The cumulative frequency value for each data point is calculated from Equation 1:

Equation 1:

$$Cumulative\ \ frequency = Rank \times \left(\frac{100}{n+1} \right)$$

Where:

n = number of data points used to develop the SSD

The cumulative frequency value (sometimes termed the potentially affected fraction of species) of each data point is then plotted against the effect concentration that represents the sensitivity of that species to the contaminant, yielding the typically S-shaped species sensitivity distribution plot with effect concentrations on the x-axis and the cumulative frequency values plotted on the y-axis.

Regardless of the statistical distribution used to fit the SSD (e.g. log-logistic, lognormal, etc.), the equation describing the distribution is known. This knowledge permits calculation of the concentration protective of any selected proportion of species. The level of protection selected is not a technical or statistical decision, instead, it is ultimately a management decision. The two most commonly used protection percentiles are protection of 95% of all tested species (e.g. Stephan et al. 1985) and 90% of all tested species (e.g. Meador et al. 2002). To afford protection to these proportion of species, the TRV derived from the SSD is set at either the 5th or 10th percentile of the adverse effect concentrations.

All species sensitivity distributions make a series of assumptions, both statistical and biological. Statistical assumptions generally entail the suitability of the distribution used to fit the SSD, and the number of samples within the SSD, which relates to the reliability and stability of the TRV derived from the SSD. This is particularly true of TRVs selected from a tail of the SSD, where the TRV is lower than all but 5% or 10% of the effects data. Biological assumptions about the SSD approach include: whether communities and ecosystems are sufficiently protected by an SSD-derived TRV intended to protect a defined proportion of species within the community or ecosystem; whether a SSD based on laboratory generated toxicity data yields the same distribution of species sensitivity observed in field situations (i.e. the species incorporated into the SSD are representative of the sensitivities of all species); and whether TRVs derived from SSDs are inherently protective of communities and ecosystems. As described in detail in Posthuma et al. (2002), many of the statistical and biological questions regarding the use of SSDs have been satisfactorily answered to the point where SSDs have been used by a number of regulatory agencies in North America (both the U.S. and Canada), Europe, Asia and Australia to derive environmental quality guidelines.

Within the context of aquatic biota tissue TRV derivation for Portland Harbor, perhaps the two most critical decisions are the minimum number of data points to be used during SSD development, and the level of protection provided by the TRV. The previously published tissue residue benchmarks used for screening in ecological risk assessments (e.g. Dyer et al. 2000, Meador et al. 2002) were derived using whole body lowest observed effect residue (LOER) data, which is the same adverse effect residue data that will be used to derive the Portland Harbor BERA TRVs. The minimum number of samples used to derive an SSD for use in regulatory programs has varied from four (Netherlands environmental risk limits), five (Australia and New Zealand water quality guidelines), eight (USEPA ambient water quality criteria) or 10 (European Union water quality guidelines). Several investigations of the number of data points needed to derive TRVs from SSDs have been performed, including Wheeler et al. 2002, Newman et al. 2000, and Roman et al. 1999. Both Wheeler et al. 2002 and Newman et al. 2000 indicated that relatively sizable data sets (between 10 and 55 data points, depending on the distribution and spread of the data) were required for a highly protective percentile TRV to be stable irregardless of the data set from which the SSD was developed.

Roman et al. (1999) concluded that with fewer than five data points, the lowest value approach (termed the assessment factor approach in their paper) is more precise than the SSD approach, but that increasingly lower TRVs may be generated from the lowest value approach as the number of toxicity studies increases. With five or more data points, the SSD approach for generating TRVs is more consistent with the risk assessment paradigm, as it yields a stable value for the TRV with increasing confidence in the reliability and protectiveness of the TRV as the amount of toxicity data used to develop the SSD increases. The protectiveness of the SSD approach in deriving TRVs has been validated by studies such as Okkerman et al. (1993), who evaluated toxicity based on studies with multiple species exposed to organic chemicals.

Based on a consideration of the literature describing the minimum number of data points required to derive an SSD, EPA recommends that a minimum of five data points be used to derive aquatic biota tissue TRVs for chemicals in the Portland Harbor BERA. Furthermore, EPA will set the level of protection of the tissue TRVs at the 5th percentile for target aquatic

ecological receptors to be evaluated at the organism level (i.e., these TRVs would be use both for juvenile salmonids and Pacific lamprey ammocoetes), and at the 10th percentile for all other aquatic biota tissue measurement endpoints which are evaluated at the population level.

The selection of these two percentiles is based on several precedents in the field of ecotoxicology. Most applicable to tissue TRV derivation may be the approach of Meador et al. (2002), who developed a species sensitivity distribution for PCB tissue residues which, if not exceeded in juvenile salmonids, are likely protective of ESA listed species from any adverse effects that may jeopardize the population's ability to recover and increase to sustainable levels. This was defined by Meador et al. (2002) as a residue protective against adverse effects on the ability of individual salmon to grow and mature normally. Meador et al. (2002) concluded that a low percentile of all listed residue-effect studies was an appropriate benchmark for protecting individual juvenile salmonids from sublethal effects that could decrease their long term survival. The PCB residue considered protective against biological effects in migrating juvenile salmonids was chosen as the 10th percentile of the 15 residue-effect concentrations identified by Meador et al. (2002).

The approach used by Meador et al. (2002) of calculating a TRV from a low percentile of a series of rank-ordered residue-effect concentrations is similar to the approach used by EPA (Stephan et al. 1985) to derive ambient water quality criteria. EPA's criterion maximum concentration (CMC, commonly called the acute criterion) is derived from the 5th percentile of an SSD for aquatic genera generated from acute toxicity data. Similarly, the criterion continuous concentration (CCC, commonly called the chronic criterion), can be derived from the 5th percentile of an SSD for aquatic genera derived from chronic toxicity data. More often, the CCC is calculated as the final acute value divided by the final acute-chronic ratio (ACR). The final ACR is based upon chronic values calculated from maximum acceptable toxicant concentrations (MATC) for at least three different species. The MATC is generally considered an estimate of a toxic threshold concentration within the range bounded by a NOEC and a LOEC, and is often considered the highest safe or no effect concentration (Cooney 1995).

ESA listed aquatic species as a group are generally not believed to be more sensitive to chemicals than aquatic species as a whole (Dwyer et al. 2005, Sappington et al. 2001, Dwyer et al. 1999). Based on measured toxicity data with threatened and endangered aquatic species, water quality criteria derived from the 5th percentile of an SSD are therefore generally protective of ESA listed species. In order to further ensure that the 5th percentile of an SSD are protective of ESA and other species to be evaluated at the individual organism level, a final check of the derived TRV will be performed.

The SSD approach has the advantage of previous use by EPA and other regulatory agencies during the development of ecological risk assessment TRVs (e.g. water quality criteria). It also has advantages over the lowest value approach in that the SSD approach uses more information from multiple studies to derive a TRV, has an explicitly defined level of protection, has well developed statistical and computational procedures available, and has been validated to some extent as being protective of ecological receptors.

The strengths and weaknesses of the species sensitivity distribution approach to aquatic biota tissue TRV derivation are as follows:

- ***Strengths***
  - Use toxicity data from all species for which data are available, consistent with the risk assessment paradigm
  - Based on sound statistical procedures, assuming the underlying assumptions of the method are met
  - Flexible, applicable to both risk assessment and risk management
  - Can be derived from any toxicological effect (e.g. survival, reproduction, etc.) or endpoint (e.g. LC_{50}, EC_{20}, LOEC, NOEC etc.)
  - Allow any level of protection desired to be selected except for 0% and 100%
  - Approach is transparent, and allows informed discussions to take place regarding the desired level of protection
  - Can be used in backwards calculations to estimate the level of protection when the contaminant occurs at a specified concentration in the environment
  - Some statistical and biological attributes of the approach have been validated

- ***Weaknesses***
  - Minimum data requirements more extensive than other TRV derivation approaches, may limit the number of chemicals for which TRVs can be developed
  - More complex mathematical derivation of TRVs than other approaches
  - Statistical assumptions of SSD derivation may be violated
  - Communities and ecosystems may not be sufficiently protected based on an SSD protecting a given percentage of the species within the community or ecosystem

Minimum Data Requirements, Data Preprocessing and Inclusion Procedures for Aquatic Biota Tissue TRV Development

Not all of the available residue-effects literature contains data suitable for deriving a TRV for use in the Portland Harbor BERA. The selection of studies suitable for TRV derivation generally followed the procedures described in the LWG (2004) *Technical Memorandum: Provisional Toxicity Reference Value Selection for the Portland Harbor Preliminary Ecological Risk Assessment*. The primary requirement is to use studies in which measured whole body residue concentrations are reported to be associated with relevant effect endpoints, defined as effects on survival, reproduction, growth and behavior (LWG 2004). Residues in all life stages of aquatic species, excluding eggs, are considered. Various exposure routes are considered: including dietary and waterborne. Injection and gavage studies were also considered during TRV derivation in LWG (2004). For the Portland Harbor BERA, injection and gavage are not considered to be ecologically relevant exposure pathways, as they are not identified as exposure pathways in the BERA conceptual site model, and will not be used to derive TRVs for the BERA.

Several specific data preprocessing questions have arisen during the development of the aquatic biota tissue TRV derivation process. Four specific preprocessing issues or questions addressed in this section are:

1. Initial dataset compilation and targeted individual study review
2. How to handle the situation where multiple toxicological endpoint LOERs are available for a single species (e.g. both survival and growth LOERs are available for rainbow trout exposed to PCBs)?
3. How to handle the situation where multiple LOERs are available for a single toxicological endpoint for a single species (e.g. three survival LOERs are available for rainbow trout exposed to PCBs)?
4. How to ensure that survival LOERs do not elevate the TRV so that it is no longer protective of the assessment endpoint of survival, reproduction and growth as evaluated with measurement endpoint data from multiple species?

Initial Dataset Compilation and Targeted Study Review. As a first step, the tissue-based toxicity values were compiled from the U.S. Army Corps of Engineers Environmental Residue-Effects Database (ERED) and a personal database maintained by Burt Shephard of EPA. The initial objective was to compile residue effects data from both databases, then calculate a single whole body-based lowest observed effect residue (LOER) value for each species with toxicity data available. This value is being termed the Final Species LOER. The Final Species LOERs are then used to derive the tissue-based TRV based on the species sensitivity distribution (SSD) approach if $n \geq 5$ or the lowest value approach if $n < 5$.

Both datasets were pre-processed to remove any effects concentrations not associated with survival, growth, reproduction, development or behavior. All no effect data were excluded as were data based on residues measured in tissues other than whole body or soft tissues. Studies where the exposure route was injection were also excluded from the evaluation. If there were discrepancies between the data in ERED and Burt Shephard's database, preference was given to the values reported in ERED as these data have undergone a more rigorous quality assurance check. Similarly, if both a review paper and the corresponding primary paper(s) were included the dataset, preference was given to the interpretation presented in the primary paper (s). Finally, in some cases, a range of effects concentrations was reported in Shephard's database; the low end of this range was used in deriving TRVs.

Because the data in ERED and Burt Shephard's database were compiled differently, it was necessary to develop operational decisions for compiling the data. In general, all of the concentration-response data from a study were compiled in ERED, while only the most sensitive data point was compiled in Burt Shephard's database. Accordingly, in developing the data set for TRV development, the lowest toxicity value was identified from each study. If a study evaluated the sensitivity of two species, then the lowest toxicity value for each species was identified from that study. The type of endpoint associated with each toxicity value (e.g., reproduction, growth, mortality, behavior) selected was also noted in compiling the data sets for TRV development. If the lowest toxicity value was the same for two or more endpoints, then that was noted as well and both endpoints were incorporated into the data set.

The toxicity data compiled were intended to be based on LOERs. The toxicity data compiled were sometimes explicitly identified as LOERs, but also sometimes represented various percent effects levels (including very high effect levels) with no explicit determination of statistical

significance from controls (which would normally be required for identification of LOERs). As discussed above, however, the lowest toxicity value was selected from each study. In some cases, since ERED compiled all of the toxicity data from a study, the lowest value from a study may be associated with a very low effect level, such as a 5% effect level. This level is within the range of control acceptability in most toxicity tests. Accordingly, because the intent was to identify low effect levels, a general rule was developed for selecting the LOER from a single study in which various effect levels were reported. It was assumed that a reasonable effect level for a threshold is between 10-25%. At least for some types of studies, 10% mortality is the limit for acceptable control mortality and, in addition, it is a relatively common effect level for setting a threshold for guidelines. An upper limit of 25% has been used as the reporting level in WET testing for example. The following provides some generic examples of how this rule was applied:

1. Only an EC07 reported: Use the value as reported.

2. An EC07, EC12, EC40, and EC77 reported: Use the reported EC12.

3. An EC40, EC77, and EC100 reported: Use the reported EC40.

4. Only an EC40 reported: Use the value as reported.

After both databases were compiled into a single database as described above, individual studies were selected and critically reviewed from each TRV database to resolve some of the more readily apparent uncertainties for individual studies compiled from either ERED or Burt Shephard's database. Studies were selected for review based on whether or not EPA determined that significant uncertainty existed in the interpretation of study results from either of the databases. In addition, most studies with LOER values closest to the proposed TRV were also selected for critical evaluation. The outcome of these evaluations—including whether or not the study was ultimately rejected for use in TRV derivation—are reported in the narrative text supporting each of the tissue TRVs.

Multiple toxicological endpoint LOERs for a single species: Assessment endpoints identified in the Portland Harbor BERA problem formulation are intended to be protective of survival, reproduction and growth of multiple aquatic biota groups. The most commonly measured adverse effect of bioaccumulated chemicals in aquatic species is mortality. Lethal body burdens of contaminants are generally higher than residues associated with adverse effects on reproduction or growth. Therefore, an SSD based on residue-effects data protective of all three toxic effects identified in the BERA assessment endpoints run the risk of being underprotective of reproductive and growth effects if the SSD is based largely on mortality data. To derive SSDs based only on reproduction and growth data runs the risk of severely limiting the number of tissue TRVs that can be derived, due to the relative lack of residue-effects data for reproductive and growth endpoints compared to the amount of data available from lethality studies.

The normal procedure used to derive a TRV from a SSD is to take the geometric mean of multiple toxicity studies available for a single species, then use the calculated geometric mean as the toxicity value within the SSD for that species. However, it does not appear reasonable to

calculate a mean of mortality, reproductive and growth LOERs to obtain the toxicity value for a given species.

The approach to handling multiple toxicological endpoint LOERs for the same species will be to incorporate the lowest LOER of the available endpoints for each species into the final SSD. This approach will result in each species accounting for only one data point within the SSD for a given chemical. Data preprocessing methods for deriving the toxicity value for a given toxicological endpoint for a given species from multiple LOERs, and incorporation of survival data into mixed toxicological endpoint SSDs will be presented in the next two sections.

Multiple LOERs for a single toxicological endpoint for a single species: A situation often encountered is where multiple LOERs are available from different studies with the same species for the same toxicological endpoint (e.g. three LOERs are available for PCB residues affecting *Daphnia pulex* fecundity). A commonly employed approach to address this situation is to calculate the geometric mean of the multiple studies, then use the calculated geometric mean as the toxicity value for that species and endpoint within the SSD. This is the approach used by EPA during its derivation of AWQC when multiple studies of the same adverse effect are available for a species (e.g. species mean acute value), or for different species of the same genera (e.g. genus mean acute value). For aquatic biota tissue TRV derivations for the Portland Harbor BERA, the geometric mean of multiple studies of a given species within the same toxicological endpoint will be used as the toxicity value incorporated into the SSD for that species and endpoint.

Processing of mortality LOERs: A TRV based largely or completely on mortality LOERs may not be protective of reproduction or growth. To ensure that the aquatic biota tissue TRVs for the Portland Harbor BERA are protective of all environmental attributes within the BERA assessment endpoints (i.e. survival, reproduction and growth), an uncertainty factor will be applied to the mortality LOERs before the mortality LOERs are further preprocessed and subsequently incorporated into an SSD.

Once the mortality LOER values are obtained, each mortality LOER is divided by an uncertainty factor of 8.3 to calculate the toxicity value for each species unless other information is available to suggest it is not necessary to apply the uncertainty factor (e.g., specific test duration data or presence of other sublethal endpoints from the same study). The value of 8.3 is the mean acute-chronic ratio of 456 same-species pairs of acute and maximum acceptable toxicant concentrations for metals, narcotics, pesticides, and other organic chemicals as calculated by Raimondo et al. (2007). Within the BERA tissue TRV derivation, the factor of 8.3 is intended to convert the LR_X concentration (LR_x = lethal residue to x percent of the study organisms) to an "LR_{LOW}" value, expected to be an $LR_{<1 \text{ to } 10}$ that should result in little or no toxicity to the test species. A LR_x based on unadjusted LR_x mortality values without the 8.3 adjustment factor would be an underprotective criterion that potentially elicits toxicity to an unacceptably high proportion of the individuals of the test species. Similarly, a tissue TRV based on LOERs lethal to a substantial portion of the test organisms within a study would not be protective of the survival, reproduction and growth assessment endpoints within the Portland Harbor BERA. The 8.3 acute-chronic ratio identified by Raimondo et al. (2007) as the mean ACR of over 400

aquatic toxicity studies will be used as the uncertainty factor to be applied to all residues associated with mortality used to generate tissue TRVs.

Ideally, the ACR would only be applied to mortality endpoints from acute (i.e., short-term) exposure durations. However, the tissue residue effects databases used to compile the TRV datasets (Burt Shephard's database and ERED) do not report study duration. Consequently, it is difficult to rigorously apply the default ACR of 8.3 (or a chemical-specific ACR if one is available). Therefore, EPA has applied an ACR of 8.3 to the toxicity values only if mortality data were available from a study. However, if sub-lethal toxicity data (i.e., effects on growth or reproduction) were also available from a study, then no ACR was applied to the mortality-based toxicity value because there was no need to estimate the sensitivity of a sublethal endpoint using an ACR. Ultimately, an ACR was applied to a mortality-based toxicity value only if mortality was the only endpoint measured in a given study. In the few cases where EPA conducted an independent evaluation of the original toxicity study, study duration was evaluated to determine whether it was appropriate to apply an ACR to any mortality-based endpoint. If the study duration would clearly be considered "chronic" for a particular organism (e.g., substantially greater than 96-hr for most fish), then this ACR was not applied to the mortality endpoint.

Examples: To help clarify questions discussed in the data pre-processing sections above, a figure is included below that illustrates the overall process of how final species LOERs are derived and used to generate SSDs:

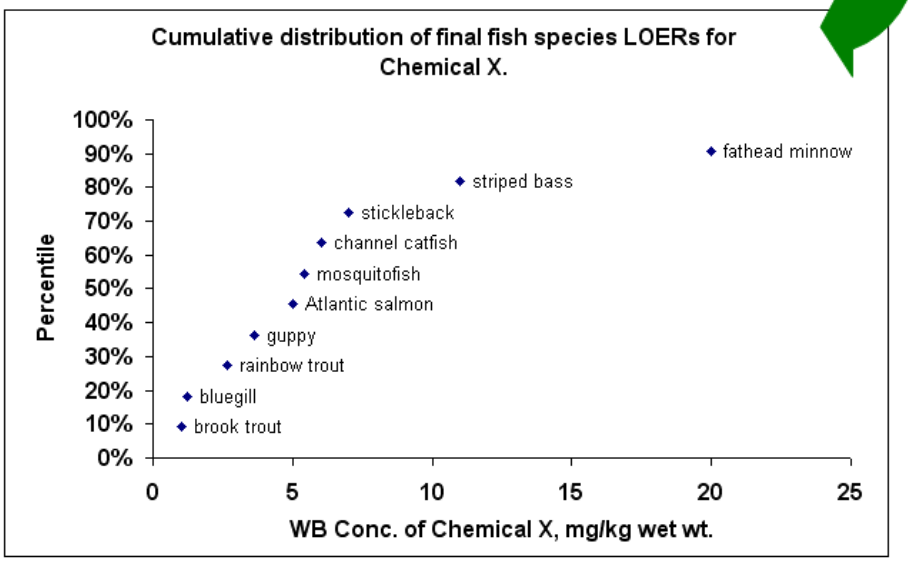
Figure 1 – LOER Derivation and SSD Development

An ACR is not applied to the mortality toxicity value because growth was also assessed in the same study.

Database	Species	Effect	WB Conc. (mg/kg wet wt.)	ACR of 8.3 Applied ?	Final WB Conc. (mg/kg wet wt.)	Geomean of Whole Body Conc. by Endpoint (mg/kg wet wt.)	Final Species LOER (mg/kg wet wt.)	Reference
ERED	Atlantic salmon	Reproduction	5	N	5	5	5	Jones et al. 1999
ERED	Bluegill	Mortality	10	Y	1.2	1.2	1.2	Doe et al. 2002
ERED	Brook trout	Growth	1	N	1	1	1	Smith et al. 2000
ERED	Brook trout	Mortality	2	N	2	2		Smith et al. 2000
ERED	Brook trout	Reproduction	2	N	2	2		Jones et al. 1999
ERED	Channel catfish	Growth	15	N	15	18.2	6.0	Shoemaker et al. 2001
ERED	Channel catfish	Growth	22	N	22			Sailer et al. 1999
Shephard	Channel catfish	Mortality	50	Y	6.0	6.0		Mason et al. 1998
Shephard	Fathead minnow	Growth	20	N	20	20	20	Carpenter 2003
ERED	Guppy	Mortality	30	Y	3.6	3.6	3.6	Miller et al. 1991
Shephard	Mosquitofish	Mortality	45	Y	5.4	5.4	5.4	Mason et al. 1998
Shephard	Rainbow trout	Growth	3	N	3	4.6	2.7	Doe et al. 2002
ERED	Rainbow trout	Growth	7	N	7			Potter 2005
Shephard	Rainbow trout	Mortality	22	Y	2.7	2.7		Baker et al. 1995
Shephard	Rainbow trout	Reduced predator avoidar	8	N	8	8		Farmer et al. 1991
ERED	Stickleback	Growth	7	N	7	7	7	Carpenter 2003
Shephard	Striped bass	Growth	11	N	11	11	11	Mason et al. 1998

Although sublethal toxicity data are available for rainbow trout from other studies, an ACR is applied to this mortality-based toxicity value because no sublethal data are available from the same study.

The Final Species LOER is based on the most sensitive endpoint for each species.



Review Process: Once the TRVs have been derived, a final review should be made. The purpose of the review is to check the accuracy of the calculations, and to ensure the desired protectiveness of the TRVs has been attained for all receptor species. If the derived TRV is higher than an adverse effect residue from the literature for a target ecological receptor being assessed, the TRV should be reevaluated and revised downward if necessary for protection of the target receptor. This process is analogous to the "final checks" step in derivation of AWQC (Stephan et al. 1985) in which the SSD-based final acute or chronic values are compared to individual studies to see if the calculated values might have to be lowered to protect this individual species. This evaluation is particularly important for receptor species to be evaluated at the organism level. If the derived TRV is higher than an adverse effect residue from the literature for a target ecological receptor being assessed at the organism level, the TRV will be reevaluated and revised downward if necessary for protection of the target receptor. In particular, the available salmonid residue-effects data will be evaluated closely to ensure organism-level TRVs based on SSDs are adequately protective.

Aquatic Biota Tissue TRV Derivation Procedure for the Portland Harbor BERA

Studies excluded from use in deriving aquatic biota tissue TRVs in the BERA include the following:

- Endpoints were not related to effects on survival, reproduction, growth or fish behavior
- Biota were exposed to mixtures in the laboratory. Exceptions to this are certain mixtures of related chemicals such as PCB Aroclors, Clophens or other PCB mixtures; mixtures of DDT and its metabolites DDD and DDE; or mixtures of chemicals such as dioxins, furans and certain PCB congeners with dioxin-like (i.e. 2,3,7,8-TCDD) mechanisms of action where the toxicity can be expressed as toxic equivalency factors relative to the toxicity of 2,3,7,8-TCDD.
- Studies where biota were exposed to chemicals in the field. This is because effects observed in field studies generally cannot be associated with a specific chemical

The specific requirements and toxicity data preprocessing approaches to be used during the derivation of SSD-based aquatic biota tissue TRVs for use in the Portland Harbor BERA are presented below. Most of these requirements are also appropriate for use with the lowest value approach to deriving TRVs.

If the sample size is ≥5, the SSD approach will be used and if the sample size is <5 the lowest value approach will be used[1].

- TRVs to be based on lowest observed effect residue (LOER) data affecting survival, reproduction, growth or (for fish only) behaviors that can be linked reliably to survival, reproduction, or growth

[1] Sample size refers to the number of species with tissue-based toxicity data available that meet the requirements outlined above, not the total number of individual toxicity data points. As the intent of the SSD approach is to have only one data point for each species in each chemical SSD, the approach is a true SSD approach.

- All LOERs have equal weight in the SSD (i.e. no one adverse effect such as reproduction is weighted more heavily than any other adverse effect)
- LOERs must be measured, not modeled or predicted.
    - LOERs reported in a companion study to the citation reporting adverse effects, but not in the original effects study are acceptable for use
    - LOERs described in terms of a measured bioconcentration or bioaccumulation factor from a water or dietary exposure concentration or dose are acceptable once converted into the equivalent measured residue value
- Minimum of five toxicity data points required to derive a TRV from an SSD
- 10th percentile of the LOER SSD to be used as the TRV for measurement endpoints evaluated at a population or community level of biological organization
- 5th percentile of the LOER SSD to be used as the TRV for measurement endpoints evaluated at the organism level (i.e., these TRVs would be applied to both juvenile salmonids, and lamprey ammocoetes)
- Growth and reproduction LOERs to be weighted equally, as reported from the literature, without application of any uncertainty factors
- Studies where control group data are available for comparison to treatment groups are required. However, it should be noted that the presence of control groups does not necessarily mean it is always possible to identify LOERs using rigorous statistical methods.
- Studies where both adverse effect residues and the magnitude of the observed effect are statistically significantly elevated above controls are preferred, but is not an absolute requirement for a study to be incorporated into an SSD. Studies without statistical significance reported should be noted in the data tables listing all studies used in TRV derivation.
- LOER residues for mortality will be divided by an uncertainty factor of 8.3 (Raimondo et al. 2007) to convert lethal residues to residues where lethality is indistinguishable from acceptable control mortality, then weighted equally with the growth and reproduction LOERs, without application of any other uncertainty factors. Use of this default uncertainty factor will be used for all survival LOERs unless sufficient data exist to estimate chemical specific acute-chronic ratios.
- Literature citation must be the primary source of the toxicity data
- Species must be reported
- Exposure to a single contaminant only in a laboratory setting
    - Exceptions to this requirement will be made for chemicals commonly evaluated as a single chemical even though they are mixtures (e.g. PCB Aroclors or Clophens; chlordane; toxaphene, DDT and its metabolic transformation products DDD and DDE, which can be reported as total DDTs; dioxins, furans and certain PCB congeners with dioxin-like (i.e. 2,3,7,8-TCDD) mechanisms of action where the toxicity can be expressed as toxic equivalency factors relative to the toxicity of 2,3,7,8-TCDD
- Individual literature citations must report information on a minimum of two exposures concentrations or doses: one control and at least one contaminant exposure
- EPA prefers the TRVs to be presented in units of mg/kg (or µg/g), whole body wet weight. Dry weight TRVs are acceptable as long as it is clearly stated whether the units

are in terms of wet or dry weight. A majority of the residue-effects literature is reported as wet weight. EPA does not believe sufficient residue-effects literature are available in a form to permit derivation of lipid normalized TRVs for organic chemicals
- Unless the water content of tissue in a citation is explicitly given, assume 80% water content of tissues when converting literature LOERs between wet and dry weights
- Beneficial effects (e.g. hormesis) will not be used to derive the TRV unless the hormetic effect can be directly related to an adverse effect on the assessment endpoints
- Adverse effects associated with nutritional deficiency of essential elements (e.g. copper, selenium, zinc) will not be used to derive TRVs
- LOER data from both freshwater and marine species may be used
- Species not required to be limited to North America residents
- Injection or gavage studies will not be used to derive tissue TRVs
- No uncertainty factors will be applied to either reproduction or growth LOERs
- If multiple LOERs are available for a chemical's toxicological effect in the same species (e.g. three growth LOERs are available for rainbow trout exposed to PCBs), the geometric mean of the multiple LOERs will be calculated, and the calculated geometric mean used as the single toxicity value for that species and toxicological endpoint
- If multiple LOERs are available for different toxicological effects for a single species (e.g. both survival and growth LOERs are available for rainbow trout exposed to PCBs), the toxicological endpoint with the lowest LOER for that species will be incorporated into the SSD
- Aquatic plant data should not be used to derive tissue TRVs for fish and aquatic invertebrates

Hierarchy of Procedures to Develop Aquatic Biota Tissue TRVs

The hierarchy for developing aquatic biota tissue TRVs, in units of mg/kg whole body wet weight, is as follows:

1. Taxa specific TRV using a species sensitivity distribution. The availability of residue-effects data will dictate the level to which this approach can be used, but we anticipate the lowest taxon to which tissue TRVs can be developed will likely be at the level of fish TRVs or invertebrate TRVs.
2. For selenium in fish tissues, use the EPA (2004) draft fish tissue criterion. Based on the screening level ecological risk assessment results to date, no selenium in invertebrate tissue TRV is required for the Portland Harbor BERA.
3. Aquatic biota TRV applicable to all aquatic species using a species sensitivity distribution. The SSD may include data from fish, invertebrates, and larval amphibians
4. For chemicals with insufficient residue-effects data to permit development of a species sensitivity distribution, utilize existing TRVs as previously developed and proposed by LWG in various documents if the TRVs are approved by EPA.
5. For chemicals with insufficient residue-effects data to permit development of a species sensitivity distribution, and without TRVs previously derived by LWG and approved by EPA, the lowest value approach (i.e. lowest LOER) from the available literature will be used to define the TRV.

Once the TRVs have been derived, a final review is conducted to check the accuracy of the calculations, and to ensure the desired protectiveness of the TRVs has been attained for any of the receptor species. This evaluation is particularly important for receptor species to be evaluated at the organism level. For example, if the derived TRV is higher than an adverse effect residue data point on an SSD for a salmonid species, the TRV should be reevaluated and revised downward if necessary for protection of juvenile salmonids. As no residue-effect studies are available for any lamprey species, this type of review will not be possible to ensure the protectiveness of the tissue TRVs for lamprey. The absence of any lamprey residue-effects literature against which tissue TRV protectiveness can be evaluated is an uncertainty in the BERA.

Chemicals for Which Aquatic Biota Tissue TRVs Need to be Derived

The EPA produced screening level ecological risk assessment (SLERA) for Portland Harbor as part of its review of the LWG's Round 2 Report identified 17 tissue COPCs for fish species (no fish species contained residues exceeding all 17 identified COPCs), and 23 tissue COPCs for aquatic invertebrates (again, no one invertebrate receptor contained residues exceeding all 23 identified COPCs). Ten of the COPCs were common to both fish and invertebrates, so the maximum number of COPCs for which aquatic biota tissue TRVs need to be derived, based on the results of the SLERA, is 29.

Of these 29 chemicals, seven are various PAH compounds for which Shephard (1998) concluded generally applicable tissue TRVs should not be derived. This conclusion is based in part because of the rapid metabolic transformation and/or photoactivation of parent PAH compounds to more toxic metabolites, whose toxicity is not properly evaluated by tissue benchmarks for a less toxic parent compound. Also a factor arguing against derivation of tissue TRVs for PAHs in this BERA are observations that the metabolic transformation abilities differ among species, and the transformation ability has no clear relationship with taxonomy (i.e. although a common presumption is that fish more actively transform PAHs than do invertebrates, many invertebrate species are better able to transform PAHs than some fish species). Among the freshwater invertebrate species able to metabolically transform PAHs are crayfish (Jewell et al. 1997), fingernail clams and *Chironomus riparius* (Borchert et al. 1997).

Several metals are also included in the 29 COPCs identified in the SLERA, and in the table of TRVs needed for the BERA. EPA recognizes that residue-effects relationships for metals are sufficiently complex that the simple concept of a critical body/tissue residue-effect relationship based on whole body residues may not always be a good surrogate for the concentration of metabolically available metal. In the case of the BERA TRVs for metals in aquatic biota tissues from Portland Harbor, however, our assumption is that the empirically measured whole body residue-effects data used to derive the BERA TRVs are sufficiently accurate surrogates for the true effective dose to permit their use in the assessment of ecological risks from bioaccumulated metals. Furthermore, the scientific reliability of tissue TRVs for metals relative to other chemicals (or even other lines of evidence) can be evaluated using the weight of evidence framework discussed in EPA's Problem Formulation.

The tissue TRVs required for the Portland Harbor BERA are listed below:

Fish and invertebrates	**Fish only**	**Invertebrates only**
Zinc	Chromium	Antimony
Total PCBs	Lead	Arsenic
4,4'-DDD	Mercury	Tributyltin
4,4'-DDE	Selenium	Endrin
4,4'-DDT	δ-hexachlorocyclohexane	
Total DDX	Hexachlorobutadiene	
β-hexachlorocyclohexane	Butylbenzyl phthalate	
Lindane		
Bis(2-ethylhexyl)phthalate		
Di-n-butyl phthalate		
Cadmium		
Copper		

The above lists are the chemicals of potential concern (COPC) identified during the screening level ecological risk assessment. The COPC list is based on the results of Portland Harbor sampling up through the end of Round 2 data collections, as determined by LWG's evaluation in their Round 2 report and EPA's review of the Round 2 report. A preliminary evaluation of Round 3 tissue data resulted in the addition of cadmium and copper as COPCs for fish. A more thorough evaluation of the Round 3 data may result in the identification of additional chemicals that will require derivation of tissue TRVs for the BERA.

Calculation Procedures for SSD Derived Aquatic Biota Tissue TRVs

In order to permit verification of the calculated TRVs once the toxicity data to be incorporated into each SSD has been compiled, EPA recommends that software be used that is freely available to all interested parties, making it possible for all to confirm the TRV calculations, while meeting the need for estimation of both 5th percentile and 10th percentile TRV derivations. One such program that is freely available and specifically designed to fit toxicity data to species sensitivity distributions is the BurrliOZ software from the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). BurrliOZ shows the fit of toxicity data to Burr Type 3, log-logistic and lognormal distributions. BurrliOZ also calculates both the effect concentration at a user defined percentile of the SSD, and the percentile of the SSD for a user defined environmental concentration. The software may be freely downloaded from the following web site: http://www.cmis.csiro.au/envir/Burrlioz/

A second free and publically available program that can be used to estimate percentiles of an SSD is the ET_x software (van Vlaardingen et al. 2004) developed by the Netherlands National Institute for Public Health and the Environment (RIVM). ET_x uses a log-logistic distribution to fit data to an SSD, and also estimates confidence limits around the selected effects percentile. The software may be freely downloaded from the following web site:
http://www.rivm.nl/rvs/overige/risbeoor/Modellen/ETX.jsp

The ETx version 2.0 manual can be downloaded from the following web site:

http://www.rivm.nl/bibliotheek/rapporten/601501028.html

Specific selection of the SSD model to be used will be based on which best fit the actual distribution of data for a given chemical. This "best fit" selection approach is becoming increasingly used for derivation of SSD-based environmental criteria worldwide, and so is appropriate for use in the Portland Harbor BERA.

Calculation Procedures for Lowest Value Approach Derived Aquatic Biota Tissue TRVs

The lowest species mean LOER will be used as the TRV for sample sizes <5. The species mean LOER will be calculated as the geometric mean LOER for a given species. The species mean LOER will be based on the most sensitive endpoint of the available data for that species. For example, if both growth and mortality toxicity data are available for a species, and growth is a more sensitive endpoint than mortality, then the species mean LOER will only be calculated from the growth-based toxicity data. Thus, the tissue TRV from the lowest value approach will reflect the most sensitive endpoint for the most sensitive species. It should be noted that the lowest value approach can be less conservative than the SSD approach for moderate sample sizes, which can result in 5th or 10th percentiles lower than the lowest toxicity value. This can result in a TRV that is less conservative for the chemical with the smaller sample size (i.e., too small to use a SSD). This uncertainty will need to be addressed in the Uncertainty Analysis section of the BERA, and incorporated accordingly into chemical-specific implementation of the weight of evidence scheme for any tissue-based line of evidence.

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Attachment 1
Response to June 30, 2008 Questions
Toxicity Reference Value Methodology – Aquatic Biota Tissue

1. Comment noted. EPA acknowledges that some aspects of these methods are untested and, as a result, a critical evaluation of any SSD-derived TRV on a chemical specific basis is entirely appropriate.

2. Agreed. EPA has omitted egg tissue data from consideration in development of tissue TRVs. The methods document will be corrected accordingly.

3. EPA agrees that any acute-chronic ratio (ACR) should, strictly speaking, only be applied to mortality endpoints from short-term acute studies. However, the tissue residue effects databases used to compile our datasets (Burt Shephard's database and ERED) do not report study duration. Consequently, it is difficult to rigorously apply the default ACR of 8.3 (or a chemical-specific ACR if one is available). Therefore, EPA has applied an ACR of 8.3 to the toxicity values if mortality data were the only endpoints reported in a study. However, if sub-lethal toxicity data (i.e., effects on growth or reproduction) were also available from a study, then no ACR was applied to the mortality-based toxicity value because there was no need to estimate the sensitivity of a sublethal endpoint using an ACR. Ultimately, an ACR was only applied to a mortality-based toxicity value if mortality was the only endpoint measured in a given study. In the few cases where EPA conducted an independent evaluation of the original toxicity study, study duration was evaluated to determine whether it was appropriate to apply an ACR to any mortality-based endpoint. If the study duration would clearly be considered "chronic" for a particular organism (e.g., substantially greater than 96-hr for most fish), then this ACR was not applied to the mortality endpoint.

4. The tissue TRV methodology does state, on page 9, how multiple LOERs for single species would be addressed, but not specifically about how to handle multiple LOERs from a single paper. In practice, they have turned out to be the same, with the lowest LOER from each endpoint (survival, growth, or reproduction) being selected from each species from each study. All of the LOERs of a single endpoint type are averaged together as a geometric mean, and then the final species LOER chosen as the lowest mean or individual LOER. In the revised TRV methodology, we will include a figure with an example to help clarify how multiple LOERs were addressed. With respect to studies with shorter duration results, we considered application of an ACR according to the refinements discussed in #3 above.

5. EPA agrees that sample size by itself should not determine whether aquatic invertebrate data are included or excluded. In practice, EPA did not feel it was appropriate to combine fish and invertebrate data into a single "aquatic life" SSD unless a particular chemical was identified as a COPC from the screening-level risk assessment (SLERA) for both groups of receptors. Thus, if a chemical only screened in for fish, only fish data were used to derive a TRV regardless of whether it was derived using the SSD or lowest value approaches. For COPCs that screened in for both receptor groups, a combined "aquatic life" SSD will only be used if either the fish or the invertebrate data sets are not individually large enough to derive a TRV using the SSD approach.

6. Bioavailability, uptake, and toxicity processes are more diverse and complex for individual metals, species, environments, and exposure routes than for organic chemicals. No single unifying factor resolves these differences the way fugacity/hydrophobicity does for organics. Uptake of organics generally occurs via passive transport whereas metals require active or facilitated transport. Distribution within the organism is also different: commonly non-polar interactions and water/lipid solubility drives the distribution of organics in tissues, compared to ligand binding and active transport into cells for metals. There is no baseline mode of toxic action for metals analogous to non-polar narcosis for organics. Thus, for metals, a multi-faceted conceptual and mathematical construct may be necessary to link environmental exposure to effective internal dose and subsequently to toxicity.

   Toxicity of a metal is a function of both uptake characteristics of the organism and the species-specific detoxification capabilities. More specifically, toxicity results from the interaction of three rate processes - the rate of uptake, the rate of detoxification, and the rate of excretion. If the rate of metal uptake into an organism is greater than the combined rate at which it can be excreted or detoxified, then that metal will accumulate internally in metabolically available forms which are available to bind to internal molecule(s) and cause toxic effects. Thus, bioaccumulation of metabolically available metal determines toxicity, not necessarily total metal.

   Therefore, like organic contaminants, the dose and toxicity of metals depends upon the internal tissue burden. The specific mechanistic differences between metals and organics do not invalidate the use of tissue residue approaches to evaluate metal residues. EPA recognizes that residue-effects relationships for metals are sufficiently complex that the simple concept of a critical body/tissue residue-effect relationship based on whole body residues may not always be a good surrogate for the concentration of metabolically available metal. In the case of the BERA TRVs for metals in aquatic biota tissues from Portland Harbor, however, our assumption is that the empirically measured whole body residue-effects data used to derive the BERA TRVs are sufficiently accurate surrogates for the true effective dose to permit their use in the assessment of ecological risks from bioaccumulated metals.

7. EPA agrees that having control group data is strongly preferred and should be a requirement. As a result, EPA will revise the TRV methodology accordingly. However, it should be noted that it is often difficult to ascertain whether a LOER from any given study was derived using a formal statistical hypothesis test, as would typically be expected. For the most part this is because statistical significance information is not always available in either Burt Shephard's or the ERED databases and can even be difficult to ascertain following examination of the original study. EPA recognizes this is not an optimal situation, but we have used best professional judgment to identify LOERs as rigorously as the information available allows. We have also included additional practical refinements used by EPA to make these best professional LOER determinations in the revised TRV methodology.

Benthic TRV Summary Table

Chemical	Concentration mg/kg ww		
	Screening Value	10th Percentile	LOAEL
Aluminum	33	nd	nd
Arsenic	1.7	2.00	nap
Cadmium	0.09	0.35	nap
Copper	3.1	7.67	nap
Zinc	27	24.07	nap
TBT	0.05	0.15	nap
BEHP	0.39	nc	3.12
Dibutyl phthalate	0.27	nc	3855
PCBs	0.72	1.32	nap
DDD	0.054	nc	1.81
Total DDx	na	0.97	nap

na: not available
nap: not applicable - sufficient data for SSD
nc: not calculated - insufficient data
nd: not determined will be discussed in the uncertainty section

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Arsenic

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR Value	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Argopecten irradians (bay scallop)	Mortality	LC50	38.3	3.803	yes	10.1	10.1	water	96 hours	Nelson et al. 1976		Yes	
Crangon crangon (shrimp)	Mortality	LC50	21	3.803	yes	5.52	5.52	water	180 hours	Madsen 1992	LOAEL based on the experiment with the smallest organisms (and lowest mortality LOAELs); LT50 was 180 hrs and corresponding tissue residues at this time were 21 mg/kg ww	Yes	
Hyalella azteca (amphipod)	Mortality	LD25	1.87	-	no	1.87	1.87	water	4 weeks	Norwood et al. 2007		Yes	
Littorina littoralis (periwinkle)	Mortality	100% mortality	20	3.803	yes	5.26	5.26	water	8 days	Klumpp 1980	whole body tissue at day 4 with slow response to physical stimulus; 100% mortality was observed by day 8	Yes	
Potamopyrgus antipodarum (New Zealand mud snail)	Mortality	54% morbidity	92.0	-	no	92.0	92.0	water	30 days	Hickey and Martin unpub (2002)	endpoint effect is snail morbidity (inability to overturn) so an ARC was not applied	Yes	
Moina macrocopa (cadoceran)	Growth	change in growth	3.58	-	no	3.58	-	water	7 days	Maeda et al. 1990		No	At most exposure concentrations growth was similar or higher than in control. No tissue concentration was provided at the exposure concentration with reduction in growth

na - not applicable; study not acceptable for inclusion in SSD derivation

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Cadmium

Species	Endpoint	Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Acartia tonsa (copepod)	Reproduction	decreased egg production	0.45	-	no	0.45	0.45	food	4 hours	Hook and Fisher 2002	concentration estimated from a graph; effects observed for 1 wk following 4 hr exposure; egg production was significantly reduced	Yes	
Allorchestes compressa (amphipod)	Growth	reduction in biomass	16.1	-	no	16.1	16.1	water	4 weeks	Ahsanullah and Williams 1991	growth was the most sensitive endpoint; LOAEL based on minimum significant toxic effects (MEC) for biomass (11 ug/L) using regression equation; growth was the most sensitive endpoint	Yes	
Anadara granosa (clam)	Mortality	LC50	91	8.3	yes	11	11	water	96 hours	Patel and Anthony 1991		Yes	
Argopecten irradians (bay scallop)	Growth	reduced growth, detachment of byssal threads	245	-	no	245	245	water	6 weeks	Pesch and Stewart 1980	growth sigificantly lower growth than in control; LOAEL based on soft tissue of scallop	Yes	
Artemia salina (brine shrimp)	Growth	inhibition of growth	5.4	-	no	5.4	5.4	water	7 days	Jayasekara et al. 1986	growth was significantly inhibited in shrimps exposed to 5 and 2 ppm Cd; tissue concentration was lowest for the 5 ppm exposure	Yes	
Cambarus latimanus (crayfish)	Mortality	17% mortality	22.4	-	no	22.4	22.4	water	5 months	Thorp et al. 1979	0% mortality in control; significant mortality observed at LOAEL	Yes	
Carcinus maenas (green crab)	Mortality	65% mortality	22.3	8.3	yes	2.7	2.7	water	12 days	Jennings and Rainbow 1979	20% mortality in control; tissue concentration based on the total absorbed Cd	Yes	
Ceriodaphnia dubia (cladoceran)	Reproduction	decrease in reproduction	0.20	-	no	0.20	0.20	food	7 days	Sofyan et al. 2007	waterfleas exposed through water, diet or a combination of water and diet; lowest LOAEL based on diet exposure; significant decrease observed	Yes	
Chironomus riparius (midge)	Reproduction, Mortality	delay onset of development; 55% mortality	22.6	-	no	22.6	7.64	water	5 weeks	Timmermans et al. 1992[a]	8% mortality in control; statistical significance of reproductive effect not dicussed; tissue concentration range in instars over the exposure duration was 22.6 to 74 mg/kg ww; survival and reproduction endpoints more senstive than growth	Yes	
Chironomus riparius (midge)	Mortality	reduction in survival	7.6	-	no	7.6	-	water and food	4-8 weeks	Postma et al. 1994	significant reduction in mortality	Yes	
Chironomus riparius (midge)	Mortality	increased mortality	2.6	-	no	2.6	-	water	9 generations	Postma and Davids 1995[a]	statistically greater mortality after 4 generations; tissue concentration read from graph	Yes	
Chironomus riparius (midge)	Growth	reduced body weight	221	-	no	221	-	sediment	10 days	Gillis et al. 2002[a]	significant reduction in body weight	Yes	
Crassostrea virginica (eastern oyster)	Reproduction	24% increase in abnormal embryos from exposed parents	54	-	no	54	54	water	37 weeks	Zaroogian and Morrison 1981	no apparent effect on fecundity was observed at LOAEL	Yes	

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Cadmium

Species	Endpoint	Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Daphnia galeata mendotae (cadoceran)	Mortality, Growth	reduced survival and growth	8.56	-	no	8.56	8.56	water	22 weeks	Marshall 1978	mortality and growth significantly effected compared to control	Yes	
Daphnia magna (cadoceran)	Mortality	>50% mortality	5.8	8.3	yes	0.70	1.5	water	24 hours	Barata et al. 2002[a]	different clones of waterfleas were tested; lowest tissue residues range from 5.8 to 9.8 mg/kg ww in clones exposed to 10 ug/L Cd in water; LC50s ranged from 5 - 8 ug/L in the most sensitive clone; other clones had no effects up to 11.8 mg/kg ww; effect and tissue concentration read from graphs	Yes	
Daphnia magna (cadoceran)	Mortality, Growth	20% increase in mortality, significant reduction body length	2.0	-	no	2.0	-	water	41 days	Heugens et al. 2006[a]	high uncertainty; experiment conducted with varying food, temperature, and Cd exposure concentrations; LOAEL based on lowest residue with growth and survival effect measured at 10°; no consistent dose response; at 20° and 26° survival LOAELs were 18 and 9.4 mg/kg, respectively and growth LOAELs were 4 and 3.2 mg/kg, respectively; concentrations estimated from graph	Yes	
Daphnia magna (cadoceran)	Mortality, Growth, Reproduction	67% mortality; decreased reproduction & growth	2.4	-	no	2.40	-	water	28 days	Dillon and Gibson 1987	growth and reproduction significantly reduced; only one tissue composite available from the affected exposure group	Yes	
Daphnia magna (cadoceran)	Growth	reduction in body weight	13.3	-	no	13.3	-	water	6 generations	Guan and Wang 2006[a]	significant decrease in body weight between F5 generation in exposed organism compared to control; however, no significant growth effect in F6 generation or any previous generations with body burdens up to 17.3 mg/kg ww; LOAEL is concentration in F5 generation; only one exposure dose tested	Yes	
Daphnia magna (cadoceran)	Growth, Reproduction	reduced body size, scope for growth, net reproduction rate	11	-	no	11	-	water	2 weeks	Smolders et al. 2005[a]	Experiment with several different food ration levels and cadmium concentrations; Concentrations read from graph; LOAEL is lowest concentration exposed to 2.5 x 10-8 mol/L Cd (one of the high ration groups) and NOAEL is the highest concentration exposed to 1.0 x10-8 mol/L (the lowest ration group)	Yes	
Daphnia magna (cadoceran)	Reproduction	reduction in number of newborns	6.4	-	no	6.4	-	food	20 days	Ferard et al. 1983[a]	signficant inhibition of reduction (approximately 50% of control)	Yes	

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Cadmium

Species	Endpoint	Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Dreissena polymorpha (zebra mussel)	Behavior	decrease in filtration rate	16	-	no	16	14	water	11 weeks	Kraak et al. 1992	LOAEL based on graph; at LOAEL, 60% decrease in filtration rate observed; 28% mortality at tissue residues of 100 mg/kg ww	Yes	
Dreissena polymorpha (zebra mussel)	Behavior	decrease in filtration rate	12	-	no	12	-	water	48 hours	Kraak et al. 1994		Yes	
Elasmopus rapax (amphipod)	Mortality	LC50	4.5	8.3	yes	0.54	0.54	water	96 hours	Zanders and Rojas 1992	tissue residues measued in live tissues	Yes	
	Mortality	LD50	20.0	-	no	20	20	water	121 days	Meador 1993	tissue concentration based on lowest LC50 (residues = 100 mg/kg dw)	Yes	
	Mortality	50% mortality	48.4	8.3	yes	5.8	5.8	food	18 days	Abel and Barlocher 1988	amphipods fed contaminated food	Yes	
Gammarus lawrencianus (amphipod)	Mortality	50% mortality	0.9	8.3	yes	0.11	0.11	water	72 hours	Wallace and Estephan 2004		Yes	
Gammarus pulex (amphipod)	Mortality	100% mortality	4.4	8.3	yes	0.53	1.76	food	13 days	Duddridge and Wainwright 1980[a]	100% mortality after 13 days dietary exposure to fungal mycelium containing cadmium; control mortality = 40% for 21 days with body burdens of 1.1 mg/kg ww	Yes	
Gammarus pulex (amphipod)	Mortality	20% mortality	48.6	8.3	yes	5.86	-	water	48 hours	Wright and Frain 1981[a]	tissue residues were slightly higher (58.4 mg/kg ww) in Ca-free water.	Yes	
Glyptotendipes pallens (midge)	Growth	decreased weight	30	-	no	30	30	water	96 hours	Heinis et al. 1990	weight was significantly reduced compared to control; deviation from normal feeding pattern was observed; concentrations estimated from graph	Yes	
Helisoma sp. (snail)	Mortality	50% mortality	630	8.3	yes	76	76	water	10 days	Carlson et al. 1991	concentrations estimated from graph	Yes	
Hyalella azteca (amphipod)	Mortality	significant increase in mortality	6.0	-	no	6.0	6.0	water	6 weeks	Borgmann et al. 1991[a]	LOAEL is lowest toxic tissue residue reported based on significant mortality	Yes	
Hyalella azteca (amphipod)	reproduction	decrease in reproduction	22	-	no	22	-	water	42 days	Stanley et al. 2005	LOAEL based on stream water exposure experiment	Yes	
Littorina littorea (periwinkle)	Growth	decrease in soft body dry weight	36	-	no	36	36	water	27 days	Marigomez and Ireland 1990	significance of weight reduction not discussed; estimated from graph that approximately a 20% reduction in weight was measured at LOAEL	Yes	
Lumbriculus variegatus (oligochaete)	Mortality	LR50	51.7	8.3	yes	6.2	22	water	48 hours	Pennttinen et al 2008[a]		Yes	
Lumbriculus variegatus (oligochaete)	Mortality	40% mortality	650	8.3	yes	78.3	-	water	10 days	Carlson et al. 1991	concentrations estimated from graph	Yes	
Macoma balthica (baltictellin)	Growth	significant reduction in condition index	14.0	-	no	14.0	14	water	5 weeks	Duquesne et al. 2004		Yes	
Melita plumulosa (amphipod)	Mortality	46% mortality	19	8.3	yes	2.3	2.3	water	10 days	King et al. 2006	17% mortality in control; concentrations and LOAEL survival estimated from graphs	Yes	

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Cadmium

Species	Endpoint	Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Mictyris longicarpus (soldier crab)	Mortality	70% reduction in survival after 21 days	7.4	8.3	yes	0.89	0.89	sediment	21 days	Weimin et al. 1994	70% mortality after exposure for 21 days to Cd spiked sediment. A tissue concentration of 37 ug/g dw can be read from Fig 6 after exposured for 21 days	Yes	
Moina macrocopa (cladoceran)	Mortality, Growth, Reproduction	decrease in survival, growth, and reproduction	20.4	8.3	yes	2.46	2.46	food	6 days	Hatakeyama and Yasuno 1981	organisms fed with cadmium-contaminated chlorella; decreased size and number of broods observed	Yes	
Monoporeia affinis (amphipod)	Reproduction	increase in malformed eggs	5.0	-	no	5.0	5.0	water	105 days	Sundelin 1983	significant increase in number of malformed eggs at LOAEL (5%); some uncertainty asssociated with LOAEL water concentration reported in table (doesn't match water concentration reported with tissue concentrations); assumed error in paper on reported water concentration	Yes	
Mysidopsis bahia (mysid)	Growth	reduced growth	1.29	-	no	1.29	1.29	water	33 days	Carr et al. 1985	growth significantly reduced	Yes	
Mysis sp. (shrimp)	Mortality	26.3% mortality	1.06	8.3	yes	0.128	0.128	water	96 hours	Zyadah and Abdel-Baky 2000[a]	26.3% mortality after 24 hours (the test was conducted for 96 hours; the first significant effect and tissue ceoncentration was measured after 24 hours); Questionable quality of the paper (errors in tables).	Yes	
Mytilus edulis (blue mussel)	Growth	reduced growth of meat and shell	240	-	no	240	240	water	9.4 weeks	Fischer 1988 TRV 1209		Yes	
Mytilus galloprovincialis (mediterranean mussel)	Reproduction	increased abnormal development of straight hinge veliger larvae	1600	-	no	1600	39	water	48 hours	Pavicic et al. 1994	LOAEL based on Cd exposure concentration (10 mg/L) and CF (160) reported in study; uncertainty because not known whether CF is based on ww conc or how CF was derived	Yes	
Mytilus galloprovincialis (mediterranean mussel)	Mortality	20% mortality	39	-	no	39	-	water	30 days	Pavicic and Jarvenpaa 1974	LOAEL based on 115mCd tagged group (only group where residues were measured)	Yes	
Neanthes arenaceodentata (polychaete)	Growth	decrease in growth	16.8	-	no	16.8	16.8	water	21 days	Jenkins and Sanders 1986		Yes	
Neomysis integer (opossum shrimp)	Mortality	LC50	0.22	8.3	yes	0.03	0.03	water	7 days	Roast et al. 2001[a]	LOAEL based on LC50 at 10 ppt salinity; at 30 ppt salinity tissue residue = 0.3 mg/kg ww	Yes	
Nephtys caeca (polychaete)	Behavior	delay in burrowing time	7.0	-	no	7.0	7.0	sediment	ne	Olla et al. 1988		Yes	
Orconectes virilis (crayfish)	Mortality	25% mortality	28.4	8.3	yes	3.42	3.42	water	2 weeks	Mirenda 1986		Yes	

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Cadmium

Species	Endpoint	Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Palaemonetes pugio (grass shrimp)	Mortality	21% mortality	2.6	8.3	yes	0.31	4.0	water	7 days	Vernberg et al. 1977[a]	only one cadmium concentration evaluated at varying salinities; LOAEL based on 5 ppt salinity; 1% mortality in control	Yes	
Palaemonetes pugio (grass shrimp)	Mortality	at least 50% mortality	52.6	-	no	52.6	-	water	6 weeks	Pesch and Stewart 1980	LC50 (0.5 mg/L) at approximately 35 days; tissue concentration measured at 42 days (6 weeks)	Yes	
Paracentrotus lividus (sea urchin)	Growth	increased frequency of larval abonormalities	0.16	-	no	0.16	0.16	water	48 hours	Radenac et al. 2001	larval abnormality frequency significantly increased; EC50 for occurrence of larval abnormaliities = 6.7 mg/kg ww.	Yes	
Physa sp. (snail)	Mortality	90% mortality	30	-	no	30	30	water	28 days	Spehar et al. 1978	32% mortality in control; tissue residue and mortalities at LOAEL and control estimated from figure; uncertainty with graph interpretation (paper indicated graph was based on log scale, but did not appear based on log scale)	Yes	
Pontoporeia affinis (amphipod)	Reproduction	increase in abnormal egg frequency	0.94	-	no	0.94	0.94	water	60 days	Sundelin 1984	significant effect observed; Based on method information in Sundelin (1983) the tissue concentrations were measured in dry weights.	Yes	
Tubifex tubifex (oligochaete)	Reproduction	reduced number of young per adult	3,415	-	no	3,415	3.12	sediment	28 days	Gillis et al. 2002[a]	significant reduction in number of young per adult	Yes	
Tubifex tubifex (oligochaete)	Mortality	20% mortality	25.9	8.3	yes	3.12	-	water	17 days	Redeker and Blust 2004	tissue residue based best fit curve model relating mortality and tissue concentrations	Yes	
Uca pugilator (fiddler crab)	Mortality	20% mortality	31.9	8.3	yes	3.84	3.84	water	24 days	Weis 1978	reduced limb generation also observed	Yes	
Anodonta grandis (freshwater mussel)	Growth	ED290	25.8	-	no	25.8	-	ne	ne	Couillard et al. 1995		No	Field study with multiple metals exposure
Baetis rhodani (mayfly)	Behavior	decreased locomotor activity	1.0	-	no	1.0	-	ne	ne	Gerhardt 1990		No	Behavior endpoint not directly related to growth, survival, or reproduction; poorly presented results in study and poor relevance of low pH conditions
Callianassa australiensis (shrimp)	Growth	reduction in growth	0.52	-	no	0.52	-	ne	ne	Ahsanullah et al. 1984		No	EPA LOAEL not associated with effect in study
Cardium edule (cockle)	Behavior	partial inhibition of burrowing	1.8	-	no	1.8	-	ne	ne	Amiard et al. 1986		No	Behavior endpoint not directly related to growth, survival, or reproduction
Chironomus salinarius (Midge)	Population	reduced population abundance	10	-	no	10	-	ne	ne	Hare et al. 1994		No	Field study with multiple metals exposure
Chironomus staegeri (midge)	Population	reduced population density	29.7	-	no	29.7	-	ne	11 months	Warren et al. 1998		No	Field study

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Cadmium

Species	Endpoint	Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Daphnia pulex (cladoceran)	Reproduction	41% reduction in brood size	9.7	-	no	9.7	-	ne	7 days	Winner 1984		No	Methods unacceptable (tissue residues and effects measured in different species and with different exposure durations)
Gammarus pulex (amphipod)	Mortality	LD50	0.52	8.3	yes	0.97	-	ne	ne	Brown and Pascoe 1989		No	No effects data presented in study
Hydropsyche sp. (caddisfly)	Mortality	mortality	9.6	8.3	yes	1.2	-	ne	ne	Dressing et al. 1982		No	No effects data presented in study
Leptophlebia marginata (mayfly)	Mortality	decreased emergence	2.6	-	no	2.6	-	ne	ne	Gerhardt 1990		No	Poorly presented results in study and poor relevance of low pH conditions
Meganyctiphanes norvegica (krill)	Mortality	increased mortality and induction of metallothionein	13.3	8.3	yes	1.6	-	ne	ne	Poirier and Cossa 1981		No	Unable to interpret foreign language paper
Nereis virens (sandworm)	Behavior	reduction in hypoglycemic response	44	-	no	44	-	ne	ne	Carr and Neff 1982		No	Reduced hypoglycemic response endpoint not directly related to growth, survival, or reproduction
Nereis virens (sandworm)	Growth	weight loss	0.59	-	no	0.59	-	sediment	14 days	Simmers et al 1984		No	Exposure to mixture of metals in the field
Palaemonetes pugio (grass shrimp)	Behavior	reduced ability to capture prey, increased metallothionein induction	0.84	-	no	0.84	-	ne	ne	Wallace et al. 2000		No	Behavior endpoint not directly related to growth, survival, or reproduction. Reduction of ability to capture prey reduced by 4-13% and observed over 2 hours
Paramoera walkeri (amphipod)	Mortality	30-40% mortality and decrease in molting	1.1	-	no	1.1	-	ne	20 days	Clason et al. 2003		No	Exposure concentrations not dose-responsive
Pseudodiaptomus sp. (copepod)	Reproduction	reproductive rate reduced	7.3	-	no	7.3	-	water	ne	Paffenhofer and Knowles 1978		No	No tissue data reported in study
Saccostrea glomerata (Sydney rockoyster)	Growth	reduction in growth	5.0	-	no	5.0	-	ne	ne	Ward 1982		No	Exposure concentrations and effects not dose-responsive
Strongylocentrotus intermedius (sea urchin)	Reproduction	increase in production of abnormal larvae	146	-	no	146	-	ne	ne	Khristoforova et al. 1984		No	No tissue residues reported in study
Tetrahymena pyriformis (protozoan)	Population	reduced population growth	10.4	-	no	10.4	-	ne	ne	Berhin et al. 1984		No	Test species not acceptable species to represent invertebrates
Tetrahymena vorax (protozoan)	Population	reduced population size	33.8	-	no	33.8	-	ne	ne	Lawrence et al. 1989		No	Test species not acceptable species to represent invertebrates
Tubificidae (oligochaetes)	Population	reduced population density	372	-	no	372	-	ne	11 months	Warren et al. 1998		No	Field study

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Cadmium

Species	Endpoint	Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Uca rapax (fiddlercrab)	Mortality	20% mortality, failure to respond to external stimulus	17.3	-	no	17.3	-	ne	96 hrs	Zanders and Rojas 1996		No	WB tissue concentrations not reported in study

na - not applicable; study not acceptable for inclusion in SSD derivation
ne - test condition data not collected from studies not included in LWG's SSD
[a] Not reviewed as part of EPA's TRV final list; based on LWG review

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Copper

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Adenophlebia auriculata (mayfly)	Mortality	LC50	800	3.23	yes	247.7	247.7	water	48 hours	Gerhardt and Palmer 1998		Yes	
Allorchestes compressa (amphipod)	Growth	reduced growth	73	-	no	73	73	water	4 weeks	Ahsanullah and Williams 1991	LOAEL is derived from the minimum risk concentration reported in study and is the tissue residue associated with the minimum significant toxic effect; growth was the most sensitive endpoint	Yes	
Argopecten irradians (bay scallop)	Growth	43% reduction in growth	64	-	no	64	64	water	6 weeks	Pesch et al. 1979	LOAEL is mean tissue concentration associated with significant reduction in growth	Yes	
Balanus amphitrite (barnacle)	Mortality	lethal body burden based on average survival time of about 70 hours	29.9	3.23	yes	9.3	9.3	water	70 hours	Prabhakara Rao et al. 1986	Controls were included but no survival data not explicitly provided	Yes	
Balanus tintinnabulum (barnacle)	Mortality	lethal body burden based on average survival time of about 20 hours	33.0	3.23	yes	10.2	10.2	water	20 hours	Prabhakara Rao et al. 1986	Controls were included but no survival data not explicitly provided	Yes	
Burnupia stenochorias (limpet)	Mortality	LC50	56	3.23	yes	17.3	17.3	water	24 hours	Gerhardt and Palmer 1998		Yes	
Callinassa australiensis (shrimp)	Mortality	LC50	145.9	3.23	yes	45.2	45.2	water	14 days	Ahsanullah et al. 1981a; 1981b		Yes	
Chironomus decorus (midge)	Growth	significant reduction in larval growth	13	-	no	13	13	water	72 hours	Kosalwat and Knight 1987	LOAEL based on from substrate concentration associated with sig reduction in larval growth (1,808 mg/kg dw) and equation for adult tissue burden (Y=0.03[X] + 10.65); uncertainty with using "adult tissue" equation for larval growth effect	Yes	
Chironomus riparius (midge)	Growth	ED16	70	-	no	70	70	water	7 days	Timmermans et al. 1992	growth effect at 7 days based on graph interpretation (estimated point at which effect was significant)	Yes	
Cirriformia spirabrancha (polychaete)	Mortality	approximately 50% mortality	10.7	3.23	no	10.7	10.7	water	24 days	Milanovich et al. 1976	LOAEL of 10.7 mg/kg ww was measured at 24 days and the LT50 was reported as 26 days	Yes	
Daphnia magna (cadoceran)	Reproduction, growth	reduced weight, number of offspring, number of broods	65	-	no	65	40.8	water	21 days	DeSchamphelaere et al. 2007	only one exposure concentration and the control tested in study	Yes	
Daphnia magna (cadoceran)	Reproduction, growth	reduced body weight (by biomass) and number of juveniles per adult	25.6	-	no	25.6	-	water	21 days	DeSchamphlaere and Janssen 2004[a]	no reproduction and reduced biomass in daphnids was observed	Yes	
Dreissena polymorpha (zebra mussel)	Mortality, Behavior	24% mortality observed and reduced filtration rate	40	-	no	40	17.9	water	9 weeks	Kraak et al. 1992	at LOAEL, filtration rate is reduced (44% of control) and 24% mortality observed; control mortality reported as less than 20%; concentrations read from graph	Yes	

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Copper

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Dreissena polymorpha (zebra mussel)	Growth	50% decrease in filtration rate	8	-	no	8	-	water	48 hours	Kraak et al. 1994		Yes	
Ephemerella grandis (mayfly)	Mortality	> 50% mortality	248	3.23	yes	76.8	76.8	water	14 days	Nehring 1976		Yes	
Gammarus pulex (amphipod)	Mortality	LC50	27.9	3.23	yes	8.6	8.6	water	96 hours	Guven et al. 1999	LOAEL based on equation and LC50 (log y = 1.523+0.078[log	Yes	
Grandidierella japonica (amphipod)	Mortality	23% mortality	78	3.23	yes	24	24	sediment	10 days	King et al. 2005[a]	survival at LOAEL is approximately 77% that of the control; only one exposure concentration tested	Yes	
Hyale crassicornis (amphipod)	Mortality	49% mortality	88	3.23	yes	27.2	27.2	sediment	10 days	King et al. 2005[a]	survival at LOAEL is approximately 51% that of the control; only one exposure concentration tested	Yes	
Hyale longicornis (amphipod)	Mortality	48% mortality	26	3.23	yes	8.0	8.0	sediment	10 days	King et al. 2005[a]	survival at LOAEL is approximately 52% that of the control; only one exposure concentration tested	Yes	
Lumbriculus variegatus (freshwater oligochaete)	Mortality	LR50	137	3.23	yes	42.4	10.5	water	48 hours	Pennttinen et al. 2008[a]		Yes	
Lumbriculus variegatus (oligochaete)	Mortality	LD50	8.3	3.23	yes	2.6	-	water	6-48 hours	Meyer et al. 2002	The value is based ona kinetic model and the mean LC50 of 25 toxicity studies	Yes	
Melita plumulosa (amphipod)	Mortality	50% mortality	94	3.23	yes	29.1	11.2	sediment	10 days	King et al. 2005[a]	survival is approximately 50% that of the control; only one exposure concentration tested	Yes	
Melita plumulosa (amphipod)	Mortality	25-45% mortality	22	3.23	yes	6.8	-	sediment	10 days	King et al. 2006[a]	tissue concentration estimated from graph; control mortality = 10%; LOAEL based on sediment exposure (higher tissues associated with mortality reported in water exposure)	Yes	
	Mortality	LC50	23	3.23	yes	7.1	-	sediment	10 days	Simpson and King 2005		Yes	
	Mortality	up to 50% mortality	201	3.23	yes	62.2	62.2	water	96 hours	Kumaraguru et al. 1980		Yes	
Mysella anomala (bivalve)	Mortality	mortality	44	3.23	yes	13.6	13.6	water	96 hours	King et al. 2004		Yes	
Mytilus edulis (blue mussel)	Mortality	increased mortality	62	-	no	62	25.3	water	21 months	Calabrese et al. 1984[a]	at LOAEL, only 4 mussels survived (number of mussels at start of experiment not reported) so this dose was reportedly "toxic"	Yes	
Mytilus edulis (blue mussel)	Mortality	LC50	33.2	3.23	yes	10.3	-	water	7-16 days	Hvilsom 1983	LOAEL is the lowest tissue reported in live organism at any expoure level (0.1, 0.2, and 0.5 ppm); 50% mortality reached at all exposure levels within 7-16 days	Yes	

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Copper

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Neanthes arenaceodentata (polychaete)	Mortality	lethal body burden based on mean number of days to death	79	3.23	yes	24.5	24.5	water	4 days	Pesch and Hoffman 1982	worms with no pre-copper exposure the lowest tissue concentration of 395 ug/g dw has a mean time to death of 3.9 days. TRV = (395/5)/8.3 = 9.5 mg/kg ww; uncertainties include: Cu accumulation is not dose-responsive; tissues of dead worms analyzed and expected to be about 14% lower than live organisms	Yes	
Paracentrotus lividus (sea urchin)	Growth	37% abonormalities in larvae	8.7	-	no	8.7	8.7	water	48 hours	Radenac et al. 2001		Yes	
Paracorophium excavatum (amphipod)	Reproduction	reduced juvenile recruitment	30.2	-	no	30.2	30.2	sediment	28 days	Marsden 2002[a]	significant reduced juvenile recruitment compared with the control obesrved; also noted that no females retained developing embryos after 28 days of expsoure; the sediment used in the experiment was field collected and spiked with copper; the control had low level of copper (5 ug/g); tissue concentrations were derived using an equation; LOAEL based on most sensitive endpoint (higher tissue residues with mortality)	Yes	
Paramoera walkeri (amphipod)	Mortality	lethal to 50% of animals	119	3.23	yes	36.8	36.8	water	8 days	Duquesne et al. 2000	tissue concentration is average BCF (2060) X 8d LC50 (290 ug/L) and coverted into wet weight	Yes	
Penaeus merguiensis (banana prawn)	Growth	reduction in growth	26	-	no	26	26	water	2 weeks	Ahsanullah and Ying 1995	growth significantly reduced at 100 ug/L where tissue conc ~ 133 - 160 ug/kg dw (26.6-32 ug/kg ww)	Yes	
Protothaca staminea (Pacific littleneck	Mortality	17% mortality	9.3	-	no	9.3	9.3	water	30 days	Roesijadi 1980	3% mortality in control	Yes	
Pteronarcys californica (stonefly)	Mortality	> 50% mortality	419	3.23	yes	129.7	129.7	water	14 days	Nehring 1976		Yes	
Saccostrea glomerata (Sydney rock oyster)	Growth	reduction in weight gain of spat	19	-	no	19	19	water	4 weeks	Nell and Chvojka 1992	significant difference in weight gain compared to the control	Yes	
Tellina deltoidalis (bivalve)	Mortality	LD50	74.0	3.23	yes	22.9	22.9	water	96 hours	King et al. 2004		Yes	
Acartia clausi (copepod)	Reproduction	reduced egg production	3.9	-	no	3.9	-	ne	ne	Moraitou-Apostolopoulos and Verriopoulos 1979		No	Unable to reproduce EPA LOAEL. Excluded because less than nutritional value of 5 mg/kg ww
Allorchestes compressa (Amphipod)	Mortality	increased mortality, weakness	43.6	3.23	yes	13.4	-	ne	ne	Ahsanullah and Florence 1984		No	Effect (weakness) not directly related to growth, survival, or reproduction
Anaitides maculata (polychaete)	Mortality	LD50	49	3.23	yes	15.2	-	ne	ne	McLusky and Phillips 1975		No	Unable to obtain and review reference

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Copper

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Calanus hyperboreus (copepod)	Mortality	LD50	1320	3.23	yes	408.7	-	ne	ne	Ritterhoff and Zauke 1997		No	Exposure to mixture of metals and effects not linked to tissue residues
Ceriodaphnia dubia (cadoceran)	Reproduction	25% reduction in number of offspring produced in 7 days	3.8	-	no	3.8	-	ne	ne	Schwartz et al. 2004		No	Unable to review study- only could locate abstract from SETAC. Excluded because less than nutritional value of 5 mg/kg ww
Crassostrea virginica (Eastern oyster)	Mortality	50% mortality in 8 weeks, reduced growth, inhibited gametogenesis	44.8	3.23	yes	13.9	-	ne	ne	Mandelli 1975		No	Mortality data not attributed to chemical exposure only and tissue residues not dose responsive
Daphnia magna (cadoceran)	Mortality, Reproduction, Growth	mortality, number of offspring, biomass	16	-	no	16	-	water	21 days	Muyssen and Janssen 2007		No	Poor dose-response of tissue burdens and effects
Daphnia magna (Cladoceran)	Mortality	100% mortality	56.3	3.23	yes	17.4	-	ne	ne	Winner et al. 1977		No	Unable to reproduce EPA LOAEL
Eudistylia vancouven (Polychaete)	Mortality	mortality, abandonment of burrows	50	3.23	yes	15.5	-	ne	ne	Young et al. 1981		No	LOAEL not based on whole body concentrations
Hyalella azteca (Amphipod)	Growth	ED25	13.3	-	no	13.3	-	ne	ne	Borgmann and Norwood 1997		No	High concentrations in background
Hydra littoralis (hydra)	Mortality, Reproduction	40% decrease in number of organisms	4.2	3.23	yes	1.3	-	water	11 days	Stebbing and Pomroy 1978[a]		No	LOAEL < nutritional requirement of 2.2 mg/kg-ww
Macoma balthica (macoma)	Mortality	28% mortality	13.0	3.23	yes	4.0	-	water	17 days	Absil et al. 1996		No	LOAEL < nutritional requirement of 5 mg/kg-ww
Mysis sp. (shrimp)	Mortality	66.7% mortality	5.9	3.23	yes	1.8	-	water	96 hours	Zyadah and Abdel-Baky 2000[a]		No	LOAEL < nutritional requirement of 5 mg/kg-ww
Mytilus edulis (Mussel)	Growth	reduced growth rate	4.3	-	no	4.3	-	water	41 days	Grout and Levings 2001		No	Exposure to multiple metals in the field. Excluded because less than nutritional value of 5 mg/kg ww
Soletellina alba (bivalve)	Mortality	mortality	8	3.23	yes	2.5	2.5	sediment	10 days	King et al. 2004		No	LOAEL < nutritional requirement of 5 mg/kg-ww
Tellina tenuis (clam)	Growth	decreased growth, condition factor, and carbohydrate and N content	54	-	no	54	-	ne	ne	Saward et al. 1975		No	Tissue residues are not dose-responsive with effects
Themisto abyssorum (amphipod)	Mortality	LD50	374	3.23	yes	115.8	-	ne	ne	Ritterhoff and Zauke 1997		No	Exposure to mixture of metals and effects not linked to tissue residues
Themisto libellula (amphipod)	Mortality	LD50	374	3.23	yes	115.8	-	ne	ne	Ritterhoff and Zauke 1997		No	Exposure to mixture of metals and effects not linked to tissue residues

na - not applicable; study not acceptable for inclusion in SSD derivation
ne - test condition data not collected from studies not included in LWG's SSD
[a] Not reviewed as part of EPA's TRV final list; based on LWG review

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Zinc

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Chaetocorophium cf lucasi (amphipod)	Mortality	32% mortality over control	148	2	yes	74	74	sediment	10 days	King et al. 2005	only one exposure concentration tested	Yes	
Chironomus riparius (midge)	Growth	decrease in growth	110	-	no	110	110	water	4 weeks	Timmermans et al. 1992	LOAEL and estimated from graph at 7 days, where growth effect was interpreted from graph; statistical significance of growth effect not discussed	Yes	
Corbicula sp. (Asiatic clam)	Growth	reduction in growth	86.6	-	no	86.6	86.6	water	30 days	Farris et al. 1989	reduced length and weight gain about 44-46% compared to control; change in length was significantly different from control	Yes	
Daphnia magna (cladoceran)	Reproduction, Growth	decreased reproduction and growth	93.6	-	no	93.6	51.2	water	8 days	Muyssen and Janssen 2002	LOAEL based on adult concentration in daphnids; effects were reported as "toxicity" and in the discussion as decrease in reproduction, growth, and energy content	Yes	
Daphnia magna (cladoceran)	Mortality, Reproduction, Growth	reduced survival number of offspring, and biomass	28	-	no	28	-	Water	21 days	Muyssen and Janssen 2007	LOAEL estimated from graph; significant effects observed	Yes	
Dreissena polymorpha (zebra mussel)	Behavior	29% decrease in filtration rate	120	-	no	120	69	water	10 weeks	Kraak et al. 1994a	tissue residue at 56% mortality = 600 mg/kg ww; control mortality = 8%	Yes	
Dreissena polymorpha (zebra mussel)	Behavior	60% decrease in filtration rate	40	-	no	40	-	Water	48 hours	Kraak et al. 1994b		Yes	
Ephemerella grandis (mayfly)	Mortality	Increased mortality	472	2	yes	236	236	water	14 days	Nehring 1976	uncertainty associated with the value because it is based on a TL50 for 14 days > 9.2 mg/L (unknown how many died -only that the TL50 could not be calculated).	Yes	
Hyale crassicornis (amphipod)	Mortality	35% mortality over control	122	2	yes	61	61	sediment	10 days	King et al. 2005	only one exposure concentration tested	Yes	
Hyale longicornis (amphipod)	Mortality	30% mortality over control	46	2	yes	23	23	sediment	10 days	King et al. 2005	only one exposure concentration tested	Yes	
Hyalella azteca (amphipod)	Mortality	38% mortality over control	27.2	-	no	27.2	27.2	water	10 weeks	Borgmann et al. 1993		Yes	
Leptoxis praerosa (snail)	Mortality	30% mortality	20	-	no	20	20	water	114 days	Reed-Judkins et al. 1997	mortality observed at day 90	Yes	
Melita awa (amphipod)	Mortality	75% mortality over control	74	2	yes	37	37	sediment	10 days	King et al. 2005	only one exposure concentration tested	Yes	
Melita plumulosa (amphipod)	Mortality	approximately 30% mortality	43	2	yes	22	22	sediment	10 days	King et al. 2006	control mortality =10%; LOAEL estimated from graph based on adult amphipod tissue	Yes	
Mytilus edulis (mussel)	Mortality	100% mortality	140	2	yes	70	70	diet	14 days	Burbidge et al. 1994	LOAEL based on depurated concentration	Yes	
Mytilus galloprovincialis (blue mussel)	Growth	abnormal development of straight hinge veliger larvae	159	-	no	159	159	water	48 hours	Pavicic et al. 1994	LOAEL based on Zn exposure concentration (0.4 mg/L) and CF (398.7) reported in study; uncertainty because not known whether CF is based on ww conc or how CF was derived	Yes	
Paracentrotus lividus (sea urchin)	Growth	occurrence of developmental abnormalities	41	-	no	41	41	water	48 hours	Radenac et al. 2001	significantly higher abnormalities observed (13.8% at LOAEL vs. 7.9% in control)	Yes	

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Zinc

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Pteronarcys californica (stonefly)	Mortality	Increased mortality	112	2	yes	56	56	water	14 days	Nehring 1976	uncertainty associated with the value because it is based on a TL50 for 14 days > 13.9 mg/L (unknown how many died -only that the TL50 could not be calculated).	Yes	
Soletellina alba (bivalve)	Mortality	70% mortality	160	2	yes	80	80	water	96 hr	King et al. 2004	mortality and tissue concentration estimated from graph; control mortality = <5%	Yes	
Tellina deltoidalis (bivalve)	Mortality	15% mortality	80	2	yes	40	40	sediment	10 days	King et al. 2004	significant reduction in survival after 10 days sediment exposure at LOAEL; Concentration read from a graph.	Yes	
Acartia sp (copepod)	Reproduction	decreased egg production	1.3	-	no	1.3	-	diet	4 hours	Hook and Fisher 2002		No	LOAEL < nutritional requirement (20 mg/kg ww)
Allorchestes compressa (amphipod)	Mortality, Growth	reduced body weight, biomass, survival	28	-	no	28	-	water	4 weeks	Ahsanullah and Williams 1991		No	No dose-response in tissue concentrations
Calanus hyperboreus (copepod)	Mortality	LD50	1750	2	yes	875	-	water	24-96 hours	Ritterhoff and Zauke 1997		No	Exposure to mixture of metals and effects not linked to tissue residues
	Mortality	LD50	2980	2	yes	1490	-	water	24-96 hours	Ritterhoff and Zauke 1997		No	Exposure to mixture of metals and effects not linked to tissue residues
	Reproduction	25% reduction in number of offspring produced in 7 days	50	-	no	50	-	ne	ne	Schwartz et al. 2004		No	Unable to review study- only could locate abstract from SETAC
Chironomus decorus (midge)	Growth	38% reduction in body weight	275	-	no	275	-	water	10 days	Bidwell and Gorrie 2006		No	Exposure to mixture of metals
Chironomus riparius (midge)	Mortality, Growth	increased mortality, reduced weight of larvae	86.3	-	no	86.3	-	water	field exposure	Groenendijk et al. 1999		No	Field study with exposure to different chemical
Chironomus tentans (midge)	Development	increase in larvae deformities	34.8	-	no	34.8	-	ne	4-6 weeks	Martinez et al. 2001		No	LOAEL not based on WB concentration and questionable endpoint relevance of endpoint to growth, survival, and reproduction
Daphnia magna (cladoceran)	Reproduction	reduction in no. juveniles per adult	11.1	-	no	11.1	-	food	21 days	De Schamphelaere et al. 2004		No	LOAEL < nutritional requirement (20 mg/kg ww); Study methods and results not acceptable for deriving LOAEL
Daphnia magna (cladoceran)	Mortality	Lethal body burden after 21 day exposure	2690	2	yes	1345	-	water	21 days	Enserink et al. 1991		No	Exposure to mixture of metals
Daphnia magna (cladoceran)	Mortality	Lethal to 50% of animals in 48 hours	115	2	yes	57.5	-	ne	ne	Schwartz et al. 2004.		No	Unable to review study- only could locate abstract from SETAC
Gammarus pulex (amphipod)	Mortality	increased mortality	90	2	yes	45	-	water	26 days	Xu and Pascoe 1993		No	Insufficient effects data presented
Haliotis diversicolor (abalone)	Mortality	Lethal body burden	198	2	yes	99	-	ne	7 days	Liao et al. 2002		No	Field study with exposure to different chemical
Hyalella azteca (amphipod)	Mortality	LB25	19.5	-	no	19.5	-	water	10 weeks	Borgmann and Norwood 1997a		No	LOAEL < nutritional requirement (20 mg/kg ww)

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Zinc

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Hydropsyche betteni (caddisfly)	Growth	Statistically significant weight reduction (13%) after 48 days	515	-	no	515	-	water	48 days	Balch et al. 2000		No	Field study
Melita matilda (amphipod)	Mortality	30% mortality over control	28	2	yes	14	-	sediment	10 days	King et al. 2005		No	LOAEL < nutritional requirement (20 mg/kg ww)
Mysella anomala (bivalve)	Mortality	28% mortality	18	2	yes	9.0	-	water	96 hr	King et al. 2004		No	LOAEL < nutritional requirement (20 mg/kg ww)
Mytilus edulis (mussel)	Growth	reduced growth	25	-	no	25	-	ne	ne	Grout and Levings 2001		No	Unable to review study- do not have full citation of reference
Orconectes virilis (crayfish)	Mortality	23% mortality	35.2	2	yes	17.6	-	water	2 weeks	Mirenda 1986		No	
Themisto abyssorum (amphipod)	Mortality	LD50	951	2	yes	476	-	water	24-96 hours	Ritterhoff and Zauke 1997		No	Exposure to mixture of metals and effects not linked to tissue residues
Themisto libellula (amphipod)	Mortality	LD50	951	2	yes	476	-	water	24-96 hours	Ritterhoff and Zauke 1997		No	Exposure to mixture of metals and effects not linked to tissue residues

na - not applicable; study not acceptable for inclusion in SSD derivation
ne - test condition data not collected from studies not included in LWG's SSD

Summary of Benthic Invertebrate Tissue-based Toxicity Values for TBT

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Armandia brevis (polychaete)	Growth	reduction in weight	0.54	-	no	0.54	0.54	sediment	42 days	Meador and Rice 2001	10.2% reduction (significant reduction) in animal weight compared to controls	Yes	
Armandia brevis (polychaete)	Mortality	LD50	20.56	12.69	yes	1.6	-	sediment	10 days	Meador et al. 1997	control mortality was high - 25% at 10 days; study reports that LD50 was corrected (increased) by adding control mortality to offset non-toxicant mortality	Yes	
Armandia brevis (polychaete)	Mortality	LC50	9.4	12.69	yes	0.74	-	water	10 days	Meador 1997	estimated from dw using 20% solids; 0% mortality in control	Yes	
Crassostrea gigas (Pacific oyster)	Growth	Growth	1.30	-	no	1.30	1.30	water and sediment	56 days	Waldock and Thain 1983	reduction in body weight gain, length gain, and condition index compared to control; 53% less increase in wet weight after 56 days exposure.	Yes	
Eohaustorius estuarius (amphipod)	Mortality	LD50	7.00	12.69	yes	0.55	0.55	water	10 days	Meador 1993	estimated from dw using 20% solids; study also cites another 10d LC50 = 11.8 mg/kg ww	Yes	
Eohaustorius washingtonianus (amphipod)	Mortality	LC50	9.03	12.69	yes	0.71	2.3	water	10 days	Meador 1997	estimated from dw using 21% solids	Yes	
Eohaustorius washingtonianus (amphipod)	Mortality	LD50	7.20	-	no	7.2	-	sediment	41 days	Meador et al. 1997	control mortality was high - 32% and 15% at 41 and 9 days, respectively; study reports that LD50 was corrected (increased) by adding control mortality to offset non-toxicant mortality	Yes	
Hinia reticulata (netted dogwhelk)	Reproduction	imposex	0.045	-	no	0.045	0.045	field exposure and water exposure in lab	field collected and 5 months in lab	Stroben et al. 1992	RPS was 42-48% at 3 to 5 months exposure to 50 ng/; tissue concentrations range from 225 to 355 ppb dw = 0.045 to 0.071 mg/kg ww	Yes	
Hyalella azteca (amphipod)	Reproduction	50% reduction in number of offspring after 10 weeks	0.28	-	no	0.28	0.28	sediment	10 weeks (2 generations)	Bartlett et al. 2004	reproductive effect was expected to be statistically significant (a 50% decrease in F0 generation).	Yes	
Hyalella azteca (amphipod)	Mortality	LC50	6.4	-	no	6.4	-	water	4 weeks	Borgmann et al. 1996	LOAEL is 4wk LC50 for young (0-1 wk old at start of experiment); body concentrations calculated not measured; 1wk LC50 for adults = 23 mg/kg ww TBT	Yes	
Mya arenaria (soft shell clam)	Growth	decrease in condition index	2.90	-	no	2.90	2.90	water	28 days	Kure and Depledge 1994	condition index ~ 77% of control	Yes	
Mytilus edulis (mussel)	Growth	significant reduction in scope of growth	1.79	-	no	1.79	1.40	water	36 hours	Page et al. 1998		Yes	
Mytilus edulis (mussel)	Growth	significant reduction in scope of growth	1.09	-	no	1.09	-	water	96 hours	Widdows and Page 1993	decline in feeding clearance rate at concentration of 0.79 mg/kg ww TBT	Yes	
Neanthes arenaceodentata (neanthes)	Reproduction, Growth	Reproduction, Growth	1.25	-	no	1.25	1.25	water	10 weeks	Moore et al. 1991	at LOAEL, 32% reduction in growth compared with control and a reproductive success of 52% compared to 90% in the controls; reproductive success defined as number of pairs successfully depositing all eggs within their tube	Yes	

Summary of Benthic Invertebrate Tissue-based Toxicity Values for TBT

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Nucella lapillus (Atlantic dogwinkle)	Reproduction	imposex	0.12	-	no	0.12	0.10	water	2 years	Gibbs et al. 1988	LOAEL based female tissue concentration where 1/3 of the females were sterile (Stage 5 or 6) at 24 months; 100% sterilization at 0.28 mg/kg ww	Yes	
Nucella lapillus (Atlantic dogwinkle)	Reproduction	imposex	0.23	-	no	0.23	-	field exposure and water exposure in lab	field collected and 6 months in lab	Stroben et al. 1992	RPS is 40% after 6 months exposure to 100 ng/l.	Yes	
Nucella lapillus (Atlantic dogwinkle)	Reproduction	imposex	0.04	-	no	0.04	-	field collected organisms exposed in lab experiment	1 month	Bryan et al. 1987	field collected organisms with controls that were untreated; LOAEL based on a field collected population exposed in a tidal tank experiment with 22.5% of females reaching Stage 4	Yes	
Rhepoxynius abronius (amphipod)	Mortality	LD50	7.8	12.69	yes	0.61	1.01	water	4 days	Meador 1993	estimated from dw using 27% solids	Yes	
Rhepoxynius abronius (amphipod)	Mortality	LR50	14.60	12.69	yes	1.15	-	water	10 days	Meador 1997	estimated from dw using 27% solids	Yes	
Rhepoxynius abronius (amphipod)	Mortality	LD50	18.70	12.69	yes	1.47	-	sediment	10 days	Meador et al. 1997	control mortality was 5% at 10 days	Yes	
Scrobicularia plana (clam)	Mortality	100% mortality	4.8	-	no	4.8	4.8	sediment	40 days	Langston and Burt 1991	LOAEL is tissue concentration at 2 weeks in experimental group where all clams died in less than 14 days exposed to 10 mg/kg TBT in sediment; in a separate experiment where clams were exposed to 10 mg/kg TBT in sediment, tissue concentrations ranged from 30.5 to 36.6 mg/kg ww;	Yes	
Crassostrea gigas (Pacific oyster)	Growth	condition index	0.75	-	no	0.75	-	water	5 months	Davies et al. 1987		No	No control or reference group to compare severity of effects
Crassostrea gigas (Pacific oyster)	Growth	ED90	2.38	-	no	2.38	-	ne	ne	Thain 1986		No	Unable to review; do not have complete citation
	Reproduction	imposex	0.88	-	no	0.32	-	water	3 months	Schulte-Oehlmann et al. 1995		No	Level of imposex not at threshold to cause impairment to reproduction
	Growth	reduction in shell length and tissue wet weight	1.2	-	no	1.2	-	water (field exposed)	84 days (field exposure)	Salazar and Salazar 1998		No	Field study and no clear dose response in tissues
Mytilus edulis (mussel)	Growth	reduction in shell length, width, and body weight	0.65	-	no	0.65	-	water	50 days	Guolan and Yong 1995		No	LOAEL not based on whole body tissue concentration
not specified (benthic invertebrates)	Growth	growth impairment	3	-	no	3	-	ne	ne	Meador et al. 2002		No	LOAEL based on unspeciified species
Nucella lapillus (Atlantic dogwinkle)	Development	ED100	0.40	-	no	0.40	-	ne	ne	Bryan et al. 1988		No	Unable to review; do not have complete citation
Nucella lapillus (Atlantic dogwinkle)	Reproduction	Reproduction	0.40	-	no	0.40	-	ne	ne	Bryan et al. 1988		No	Unable to review; do not have complete citation

Summary of Benthic Invertebrate Tissue-based Toxicity Values for TBT

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Nucella lapillus (Atlantic dogwinkle)	Reproduction	impaired reproduction and development	0.03	-	no	0.03	-	ne	ne	Gibbs et al. 1987		No	Unable to obtain and review reference
Nucella lapillus (Atlantic dogwinkle)	Reproduction	imposex	0.07	-	no	0.07	-	water	12 weeks	Gibbs et al. 1991		No	Effect not linked to imposex and not control used
Nucella lapillus (Atlantic dogwinkle)	Reproduction	50% imposex	0.33	-	no	0.33	-	water	3 months	Santos et al. 2005		No	Level of imposex not at threshold to cause impairment to reproduction
Paracentrotus lividus (sea urchin)	Mortality	reduced cell proliferation, protein synthesis, delayed effect on survival	0.29	12.69	yes	0.02	-	water	4-6 hours	Girard et al. 2000		No	LOAEL based on egg residue
Thais clavigera (rock shell)	Development	Induction of imposex	0.02	-	no	0.02	-	water	3 months	Horiguchi et al. 1997		No	LOAEL based on secondary source (methods cannot be reviewed) and level of imposex not reported
Ilyanassa obsoleta (mud snail)	Reproduction	100% imposex	0.124	-	no	0.124	-	field study	field study	Bryan et al. 1989		No	Field study
Littorina littorea (periwinkle)	Reproduction	imposex	0.29	-	no	0.29	-	field-exposed	field collected snails	Bauer et al. 1997		No	Field study
Littorina littorea (periwinkle)	Reproduction	imposex	0.14	-	no	0.14	-	field-exposed	field collected snails	Oehlmann et al. 1998		No	Field study
Nassarius reticulatus (dogwelk)	Reproduction	imposex	0.034	-	no	0.034	-	sediment	field exposed	Barreiro et al. 2001		No	Field study
Nucella lapillus (dogwelk)	Reproduction	imposex	0.51	-	no	0.51	-	field-exposed	field collected snails	Bailey and Davies 1991		No	Field study
Nucella lapillus (Atlantic dogwinkle)	Reproduction	imposex	0.0338	-	no	0.03	-	field exposure	field exposure	Ruiz et al. 1998		No	Field study
Ocinebrina aciculata (snail)	Reproduction	imposex	0.22	-	no	0.22	-	field-exposed	field collected snails	Oehlmann et al. 1996		No	Field study

Spence et al. (1990) states that, in general, sterile females are absent at RPS indices below 5%, between 5 and 40% the percentage of sterility increases, and at RPS indices exceeding 40%, most or all females are sterile. The cut-off for VDS is stage 4.
na - not applicable; study not acceptable for inclusion in SSD derivation
ne - test condition data not collected from studies not included in LWG's SSD

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Phthalates

Species	Endpoint	Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Artemia sp. (brine shrimp)	Mortality, Behavior	increased mortality, erratic swimming	32,000	8.3	yes	3,855	3,855	water	8 hours	Hudson et al. 1981	approximately 22% mortality; LOAEL based on bioaccumulation factor (2300) and water concentration (13.9 mg/L)	Yes	
Gammarus pulex (amphipod)	Behavior	reduction in locomotor activity	32	-	no	32	-	water	10 days	Thuren and Woin 1991		No	Behavior endpoint not directly related to growth, survival, or reproduction
Palaemonetes pugio (grass shrimp)	Mortality	36-59% mortality	0.50	8.3	yes	0.06	-	water	35 days	Laughlin et al. 1978		No	LOAEL based on detection limit
Aeshna sp. (dragonfly)	Behavior	reduction in ability to capture prey	14.7	-	no	14.7	14.7	sediment	61 days	Woin and Larsson 1987	Approximately 20% reduction in ability to capture prey. Observed over 40 days after 3 weeks exposure to BEHP	Yes	
Daphnia magna (water flea)	Reproduction	60-62% inhibition in reproduction	3.12	-	no	3.12	3.12	water	21 days	Sanders et al. 1973	Tissue concentration was measured after 7 days and effects observed after 14-21 days. Based on Kow of 5.11 and dibutyl phthalate Kow of 4.6 and steady-state presented in the paper for dibutyl phthalate the value was deemed acceptable	Yes	
Gammarus pulex (amphipod)	Behavior	reduction in locomotor activity	1,998	-	no	1,998	-	water	10 days	Thuren and Woin 1991		No	Behavior endpoint not directly related to growth, survival, or reproduction

na - not applicable; study not acceptable for inclusion in SSD derivation

Summary of Benthic Invertebrate Tissue-based Toxicity Values for PCBs

Analyte	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Aroclor 1254	*Armandia brevis* (polychaete worm)	Growth	28% reduction in growth rate	35.8	-	no	35.8	35.8	sediment	28 days	Rice et al. 2000	28% decrease in growth rate compared to organisms exposed to reference sediment; not statistically evaluated	Yes	
Aroclor 1242	*Chironomus riparius* (midge)	Mortality	LR50	89	8.6	yes	10.3	10.3	not specified	4 days	Kwon and Fisher unpub	LOAEL based on live animal residues; reference is conference poster (2006)	Yes	
Aroclor 1254	*Crassostrea virginica* (Eastern oyster)	Growth	height and body weight after 6 wks	119	-	no	119	62	water	8 weeks	Lowe et al. 1972	significant decrease in growth; oysters were exposed to 5 ppb prior to experiment, then to 1 ppb during experiment; no effect on mortality	Yes	
Aroclor 1016	*Crassostrea virginica* (Eastern oyster)	Growth	38% reduction in shell growth	32	-	no	32	-	water	96 hours	Hansen et al. 1974	38% reduction in shell growth @ LOAEL (7.2 ug/L); 0% reduction in control	Yes	
Aroclor 1254	*Culex tarsalis* (mosquito)	Growth	failure of pupae to metamorphosize into adults	6	-	no	6	6	water	7 days	Sanders and Chandler 1972	LOAEL calculated from 7d biomagnification factor (20,000) and water conc (1.5 ppb)	Yes	
Aroclor 1268	*Daphnia magna* (waterflea)	Mortality	LR50	11.6	8.6	yes	1.3	-	not specified	4 days	Kwon and Fisher unpub	LOAEL based on live animal residues; reference is conference poster (2006)	Yes	
PCB 101[a]	*Daphnia magna* (waterflea)	Growth	reduction in biomass	0.6	-	no	0.6	0.6	water	21 days	Dillion et al. 1990	Directed by EPA to include this study	Yes	
Aroclor 1242	*Gammarus pseudolimnaeus* (amphipod)	Reproduction	38% reduction in reproduction	76	-	no	76	76	water	2 months	Nebeker and Puglishi 1974	endpoint is number of young per surviving adult (y/a); significance of effect not reported; control = 6.8 y/a, in organisms with 76 mg/kg ww = 4.2 y/a (62% of control)	Yes	
Aroclor 1016	*Limulus polyphemus* (horseshoe crab)	Mortality	≥50% mortality	31.9	-	no	31.9	31.9	water	96 days	Neff and Giam 1977	LOAEL based on surviving crab residues; control mortality = 1%	Yes	
PCB 153[b]	*Lumbriculus variegatus* (oligochaete)	Growth, Reproduction	reduced biomass and reproduction	126	-	no	126	126	diet	35 days	Fisher et al. 1999		Yes	
PCB mixture[a]	*Nereis diversicolor* (polychaete)	Mortality	lethal body burden	200	-	no	200	200	sediment	90 days	Fowler et al. 1978	Directed by EPA to include this study	Yes	
Aroclor 1254	*Palaemonetes pugio* (grass shrimp)	Mortality	45% mortality	27	8.6	yes	3.1	0.63	water	16 days	Nimmo et al. 1974	high mortality (25%) mortality in control; significant mortality observed at LOAEL compared to control	Yes	
Aroclor 1016	*Palaemonetes pugio* (grass shrimp)	Mortality	33% mortality	1.1	8.6	yes	0.13	-	water	96 hours	Hansen et al. 1974	8% mortality in control	Yes	
Aroclor 1016	*Penaeus aztecus* (brown shrimp)	Mortality	43% mortality	42	8.6	yes	4.9	4.9	water	96 hours	Hansen et al. 1974	0% mortality in control	Yes	
Aroclor 1254	*Penaeus duorarum* (pink shrimp)	Mortality	72% mortality	33	8.6	yes	3.8	3.8	water	20 days	Duke et al. 1970	LOAEL based on live shrimp residues in the only dose group (5 ug/l) (tissue residue in dead shrimps = 16 mg/kg ww); 48hr LOAEL with 100% mortality = 4.2 mg/kg ww	Yes	

Summary of Benthic Invertebrate Tissue-based Toxicity Values for PCBs

Analyte	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
PCB 47	*Ampelisca abdita* (amphipod)	Mortality	LR50	166	8.6	yes	19.3	-	sediment	10 days	Fay et al. 2000		No	This study was not included because the congener did not meet the criteria for significance presence in Portland Harbor
PCB 47	*Artemia salina* (brine shrimp)	Growth	decreased growth and larval survival	5.4	-	no	5.4	-	ne	ne	Wang et al. 1998		No	This study was not included because the congener did not meet the criteria for significance presence in Portland Harbor
PCB 15[a]	*Chironomus riparius* (midge)	Reproduction	increased male development time to 2nd instar stage	415	-	no	415	-	ne	ne	Hwang et al. 2004		No	This study was not included because the congener did not meet the criteria for significance presence in Portland Harbor
PCB 77	*Daphnia magna* (waterflea)	Growth	reduction in biomass	11.4	-	no	11.4	-	water	21 days	Dillion et al. 1990		No	Congener 77 is a dioxin-like congenr and should therefore not be included in the SSD
PCB 1	*Lumbriculus variegatus* (oligochaete)	Growth, Reproduction	reduced biomass and reproduction	64.7	-	no	64.7	-	diet	35 days	Fisher et al. 1999		No	This study was not included because the congener did not meet the criteria for significance presence in Portland Harbor
PCB 47	*Lumbriculus variegatus* (oligochaete)	Growth, Reproduction	reduced biomass and reproduction	113	-	no	113	-	diet	35 days	Fisher et al. 1999		No	This study was not included because the congener did not meet the criteria for significance presence in Portland Harbor
PCB 15	*Lumbriculus variegatus* (oligochaete)	Growth, Reproduction	reduced biomass and reproduction	119	-	no	119	-	diet	35 days	Fisher et al. 1999		No	This study was not included because the congener did not meet the criteria for significance presence in Portland Harbor

na - not applicable; study not acceptable for inclusion in SSD derivation
ne - test condition data not collected from studies not included in LWG's SSD
[a] study was included per directive from EPA
[b] PCB congener was included in the SSD if the mean percent contribution of the congener in tissue was > 5% and the detection frequency was > 5%

Summary of Benthic Invertebrate Tissue-based Toxicity Values for DDD

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Diporeia sp. (amphipod)	Mortality	immobility (narcosis)	37.4	8.3	Yes	4.5	4.5	water	10 days	Lotufo et al. 2000a	organisms exposed to p,p'-DDD; LOAEL is ER50 based on narcosis; LR50 = 84.2 mg/kg ww	Yes	
Hyalella azteca (amphipod)	Mortality	LR50	15	8.3	Yes	1.81	1.81	water	10 days	Lotufo et al. 2000a	organisms exposed to p,p'-DDD	Yes	
Polycelis felina (planaria)	Reproduction	reduction in asexual fission and number of individuals	2.77	-	No	2.77	-	water	14 days	Kouyoumjian and Villeneuve 1979		No	problematic data reporting; residue data in control is higher than experimental organism and residues include both WB tissues and headless (regenerating) worms; organisms exposed to p,p'-DDT and cannot attribute toxicity just to DDD

Lotufo et al. 2000a - "Comparative toxicity and toxicokinetics of DDT and its major metabolites in freshwater amphipods"
na - not applicable; study not acceptable for inclusion in SSD derivation
ne - test condition data not collected from studies not included in LWG's SSD

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Total DDx

Analyte	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
DDTs	*Daphnia magna* (cladoceran)	Mortality	immobility (narcosis)	128	8.3	Yes	15	15	water	26 hours	Crosby and Tucker 1971	organisms exposed to p,p'-DDT and tissue measured for DDT only; LOAEL based on <4% dead and 64% immobile	Yes	
DDTs	*Diporeia* spp. (amphipod)	Mortality	immobility (narcosis)	5.0	-	No	5.0	5.4	water	28 days	Lotufo et al. 2000a	organisms exposed to p,p'-DDT; LOAEL is ER50 based on narcosis; LR50 = 15.6 mg/kg ww; Transformation products were not determined for the ER50 but at an exposure concentration less than the ER50 the fractions were determined after 28 days: DDT = 95.7%, DDD = 4.0% and polar metabolites = 0.03%	Yes	
DDTs	*Diporeia* spp. (amphipod)	Mortality	LR50	5.9	-	No	5.9	-	sediment	28 days	Lotufo et al. 2001a	organisms exposed to p,p'-DDT; LOAEL is 28 day LR50 based on DDT equivalents (total DDTs); significant mortality (60%) with DDT equivalent concentration of 9.1 mg/kg ww	Yes	
DDTs	*Heteromastus filiformis* (polychaete)	Behavior, Growth	reduced feeding rate and body weight	1.4	-	No	1.4	1.4	sediment	64 days	Mulsow et al. 2002	organisms exposed to DDT; body weight reduced to 66% of control; tissue measured for DDT only. The paper refers to another paper (Mulsow 1995 - BSAF0027) where they state " the sum of both extractable and non-extractable DDT was used as total DDT concentration"	Yes	
DDTs	*Hyalella azteca* (amphipod)	Mortality	LR50	2.1	8.3	Yes	0.26	0.85	water	10 days	Lotufo et al. 2000a	organisms exposed to p,p'-DDT; LOAEL presented as DDT corrected for biotransformation products and total DDTs	Yes	
DDTs	*Hyalella azteca* (amphipod)	Mortality	LR50	2.8	-	No	2.8	-	sediment	28 days	Lotufo et al. 2001a	organisms exposed to p,p'-DDT; LOAEL is 28 day LR50 based on DDT equivalents (total DDTs); mortality (51%) with DDT equivalent concentration of 2.4 mg/kg ww	Yes	
DDTs	*Leptocheirus plumulosus* (amphipod)	Mortality	LR50	2.7	-	No	2.7	2.7	sediment	28 days	Lotufo et al. 2001b	organisms exposed to p,p'-DDT; LOAEL based on DDT equivalents (total DDTs)	Yes	
DDTs	*Neanthes arenaceodentata* (polychaete)	Growth	50% reduction in growth	35.5	-	No	35.5	35.5	diet	28 days	Lotufo et al. 2000b	organisms exposed to p,p'-DDT; LOAEL based on figure; worm growth significantly affected; residues presented as DDT on the figure; The fractions of DDT parent compounds were presented based on 3 experiments exposed to the LOEL diet concentration.	Yes	
DDTs	*Calanus finmarchicus* (copepod)	Behavior	erratic behavior, reduced mobility	20.8	-	No	20.8	-	ne	ne	Harding and Vass 1977		No	unable to obtain and review reference

Summary of Benthic Invertebrate Tissue-based Toxicity Values for Total DDx

Analyte	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt)	ACR	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt)	Final Species LOAEL (mg/kg wet wt)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
DDTs	*Callinectes sapidus* (blue crab)	Growth	Growth	0.82	-	No	0.82	-	diet	5 weeks	Leffler 1975	organisms exposed to p,p'-DDT; fed contaminated food for 2-4 weeks and fed uncontaminated food for one additional week with test on limb autotomization conducted in hot water; residues measured after limb testing once they were killed immediately; residues NOT presented with dose and effects data; LOAEL based on statement in text that this residue caused some inhibition of limb autonomy in response to hot water (<2	No	data with corresponding residues and effects not reported; anecdotal effects (limb regeneration in hot water) not relevant effect (no effect observed on limb regeneration of damaged limbs)
DDTs	*Heteromastus filiformis* (polychaete)	Behavior	reduced defecation	5.9	-	No	5.9	-	sediment	28 days	Mulsow and Landrum 1995	organisms exposed to DDT; reduction in defacation rate was significant at 28 days	No	endpoint (reduced (fecal pellet production) not directly related to growth, mortality or reproduction
DDTs	*Heteromastus filiformis* (polychaete)	Behavior	altered behavior	10.8	-	No	10.8	-	ne	ne	Landrum et al. 2004		No	endpoint (reduced (fecal pellet production) not directly related to growth, mortality or reproduction
DDTs	*Penaeus duorarum* (pink shrimp)	Mortality	30% mortality	0.06	-	No	0.06	0.06	water	56 days	Nimmo et al. 1970	organisms exposed to DDT; control mortality = 17%; LOAEL based on total DDT concentration; the study attribute mortality at 56 days in part to stress related to laboratory confinement and no statistical analysis was performed to establish that the treatment effect (30% mortality) is statistically significant relative to the control effect (17% mortality); field collected shrimp had tissue residues that meet or exceed the concentrations measured in the treated shrimp, which would suggest that mortality might be due to the stress of prolonged confinement	No	Problematic effects and exposure tissue concentration data
DDTs	*Polycelis felina* (planaria)	Reproduction	threefold reduction in asexual fission, number of individuals	77.5	-	No	77.5	-	water	14 days	Kouyoumjian and Villeneuve 1979	organisms exposed to p,p'-DDT and the tissue was analyzed for DDT, DDD, and DDE; LOAEL based on DDT residue	No	Problematic data reporting; residue data in control is higher than experimental organism and residues include both WB tissues and headless (regenerating) worms

Lotufo et al. 2000a - "Comparative toxicity and toxicokinetics of DDT and its major metabolites in freshwater amphipods"

Lotufo et al. 2000b - "Effect of exposure source, worm density, and sex on DDT bioaccumulation and toxicity in the marine polychaete, *Neanthes arenaceodentata"*

Lotufo et al. 2001a - "Toxicity and bioaccumulation of DDT in freshwater amphipods in exposures to spiked sediments"

Lotufo et al. 2001b - "DDT toxicity and critical body residue in the amphipod *Leptocheirus plumulosus* in exposed to spiked sediment"

DDD – dichlorodiphenyldichloroethane

DDE – dichlorodiphenyldichloroethylene

DDT – dichlorodiphenyltrichloroethane

DDX – DDD, DDE, DDT, or any combination thereof

ne - test condition data not collected from studies not included in LWG's SSD

Fish Tissue TRV Summary Table

Chemical	Tissue Concentration mg/kg ww			
	Screening Value	5th Percentile	10th Percentile	LOAEL
Aluminum[1]	33	nav[1]	nav[1]	nav[1]
Antimony	0.03	nc	nc	9
BEHP	0.39	nc	nc	nc[a]
Cadmium	0.09	0.17	0.22	nap
Chromium	0.69	nc	nc	44.1
Copper	3.1	2.8	3.1	nap
total DDx	0.29	0.76	1.6	nap
Lead	2.2	nc	nc	4
Lindane	0.023	nc	nc	0.2
Mercury	0.46	0.37	0.44	nap
PCBs	0.72	0.43	0.93	nap
Zinc	27	nc	nc	36

nap: not applicable - sufficient data for SSD

nc: not calculated - insufficient data

a Only one study was identified and LOAEL was unacceptable

[b] EPA notes 4 mg/kg in table but 0.4 in text describing the TRV derivation

[1] EPA indicated in a 10/10/08 e-mail from E. Blischke to J. Toll that "aluminum can be eliminated from further consideration through the refined screen process for the tissue residue line of evidence."

Summary of Fish Tissue-based Toxicity Values for Cadmium

8.3

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Danio rerio (zebrafish)	Reproduction	50% reduction in number of offspring	1.02	No	1.02	1.02	diet	6 months	Rehwoldt and Karimian-Teherani 1976	LOAEL based on median residues in adult males at 2.5 months when effect observed (LOAEL at end of 6 month exposure period = 1.04 mg/kg ww where effect was still reduced)	Yes	
Fundulus heteroclitus (mummichog)	Mortality	lethal body burden	31	Yes	3.7	3.7	water	11 days	Eisler 1971	LOAEL is low range (31 - 1288 mg/kg ww) of residues in fish that died within 11 day exposure period	Yes	
Gasterosteus aculeatus (three-spined stickleback)	Mortality	80% mortality	0.51	No	0.90	0.90	water	79 days	Pascoe and Mattey 1977	Authors subtracted control residues from reported LOAEL	Yes	
Gobio gobio (gudgeon)	Mortality	lethal body burden	1.4	No	1.4	1.4	water	33 days	Knapen et al. 2004	LOAEL based on fish from a reference lake in field experiment where Zn concentrations in water and sediment were 113 ug/L and 117 ug/g, respectively; LOAEL based on chronic experiment and read from graph	Yes	
Jordanella floridae (American flagfish)	Growth	reduction in female body length	4	No	4	0.7	water	2 generations	Spehar 1976	female growth was significantly reduced in fish exposed to 16 ug/L; LOAEL based on 100 day residues; unclear whether tissue concentrations reported in dw or ww; assumed dw	Yes	
Jordanella floridae (American flagfish)	Mortality	24% ave mortality (F0) and 25% ave morality (F1)	5.6	Yes	0.7		water	30 days	Spehar et al. 1978	LOAEL read from graph and is WB concentration at 30 days; fish initially exposed as embryos	Yes	
Lates calcarifer (seabass)	Mortality	reduced survival	20.4	Yes	2.46	2.46	water	16 days	Shazili 1995	sac-fry study	Yes	
Leiostomus xanthurus (spot)	Mortality	LC50	8.3	Yes	1.0	1.0	ne	200 hours	Middaugh et al. 1975	sac-fry study	Yes	
Lepomis macrochirus (bluegill)	Mortality, Behavior	50% mortality, erratic swimming behavior loss of equilibrium	0.21	No	0.21	0.21	water	6 months	Cearley and Coleman 1974	LOAEL read from graph; behavior anecdotally reported and not statistically evaluated	Yes	
Morone saxatilis (striped bass)	Mortality	increased mortality	2.9	Yes	0.35	0.35	ne	120 hrs	Wright et al. 1985		Yes	
Oncorhynchus mykiss (rainbow trout)	Behavior	eliminated predator avoidance behavior, inhibited cortisol release	0.02	No	0.02	-	ne	1 week	Scott et al. 2003	tissue residues not related to effect (not dose-responsive towards effect)	Yes	
Oncorhynchus mykiss (rainbow trout)	Mortality	90% mortality within 6 days	1.84	Yes	0.22	0.36	water	29 days	Pascoe et al. 1986	LOAEL is based on exposure to 1 mg/L Cd in soft water at end of experiment; 30% mortality in hard water with residues of 1.64 mg/kg ww	Yes	
Oncorhynchus mykiss (rainbow trout)	Mortality, Behavior	survival reduced, impaired swimming, lower Ca influx	0.60	No	0.60	-	water	30 days	Hollis et al. 2000		Yes	
Salmo salar (Atlantic salmon)	Growth	80-94% mortality, reduction in growth	0.48	No	0.48	0.24	water	30 days	Peterson et al. 1983	LOAEL read from graph and is WB tissue concentration at 27 days; ACR not applied because growth also evaluated	Yes	

Summary of Fish Tissue-based Toxicity Values for Cadmium

8.3

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Salmo salar (Atlantic salmon)	Growth	reduction in growth	0.12	No	0.12		ne	ne	Rombough and Garside 1982	alevin residues estimated from graph dw converted to ww assuming 20% solids	Yes	
Salvelinus fontinalis (brook trout)	Growth	decreased weight gain	0.25	No	0.25	0.21	water	3.5 years	Benoit et al. 1976	effect weight gain at 12 weeks in F3 generation	Yes	
Salvelinus fontinalis (brook trout)	Growth	28% reduction in body weight and 37% mortality	0.183	No	0.18		water	55 days	Hansen et al. 2002	control mortality = <1%; study states that [Cd] in WB residues does not accumulate to critical lethal body residues "since a slower rate of accumulation can result in greater Cd tissue concentrations and lesser lethal effects than faster rates of accumulation"	Yes	
Salvelinus fontinalis (brook trout)	Mortality	20% mortality	144	No	144.00		water	30 days	Hamilton et al. 1987	LOAEL based on lowest exposure concentration (<3.6 ug/L); growth was not affected although mortality was significantly reduced; 2% mortality in controls; study does not clearly report whether LOAEL is in wet weight or dry weight; assumed wet weight	Yes	
Belone belone (garpike)	Behavior	Decreased heartbeat, abnormal pectoral fin movement	0.12	No	0.12	-	na	na	von Westernhagen et al. 1975	egg/embryo study through hatching; does not include sac-fry exposure or effects	No	LOAEL based on egg/embryo residue
Clupea harengus (herring)	Behavior	Increase in abnormal trembling of larvae	18.90	No	18.90	-	water	na	von Westernhagen et al. 1974	egg/embryo study through hatching; does not include sac-fry exposure or effects	No	LOAEL based on egg/embryo residue
Cyprinodon variegatus (sheepshead minnow)	Growth, Reproduction	decrease in length, overall delay in hatching time and premature hatching	0.50	No	0.50	-	na	na	Meteyer et al. 1988	effects are for ebryo stages prior to, or at hatch; 2 d post hatch accumulation data presented but no adverse effects reported	No	LOAEL based on egg/embryo residue
Fundulus heteroclitus (mummichog)	Mortality	50% mortality	6.5	No	6.5	-	injection	na	van den Hurk et al. 1998a		No	LOAEL based on injection exposure
Gasterosteus aculeatus (three-spined stickleback)	Mortality	LD10	0.75	Yes	0.09	-	water	7 days	Woodworth and Pascoe 1983		No	whole body data are not presented
Haemulon sciurus (bluestriped grunt)	Mortality	lethal body burden	6.6	Yes	0.80	-	injection	na	Hogstrand and Haux 1989		No	LOAEL based on injection exposure
Ictalurus punctatus (channel catfish)	Mortality	68% larval mortality	0.94	Yes	0.11	-	na	na	Birge et al. 1979		No	LOAEL based on egg/embryo residue
Morone saxatilis (striped bass)	Mortality	reduced larval survival	1.0	Yes	0.12	-	na	na	Wright 1988	sac-fry study; residue associated with adverse effects not clearly reported	No	mean residues at treatment levels can't be determined from data
Oncorhynchus mykiss (rainbow trout)	Mortality	reduced alevin survival	0.21	No	0.21	-	na	na	Beattie and Pascoe 1978	mortality effects are presented but can't be related to the tissue residues reported	No	NOERs but no LOAELs are reported

Summary of Fish Tissue-based Toxicity Values for Cadmium

8.3

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Oncorhynchus mykiss (rainbow trout)	Mortality	43.2% mortality	7.30	No	7.30	-	diet	30 days	Szebedinszky et al. 2001		No	whole body tissue residues not presented
Platichthys flesus (European flounder)	Reproduction	reduced viable hatch	21	No	21	-	na	na	Westerhagen and Dethlefsen 1995		No	Unable to obtain and review paper
Poecilia reticulata (guppy)	Growth	reduction in body length	1.0	No	1.0	-	diet	30 days	Hatakeyama and Yasuno 1982		No	effect was not persistent (fish recovered growth in subsequent sampling)
Puntius gonionotus (java barb)	Mortality	increased mortality	11.55	Yes	1.39	1.39	water	4 days	Mungkung et al. 2001		No	mortality data not reported; fish were exposed to 96 hr LC50 but mortality data were not reported
Rhamdia quelen (silver catfish)	Mortality	reduced larval survival	0.20	Yes	0.02	-	na	3 days	Benaduce et al. 2008	rejected because 85% mortality in controls	No	unacceptable control mortality
Salmo trutta (brown trout)	Mortality	100% mortality	1.33	Yes	0.16	-	injection	2 weeks	O'Neill 1981		No	LOAEL based on injection exposure

na - not applicable; study not acceptable for inclusion in SSD derivation

Summary of Fish Tissue-based Toxicity Values for Chromium

Cr ACR = 8.3

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Fundulus heteroclitus (mummichog)	Growth	15% reduction in larval growth	44.1	No	44.1	44.1	water	30 days	Roling et al. 2006		Yes	
Oncorhynchus mykiss (rainbow trout)	Mortality	50% mortality	2.8	No	2.8	-	water	36 days	Fromm and Stokes 1962		No	no controls were used
Oncorhynchus mykiss (rainbow trout)	Mortality	25% mortality	8.7	Yes	1.05	-	water	2-4 days	van der Putte et al. 1981		No	application of ACR results in LOAEL < no effect tissue residues reported in study; no controls used
Oncorhynchus tshawytscha (chinook salmon)	Mortality	70% mortality	1.3	No	1.3	1.3	water	134 days	Farag et al. 2006		No	tissue residues not dose responsive

Summary of Fish Tissue-based Toxicity Values for Copper

3.23

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Chelon labrosus (grey mullet)	Growth, Behavior	43% reduction in growth rate; 29% reduction in food intake	4.59	No	4.6	4.6	diet	10 weeks	Baker et al. 1998	additional effects included: induced hepatic lipid peroxidation	Yes	na
Fundulus heteroclitus (mummichog)	Mortality	30% mortality	26.2	Yes	8.1	8.1	water	96 hour	Eisler and Gardner 1973	LOAEL based on surving tissue residues	Yes	na
Oncorhynchus mykiss (rainbow trout)	Mortality	31% mortality	4.48	No	4.5	4.5	diet + water	60 days	Mount et al. 1994	fish were also exposed to additional metals at low levels (Zn, Cd, and Pb); WB concentrations of these additional metals were: Cd = 0.6 mg/kg ww; Pb = 1.35 mg/kg ww, Zn = 104 mg/kg ww; no effect on survival was observed in fish with there WB concentrations and higher of Zn, Cd, and Pb; therefore, this mixture study was considered appropriate for use as Cu LOAEL because effects were assumed to be the result of Cu exposure	Yes	
Oreochromis niloticus (Nile tilapia)	Growth	reduced growth and condition factor	3.73	No	3.7	3.7	diet	7 weeks	Ali et al. 2003	additional effects included: biochemical and behavioral alterations	Yes	na
Salmo salar (Atlantic salmon)	Growth	approximate 27% growth reduction	3.1	No	3.1	3.1	diet	12 weeks	Lundebye et al. 1999	fed 700 mg/kg Cu	Yes	
Cichlasoma nigrofasciatum (convict cichlid)	Reproduction	reduced hatching	125	No	125	-	water	ne	Ozoh and Jacobson 1979	sac-fry stage was not exposed	No	LOAEL based on egg/embryo residues
Clarias anguillaris (catfish)	Behavior	reduced feeding	3.1	No	3.1	-	water	8 weeks	Daramola and Oladimeji 1989		No	effects data not presented for each species and dose level; unable to quantify magnitude of effect
Cyprinus carpio (common carp)	Behavior	decreased swimming and catalase activity, liver necrosis, skin color change	10.0	No	10.0	-	injection	na	Varanka et al. 2001		No	LOAEL based on injected dose
Cyprinus carpio (common carp)	Mortality	22% mortality	11.7	Yes	3.6	-	water	na	Flik et al. 2002	some post-hatch exposure occurred but primarily exposed pre-hatch.	No	LOAEL based on egg/embryo residues
Cyprinus carpio (common carp)	Mortality	47% mortality	11.4	No	11.4	-	water	na	Stouthart et al. 1996	mortality endpoint is for eggs; ability to fill swim bladder is only sac-fry endpoint	No	LOAEL based on egg/embryo residues
Leiostomus solidissima (killifish)	Mortality	reduction in percent of live hatch	9.9	No	9.9	-	na	na	Dillon and Gibson 1985		No	secondary citation

Summary of Fish Tissue-based Toxicity Values for Copper

3.23

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Mugil cephalus (striped mullet)	Mortality	80-90% mortality	3.0	No	3.0	-	water	7 days	Zyadah and Abdel-Baky 2000		No	uncontrolled study
Oncorhynchus mykiss (rainbow trout)	Growth	reduced growth	2.0	No	2.0	-	water	60 days	Hansen et al. 2002		No	LOAEL < 2.2 mg/kg ww
Oncorhynchus mykiss (rainbow trout)	Growth	24% reduction body weight	0.91	No	0.91	-	water	60 days	Marr et al. 1996		No	LOAEL < 2.2 mg/kg ww
Oncorhynchus mykiss (rainbow trout)	Growth	reduced growth	2.0	No	2.0	-	water	78 days	Seim et al. 1984		No	LOAEL < 2.2 mg/kg ww
Oncorhynchus mykiss (rainbow trout)	Growth, Mortality	56% reduction in growth and 11% mortality	1.4	No	1.4	-	water + diet	28 days	Kamunde et al. 2005		No	LOAEL < 2.2 mg/kg ww
Oncorhynchus mykiss (rainbow trout)	Mortality	reduced survival	1.04	No	1.04	-	water	8 hours with 72 hours recovery	Handy 1992		No	LOAEL < 2.2 mg/kg ww
Oncorhynchus mykiss (rainbow trout)	Reproduction	40% reduction in viable hatch	121	No	121	-	na	na	Leland 1983		No	No residue data reported
Oreochromis niloticus (Nile tilapia)	Behavior	reduced feeding	6.9	No	6.9	-	water	8 weeks	Daramola and Oladimeji 1989		No	effects data not presented for each species and dose level; unable to quantify magnitude of effect
Pimephales promelas (fathead minnow)	Behavior	12% reduction in critical swimming speed, reduced whole body sodium	7.0	No	7.0	-	water	8 to 9 days	Kolok et al. 2002		No	Adverse effect not observed
Poecilia reticulata (guppy)	Behavior	reduced swimming speed, increased fin movement	7.25	No	7.3	-	water	8 days	Khunyakari et al. 2001		No	behavior effects not related to growth, mortality or reproduction
Salvelinus confluentus (bull trout)	Mortality	7% mortality	1.52	No	1.52	-	water	60 days	Hansen et al. 2002		No	LOAEL < 2.2 mg/kg ww

na - not applicable; study not acceptable for inclusion in SSD derivation

Summary of Fish Tissue-based Toxicity Values for Lead

8.3

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Pimephales promelas (fathead minnow)	Behavior	reduction in feeding rate and ability to capture and eat prey	26.2	No	26.2	26.2	water	4 weeks	Weber et al. 1991	Life stage = juvenile; significant reduction in feeding rate and ability to capture and eat prey	Yes	
Salvelinus fontinalis (brook trout)	Growth	body weight	4.02	No	4.02	4.02	water	3 generations/ 3 years	Holcombe et al. 1976	body weight significantly decreased in 12-wk old fish (F3) at 119 µg/L	Yes	
Carassius auratus (goldfish)	Mortality	reduced survival	180	Yes	21.7	-	water	96 hour	Coello and Khan 1996		No	no negative controls
Lepomis cyanellus (green sunfish)	Mortality	reduced survival	425	Yes	51.2	-	water	96 hour	Coello and Khan 1996		No	no negative controls
Micropterus salmoides (largemouth bass)	Mortality	reduced survival	25	Yes	3.0	-	water	96 hour	Coello and Khan 1996		No	no negative controls
Oncorhynchus mykiss (rainbow trout)	Mortality	Lethal body burden within 48 hours	2	Yes	0.24	-	na	48 hours	Bell et al. 1993		No	injection study; no tissue residue data presented
Salmo trutta (brown trout)	Mortality	100% mortality	3.0	No	3.0	-	IP injection	single inj + 7 wks	O'Neill 1981		No	LOAEL is injected dose; no tissue residue data presented

na - not applicable; study not acceptable for inclusion in SSD derivation

Summary of Fish Tissue-based Toxicity Values for Mercury

3.731

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Carassius auratus (goldfish)	Mortality	80% mortality	4.4	Yes	1.2	1.2	water	4 days	Heisinger et al. 1979	study looked at interactive effects of Hg and Se; increased mortality in Hg-only treatment; LC50 calculated; dw value converted to ww assuming 20% solids	Yes	
Gambusia affinis (mosquitofish)	Behavior	decreased ability to avoid predation	0.67	No	0.67	0.67	water	60 hours	Kania and O'Hara 1974		Yes	
Notemigonus crysoleucas (golden shiner)	Behavior	altered predator avoidance behavior	0.536	No	0.536	0.536	food	90 days	Webber and Haines 2003		Yes	
Oncorhynchus mykiss (rainbow trout)	Growth	recuced growth	10	No	10	3.0	diet	84 days	Rodgers and Beamish 1982	LOAEL based on text statement	Yes	
Oncorhynchus mykiss (rainbow trout)	Mortality	reduced survival	11.2	Yes	3.0		water	12-33 days	Niimi and Kissoon 1994		Yes	
Pimephales promelas (fathead minnow)	Growth	recuced growth	1.31	No	1.31	0.41	food	3 months	Snarski and Olson 1982		Yes	
Pimephales promelas (fathead minnow)	Reproduction	reduced spawning success	0.864	No	0.86		diet	250 days	Drevnick and Sandheinrich 2003		Yes	
Pimephales promelas (fathead minnow)	Reproduction	reduced spawning success	0.56	No	0.56		diet	>1yr	Hammerschmidt et al. 2002	LOAEL is average residue in male carcass; spawning success was 75% in control; no statistics	Yes	
Pimephales promelas (fathead minnow)	Reproduction	reduced spawning	0.143	No	0.143		diet	>21 days	Sandheinrich and Miller 2006		Yes	
Salvelinus fontinalis (brook trout)	Reproduction	reduction in reproduction	3.4	No	3.40	3.40	water	756 days	McKim et al. 1976	LOAEL measured in parental fish at 39 weeks	Yes	
Semotilus atromaculatus (creek chub)	Mortality	30% mortality	3.72	Yes	1.00	1.00		48 hours	Kim et al. 1977		Yes	
Anguilla anguilla (European eel)	Mortality	25% mortality	15.3	Yes	4.10	-	water	60 days	Noel-Lambot and Bouquegneau 1977		No	no controls were used in this study
Esox lucius (northern pike)	Growth	Lowered blood alkaline phosphatase, emaciation	7	No	7	-	na	na	Lockhart et al. 1972		No	field study; fish collected from a contaminated site
Esox lucius (northern pike)	Mortality	LD50	15	Yes	4.020369874	-	na	na	Miettinen et al. 1970		No	could not obtain paper for review

Summary of Fish Tissue-based Toxicity Values for Mercury

3.731

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Fundulus heteroclitus (mummichog)	Mortality	43% male mortality	0.47	No	0.47		diet	42 days	Matta et al. 2001		No	Reported mortality due to aggression within tanks and not a direct effect of Hg exposure. Aggressive behavior resulting in death of submissive fish is typical of killifish in aquaria. The behavior endpoint was not experimentally investigated so is not acceptable for TRV derivation (anecdotal).
Oncorhynchus mykiss (rainbow trout)	Behavior	lloss of equilibrium, skin darkening	19	No	19	-	diet	9 months	Matida et al. 1971		No	field study; fish exposed to prey from a contaminated site
Oncorhynchus mykiss (rainbow trout)	Mortality	LD50	11.9	Yes	11.9	-	na	na	Miettinen et al. 1970		No	could not obtain paper for review
Oncorhynchus mykiss (rainbow trout)	Mortality, Growth	60% mortality, reduced feeding, growth inhibition	11.2	No	11.2	-	water	83 days	Boudou and Ribeyre 1984		No	not clear that uncontaminated controls were used (based on extended abstract); in french
Pimephales promelas (fathead minnow)	Mortality	14% mortality	0.77	Yes	0.206378987	-	water	120-h	Handy 1995		No	no experimental controls were used; only pre-exposrue controls were used for tissue residues
Salmo trutta (brown trout)	Behavior	loss of equilibrium, abnormal swimming pattern	5	No	5	-	water	5 days	Skak and Baatrup 1993		No	behavior endpoint was not experimentally investigated and is not clearly linked to effects on growth, mortality, or reproduction
Thymallus thymallus (grayling)	Behavior	altered behavior	0.27	No	0.27	-	water	10 days	Fjeld et al. 1998		No	LOAEL based on egg tissues

na - not applicable; study not acceptable for inclusion in SSD derivation

Summary of Fish Tissue-based Toxicity Values for Zinc

2

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	LWG Notes	Used in LWG SSD derivation?	Reason for not using in SSD
Fundulus heteroclitus (mummichog)	Mortality	30% mortality	1,266	Yes	633	633	water	96 hours	Eisler and Gardner 1973	LOAEL based on tissue residues in dead fish; LOAEL in surviving fish = 1,502 mg/kg ww	Yes	
Jordanella floridae (American flagfish)	Growth, Mortality	reduced survival and female growth	44	No	44	36	water	2 generations	Spehar 1976	female growth was significantly reduced in fish exposed to 51 ug/L (and were not exposed as embryos); LOAEL based on 30 day residues; unclear whether tissue concentrations reported in dw or ww; assumed dry weight based on similar methods reported in Spehar et al. 1978 where residues were reported as dry weight	Yes	
Jordanella floridae (American flagfish)	Mortality	20% ave mortality (F0) and 23% ave morality (F1)	58	Yes	29		water	30 days	Spehar et al. 1978	no effects on growth after 100 days; LOAEL based on graph and based on WB concentration at 100 days; average control mortality = 15%	Yes	
Poecilia reticulata (guppy)	Growth	female body weight, number of females giving birth	415	No	297	297	water	134 days	Pierson 1981	values not significantly different from control according to paper statistics; however, they were 60% of the control value; LOAEL is an average female WB concentration of fish exposed to 0.605 and 0.609 mg/L	No	conclusions not supported by statistical analysis of data included in paper
Cichlasoma nigrofasciatum (zebra cichlid)	Reproduction	reduced hatching	36	No	36	-	water	na	Ozoh and Jacobson 1979	sac-fry stage was not exposed	No	LOAEL based on embryo tissue residues; no tissues residues reported in study
Gasterosteus aculeatus (threespine stickleback)	Mortality	increased mortality	270	Yes	135	-	water	approx. 24 hours	Matthiessen and Brafield 1977		No	no mortality observed and/or reported in paper
Jordanella floridae (American flagfish)	Growth	reduced growth	200	No	200	-	na	na	Dillon 1984		No	secondary citation; see Spehar (1976)
Mugil cephalus (striped mullet)	Mortality	70% mortality	23.1	Yes	11.6	-	water	up to 72 hrs	Zyadah and Abdel-Baky 2000		No	no control data used in study, methods for individual expsoure levels and experiments not reported

Summary of Fish Tissue-based Toxicity Values for Zinc

2

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	LWG Notes	Used in LWG SSD derivation?	Reason for not using in SSD
Oncorhynchus mykiss (rainbow trout)	Mortality	lethal body burden	5500	Yes	2750	-	water	96 hrs	Connolly 1985		No	no measured tissue residues; effects data from secondary source and residues predicted using modeling equation
Oncorhynchus mykiss (rainbow trout)	Reproduction	reduction in percent viable hatch	101	No	101	-	water	42 days	Leland 1983		No	no tissue residue data reported
Poecilia reticulata (guppy)	Reproduction	reduction in # spawnings & time to spawn	0.3	No	0.3	-	na	na	Dillon 1984		No	secondary citation; see Pierson (1981)
Salmo salar (Atlantic salmon)	Behavior	decreased food intake within 10 days	38	No	38	-	water	80 days	Farmer et al. 1979		No	tissue residues not dose-responsive; no effects on growth and food intake rate recovered by end of experiment
Salmo salar (Atlantic salmon)	Growth	17% reduction in growth	4.8	No	4.8	-	water	42 day	Dube et al. 2005		No	fish exposed to a mixture of metals
Salvelinus fontinalis (brook trout)	Reproduction	reduced hatchability of 2nd generation embryos	22.6	No	22.6	-	water	24 wks (adult exposure)	Holcombe et al. 1979	residue data are for newly hatched larvae	No	LOAEL based on embryo tissue residues
Salvelinus fontinalis (brook trout)	Reproduction	reduced hatchability	30	No	30	-	na	na	Dillon 1984		No	secondary citation; see Holcombe et al. (1979)

na - not applicable; study not acceptable for inclusion in SSD derivation

Summary of Fish Tissue-based Toxicity Values for BEHP

Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Oncorhynchus mykiss (rainbow trout)	reproduction (sac-fry mortality)	Sac fry mortality	1.5	No	1.5	-	water	10 day prior to hatch and effects measured 24 days post hatch	Mehrle and Mayer 1976	fry tissue residues calculated from bioconcentration factor and water concentrations reported in paper (tissue conc=[BCF x water conc]/1000); LOAEL based on tissue residues measured in surviving fry 20 days after mortality was observed in the earlier life stage sac-fry. Mortality not correlated with tissue residues so no tissue residue LOAEL identified.	No	time when residues measured differ from when effects observed

Summary of Fish Tissue-based Toxicity Values for DDx

8.3

COPC form	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
DDT (total)	*Carassius auratus* (goldfish)	Behavior Directly Linked to Mortality	equilibrium loss and convulsions	5.1	Yes	0.61	11	water	6 hrs (32 day recovery)	Gakstatter and Weiss 1967	goldfish exhibited severe symptoms of toxicity including convulsions and equilibrium loss.	Yes	
DDT (total)	*Carassius auratus* (goldfish)	Mortality	20% mortality	200	No	200	--	food and water	38 days	Rhead and Perkins 1984	radio tracer study; mortality is slightly less than 2X control mortality, however it is dose responsive with >80% mortality in higher dose group	Yes	
DDT (total)	*Lepomis cyanellus* (green sunfish)	Mortality	reduced survival	24	No	24	24	water	90 days	Hamelink et al. 1971	no statistical analysis of effects; effect threshold is anecdotally stated in the text.	Yes	
DDT (total)	*Lepomis gibbosus* (pumpkinseed)	Mortality	reduced survival	24	No	24	24	water	90 days	Hamelink et al. 1971	no statistical analysis of effects; effect threshold is anecdotally stated in the text.	Yes	
DDT (total)	*Lepomis macrochirus* (bluegill)	Behavior Directly Linked to Mortality	equilibrium loss and convulsions	4.2	Yes	0.51	0.51	water	5 hrs (32 day recovery)	Gakstatter and Weiss 1967	goldfish exhibited severe symptoms of toxicity including convulsions and equilibrium loss	Yes	
DDT (mixture)	*Oncorhynchus clarkii* (cutthroat trout)	Mortality	significant mortality	3	No	3	3	water	612 days (mortality observed at 111 days)	Allison et al. 1964 (more detailed report version of Allison et al. 1963)	LOAEL is tissue concentration at (166d, 5.5 months) in fish exposed to 0.1 mg/kg DDT in water where mortality was significant "after 4 months" (approximately 120d), note that tissue concentrations at this dose increased from 1.8 mg/kg at the previous sampling (111d). Units assumed to be ww.	Yes	
DDT (total)	*Oncorhynchus kisutch* (Coho salmon)	Mortality	85% mortality	33.8	No	33.8	33.8	food	64 days	Buhler et al. 1969	juvenile fish exposed for 64 days (trial V), not statistically evaluated, tissues sampled at 39 days	Yes	
DDT (total)	*Oncorhynchus tshawytscha* (Chinook salmon)	Mortality	18% mortality	12.3	No	12.3	12.3	food	64 days	Buhler et al. 1969	trial I datat not used, residue at d 7 but exposed for 40d; LOAEL based on trial II 64 day exposure; not statistically evaluated; tissues sampled at 65 days.	Yes	
Technical grade DDT	*Pimephales promelas* (fathead minnow)	Mortality	~25% reduced survival	56.8	No	56.8	56.8	diet	266 days	Jarvinen et al. 1977	LOAEL is associated with the food only exposure; ΣDDX LOAEL from the study was identified as the grand mean ΣDDX concentration calculated from all time intervals.	Yes	
DDT (total)	*Salvelinus fontinalis* (brook trout)	Reproduction	offspring (sac-fry and embryo) mortality	2.8	No	2.8	2.8	food	156 days	Macek 1968a	range of parental tissue residues was 2.8 to 3.0; residues in offspring (fry) ranged from 2.62 to 3.09 ug/g ww	Yes	
DDT (4,4'-DDE)	*Salvelinus namaycush* (lake trout)	Mortality	34.4% fry mortality	0.29	No	0.29	-	water and diet	176 days	Berlin et al. 1981	Control and treated eggs started with elevated PCBs and DDTs (7.6 and 3.8 µg/g, respectively)	Yes	

Summary of Fish Tissue-based Toxicity Values for DDx

8.3

COPC form	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
DDT (total)	*Carassius auratus* (goldfish)	Behavior	locomotor activity reduced	1.49 - 1.84	No	1.49 - 1.84	-	water	4 days	Davy et al. 1972	consecutive turns in locomoter pattern	No	behavior endpoint not directly related to growth, survival, or reproduction
DDT (total)	*Fundulus heteroclitus* (killifish)	Mortality	25% mortality	5.2	Yes	0.63		water	24 hrs	Crawford and Guarino 1976	LOAEL is residues in 10 different tissues of fish exposed to 0.1 ppm DDT for two 24hr DDT doses at 24 hrs after exposures	No	Study did not report a wb concentration or weighting factors for individual tissues
ne	*Gadus morhua* (Atlantic cod)	Behavior	altered behavior	7	No	7	-	ne	na	Dillon 1984		No	Secondary citation from review paper
DDT (total)	*Gambusia affinis* (mosquito fish)	Mortality	reduced survival	26.5	No	26.5	-	water	16 days	Pillai et al. 1977		No	residue and effects data from two different experiments
DDT (mixture)	*Lagodon rhomboides* (pinfish)	Mortality	44% mortality at 10 days	0.55	No	0.55	-	diet	15 days	Butler 1969	residues in surviving fish were much higher- avg. 4.23 at same treatment level.	No	no clear dose-response of tissues with mortality
DDT (2,4'-DDT)	*Micropogonias undulatus* (Atlantic croaker)	Behavior	reduced larval swimming ability	0.07	No	0.07	-	diet	1 month	Faulk et al. 1999	fertilized eggs analyzed	No	LOAEL based on egg residues
Purified DDT	*Misgurnus anguillicaudatus* (pond loach)	Mortality	Lethal body burden in 24 hours	25	Yes	3.0	-	water	48 hours	Yang and Sun 1977	residues determined by subtraction from water concentration before and after exposure.	No	tissue residue not measured
ne	*Oncorhynchus kisutch* (Coho salmon)	Mortality	LD50	56	Yes	6.7	-	na	na	Cleveland et al. 1993		No	No DDT data are presented in selenium study
DDT (technical)	Oncorhynchus kisutch (Coho salmon)	Mortality	LD50	95	Yes	11	-	diet	120 days	Buhler and Shanks 1970	body burden calculated from dietary intake	No	tissue residue not measured
ne	*Oncorhynchus kisutch* (Coho salmon)	Mortality	reduced survival	0.83	Yes	0.1	-	na	na	Johnson and Pecor 1969 (as cited in Beckvar et al. 2005)	correlation between DDTs and larval survivial, fish from OR vs Great Lakes.	No	LOAEL based on field collected fish; no controls
DDT (total)	*Oncorhynchus mykiss* (rainbow trout)	Mortality	70% fry mortality	0.464	No	0.464	-	field	60 days	Cuerrier et al. 1967	correlation between DDTs and larval survivial in fish from various hatcheries	No	LOAEL based on egg residues taken from field-collected adults
DDT (total)	*Oncorhynchus mykiss* (rainbow trout)	Mortality	early life-stage mortality	1.27	No	1.27	-	field (maternal transfer and water)	field exposure	Hopkins et al. 1969	correlations between tissues in fish from throughout New Zealand and reproduction	No	LOAEL based on egg residues taken from field-collected adults

Summary of Fish Tissue-based Toxicity Values for DDx

8.3

COPC form	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
ne	*Oncorhynchus mykiss* (rainbow trout)	Mortality	50% mortality; increased learning rate	30	Yes	3.6	-	gavage	96 hrs	McNicholl and Mackay 1975b	gavage	No	fish exposed via gavage; no tissue residue data reported
ne	*Pimephales promelas* (fathead minnow)	Mortality	decreased hatchability	24	No	24	-	water	266 days	Cuerrier et al. 1976		No	Could not obtain paper
ne	*Pimephales promelas* (fathead minnow)	Mortality	25% mortality	57	No	57	-	diet and water	266 days	Cuerrier et al. 1976, 1977		No	Could not obtain paper
DDT (mixture)	*Pleuronectes americanus* (winter flounder)	Reproduction	99% embryo mortality	2.4	No	2.4	-	water	10 days	Smith and Cole 1973	eggs analyzed from adults exposed through diet	No	LOAEL based on egg residue from eggs taken from field-collected adults
DDT (total)	*Poecilia latipinna* (sailfin molly)	Mortality, Growth	78% mortality, decreased growth, lipids and triglycerides in 21 days	92.7	Yes	11.17	-	water	21 days	Benton et al. 1994		No	Discrepancy in LOAEL units; contacted authors, and they don't know which units are correct
DDT (total)	*Salvelinus fontinalis* (brook trout)	Mortality	reduced survival during stress (starvation)	20.2	No	20.2	11.9	diet	26 wks	Macek 1968b	EPA's LOAEL of 11.2 µg/g is for increased wt during feeding period.	No	Fish were exposed to multiple stressors (starvation and DDT)
ne	*Salvelinus fontinalis* (brook trout)	Mortality	increased mortality	11.92	No	11.92	-	na	na	Burdick et al. 1972 (as cited in Beckvar et al. 2005)		No	secondary citation; LOAEL based on egg residue from eggs taken from field-collected adults
DDT (mixture)	*Salvelinus namaycush* (lake trout)	Mortality	fry mortality	2.9	No	2.9	-	field (water)	4 yr study	Burdick et al. 1964	correlations between tissues in fish from field locations and reproduction	No	LOAEL based on egg residue from eggs taken from field-collected adults
DDT (total DDE)	*Salvelinus namaycush* (lake trout)	Mortality	decreased survivorship of fry	1.27	No	1.27	-	water/ parental transfer	na	Mac et al. 1985		No	LOAEL based on egg residue from eggs taken from field-collected adults

na - not applicable; study not acceptable for inclusion in SSD derivation

Summary of Fish Tissue-based Toxicity Values for Lindane

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Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Cyprinodon variegatus (sheepshead minnow)	Mortality	LC50	79	Yes	3.2	3.2	water	96 hours	Schimmel et al. 1977		Yes	
Gasterosteus aculeatus (threespine stickleback)	Mortality	25% mortality, hyperactivity	10.0	Yes	0.4	0.4	water	9 days	Hansen 1980		Yes	
Lagodon rhomboides (pinfish)	Mortality	LC50	5.22	Yes	0.2	0.2	water	96 hours	Schimmel et al. 1977		Yes	
Ictalurus punctatus (channel catfish)	Mortality	threshold for lethality	106.7	Yes	4.268	-	injection	na	Nimrod and Benson 1996		No	injection study; no control residue conc or statistics reported
Oncorhynchus mykiss (rainbow trout)	Behavior	lethargy in fry	0.103	No	0.103	-	na	27 days	Ramamoorthy 1985		No	behavior not clearly linked with growth, mortality, reproduction, also not experimentally evaluated
Pimephales promelas (fathead minnow)	Mortality	27% mortality	9.53	No	9.53	-	water	48 days	Macek et al. 1976		No	wbole body tissue residues not reported (LOER based on eviscerated carcasses)
Pseudorasbora parva (mostugo)	Mortality	Lethal in 24 hours	1246	Yes	49.84	-	na	24 hrs	Kanazawa 1981		No	Secondary citation
Salmo salar (Atlantic salmon)	Mortality	reduced survival	1.2	Yes	0.05	-	na	15 days	Carlberg et al. 1986		No	fish exposed to mixture of chemicals

na - not applicable; study not acceptable for inclusion in SSD derivation

Summary of Fish Tissue-based Toxicity Values for PCBs

8.6

COPC form	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Aroclor 1260	*Barbus barbus* (barbel)	Reproduction	reduced fecundity	0.52	No	0.52	0.52	diet	50 days	Hugla and Thome 1999	study has several problems including: fish were reared under elevated temperatures to alter their reproduction, 2) the number of fish used in the experiment was not clearly reported and 3) statistical analyses appear to be based on an incorrect number of treatment levels; LOAEL determined assuming 80% moisture in organism, LOAEL is concentration following exposure; reproductive LOAEL of 2.6 mg/kg ww based on failure to spawn	Yes	
Clophen A50	*Carassius auratus* (goldfish)	Mortality	lethal body burden	250	Yes	29	29	water	5-21 days	Hattula and Karlog 1972	lethal body burden ranged from 250 to 324 mg/kg ww over all treatments; PCBs dissolved in acetone (0.5 mL/L); An of 8.3 ACR was applied to the LOAEL of 250 mg/kg ww because fish were exposed for less than 8 days (an acute period)	Yes	
Aroclor 1254	*Cyprinodon variegatus* (sheepshead minnow)	Mortality	23% reduction in fry survival within 7 days	9.3	No	9.3	15	water	28 days	Hansen et al. 1974	increase in fecundity; reduced fry survival; LOAEL based on adult female residues	Yes	
Aroclor 1016	*Cyprinodon variegatus* (sheepshead minnow)	Mortality	86% fry mortality	200	Yes	23		water	28 days	Hansen et al. 1975	LOAEL based on fry concentration	Yes	
Aroclor 1242	*Ictalurus punctatus* (channel catfish)	Growth	40% reduction in body weight gain	14.3	No	14.3	14.3	diet	20 wks	Hansen et al. 1976	increased liver/body weight ratio; LOAEL is WB concentration in fingerlings minus stomach and contents; exposure was via feeding	Yes	
Aroclor 1254	*Lagodon rhomboides* (pinfish)	Mortality	increased mortality	14	Yes	1.6	13	water	14-35 days	Hansen et al. 1971	inclusion is conservative because subsequent longer term study with Aroclor 1016 was conducted by the same lab with order of magnitude higher LOAEL	Yes	
Aroclor 1016	*Lagodon rhomboides* (pinfish)	Mortality	50% mortality	106	No	106	-	water	42 days	Hansen et al. 1974	significant reduction in survival (6% mortality in control); loss of equilibrium; erratic swimming also observed at LOAEL	Yes	
Aroclor 1254	*Leiostomus xanthurus* (spot)	Mortality	LD17	46	Yes	5.3	5.3	water	20 days	Hansen et al. 1971	LOAEL based on increased mortality in 5 µg/L exposure; mortality did not appear directly related to body burden; body burden increased with exposure duration	Yes	
Aroclor 1254	*Oncorhynchus kisutch* (Coho salmon)	Mortality	100% mortality	645	No	645	645	diet	~260 days	Mayer et al. 1977	all fish died within 265 days of dose; no statistics, no control; LOAEL based on fingerling tissues; fish exposed to PCBs vis radiolabeled contaminated food	Yes	
Aroclor 1254:1260 (1:2 ratio)	*Oncorhynchus mykiss* (rainbow trout)	Growth	decreased length	120	No	120	120	water	90 days	Mayer et al. 1985	LOAEL in young tissue residues; no effect on mortality or vertebrae strength	Yes	
PCB 153	*Oncorhynchus tshawytscha* (chinook salmon)	Mortality	24 - 28% mortality	3.6	Yes	0.42	0.42	water	15 days	Broyles and Noveck 1979	PCB 153; no TEF; exposed during sac-fry stage; eggs were obtained from Lk MI fish no control residues presented; authors estimate additional 3-11 µg/g PCBs from background. Also see Berlin regarding DDTs.	Yes	

Summary of Fish Tissue-based Toxicity Values for PCBs

8.6

COPC form	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Clophen A50	*Phoxinus phoxinus* (minnow)	Reproduction	reduction in time to hatch, fry death	25	No	25	25	diet	45 days	Bengtsson 1980		Yes	
Aroclor 1248, 1260 mixture	*Pimephales promelas* (fathead minnow)	Growth	33% reduction in weight, 30% reduction in standing crop	50	No	50	50	water	30 days	DeFoe et al. 1978	at LOAEL, reduced weight of second generation at 30 day observed	Yes	
Aroclor 1254	*Pimephales promelas* (fathead minnow)	Reproduction	reduced spawning	196	No	196	-	water	30 days	Nebeker et al. 1974	LOAEL is the mean male concentration, the mean female concentration associated with this reproductive endpoint was 429 mg/kg; average LOAEL over all males and females is 343 mg/kg	Yes	
PCB congener or congener mixture (2 congeners)	*Poecilia reticulata* (guppy)	Mortality	increased mortality, loss of equilibrium, color change	190	No	190	190	water	65 days	Opperhuizen and Schrap 1988	based on mixture of PCB 133 and PCB 197; ACR not applied because >30 days exposure	Yes	
PCB Aroclor mixture	*Salmo salar* (Atlantic salmon)	Growth	reduction in live fry body weight	1.1	No	1.1	1.1	water	48 hours	Fisher et al. 1994	exposed during egg stage, sac fry (and fry concentrations) represent growth dillution	Yes	
Aroclor 1254	*Salvelinus fontinalis* (brook trout)	Growth	reduced survival	125	No	125	125	water	10 days prior to hatch and 118 days after hatch	Mauck et al. 1978	fry residue measured at 118 days; growth effect reported at 48 days but disappeared at 118 days; exposure as eggs; increased fry mortality (21% to 100%) at tissue residue in fry = 125 mg/kg ww	Yes	
Aroclor 1254	*Salvelinus namaycush* (lake trout)	Mortality	significant increase in fry mortality	1.53	No	1.53	1.28	water and diet	176 days	Berlin et al. 1981	control and treated eggs started with elevated PCBs and DDTs (7.6 and 3.8 µg/g, respectively)	Yes	LOAEL based on field collected fish from a contaminated site
PCB 153	*Salvelinus namaycush* (lake trout)	Mortality	51-87% mortality	9.2	Yes	1.1	-	water	15 days	Broyles and Noveck 1979	PCB 153; no TEF; exposed during sac-fry stage; eggs were obtained from Lk MI fish no control residues presented; authors estimate additional 3-11 µg/g PCBs from background. Also see Berlin regarding DDTs.	Yes	LOAEL based on sac-fry concentrations
PCB-5Cl	*Brachydanio rerio* (zebra fish)	Mortality	LD82	4241	Yes	493.1	-	gavage	na	Bouraly and Millischer 1989		No	exposure route not acceptable (gavage)
Aroclor 1268	*Fundulus heteroclitus* (mummichog)	Growth	increased growth	1.3	No	1.3	-	na	na	Matta et al. 2001	positive effect is not clearly hormesis, positive effect at mid and two high concetrations are similar.	No	LOAEL is associated with a positive effect (increased weight)
PCB congener mixture (8 congeners)	*Fundulus heteroclitus* (mummichog)	Mortality, Reproduction	female mortality, egg production, food consumption	3.8	No	3.8	-	IP injection	50 days (during spawning)	Black et al. 1998		No	LOAEL based on injected concentration
ne	*Gadus morhua* (Atlantic cod)	Behavior	changes in swim posture	110	No	110	-	na	na	Dillon 1984	behavior effect observed was swim posture; based on Olofsson and Lindahl (1979)	No	secondary citation
Aroclor 1254	*Micropogonias undulatus* (Atlantic croaker)	Growth	reduction in larval growth rate and impaired response to startle stimulus	3.2	No	3.2	-	maternal transfer to eggs	2 wks during reproduc-tion (adults)	McCarthy et al. 2003	eggs were collected within 8 h of fertilisation; Samples of eggs were frozen and stored at –20°C until analysis of their Aroclor 1254 concentrations.	No	LOAEL based on egg concentration

Summary of Fish Tissue-based Toxicity Values for PCBs

8.6

COPC form	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
PCB congeners mixture (3 congeners)	*Oncorhynchus kisutch* (Coho salmon)	Growth	reduced growth	3.48	No	3.48	-	diet	165 days	Gruger et al. 1975		No	based on exposure to 3 individual PCB congeners (77, 153, 155); PCB 77 is coplanar with a TEF
PCB congener or congener mixture	*Oncorhynchus kisutch* (Coho salmon)	Growth	significant increased rate of growth (weight gain)	2.3	No	2.3	-	injection	na	Gruger et al. 1976	injection study	No	Positive growth effect observed at LOAEL; injection study
Aroclor 1254	*Oncorhynchus kisutch* (Coho salmon)	mortality	reduction in ability to adapt to seawater (6% mortality)	0.15	No	0.15	-	injection	single inj + 6 wks	Folmar et al. 1982	egg data unacceptable because exposed via injection	No	LOAEL based on egg concentration; injection study
Total PCBs (pesticides also reported)	*Oncorhynchus mykiss* (rainbow trout)	Growth	reduction in growth	1.6	No	1.6	-	na	na	Dillon 1984	presence of other chlorinated chems makes this unacceptable	No	Field study and not based on primary citation
Aroclor 1254	*Oncorhynchus mykiss* (rainbow trout)	Growth	reduction in fry growth	1.64	No	1.64	-	maternal transfer	60 days	Hendricks et al. 1981	sac fry concentrations are also reported, however, exposure was during egg phase so sac-fry represent growth dillution, not exposure through gills. Egg concentration reached 2.3 mg/kg 21 d after spawning	No	LOAEL based on egg concentration
Aroclor 1242	*Oncorhynchus mykiss* (rainbow trout)	Mortality	10% mortality	10.8	Yes	1.255813953	-	na	na	Hogan and Brauhn 1975	comparison among hatcheries, no controls	No	LOAEL based on egg concentration
Aroclor 1254	*Oncorhynchus mykiss* (rainbow trout)	Mortality	reduction of LD50 for other chemcials	0.28	No	0.28	-	na	na	Meador et al. 2002	primary citaiton is Bills and Marking 1981	No	effect is not a direct evaluation of growth, survival, or reproduction and based on secondary citation
PCB 126	*Oryzias latipes* (Japanese medaka)	Mortality, Growth	reduced body weight, 23.5% mortality	0.072	No	0.072	-	aqueous	96 hr	Kim and Cooper 1998	at LOAEL, effects were observed over 4 wks following exposure but residues were measured after 96 hr exposure; jaw deformities and fin erosions were also observed; control mortality was 0%	No	exposure to one coplanar PCB congener (126) with TEF
Clophen A50	*Phoxinus phoxinus* (minnow)	Reproduction	reduction in percent hatching	10	No	10	-	na	na	Dillon 1984	not completely clear which study from Dillon 1984 this refers to. Bengtsson is the only Clophen A50 study.	No	field study and not based on primary citation; Bengtsson (1980)
Aroclor 1254	*Pimephales promelas* (fathead minnow)	Mortality	increased mortality	429	No	429	-	ne	ne	Reiser et al. 2004	primary citation is Nebeker et al. 1974	No	based on secondary citation

Summary of Fish Tissue-based Toxicity Values for PCBs

8.6

COPC form	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Aroclor 1242, 1254, or 1260	*Pimephales promelas* (fathead minnow)	Mortality	lethal body burden	1.86 - 749	No	1.86 - 749	-	water	up to 300 hrs	van Wezel et al. 1995a		No	exposures were too short to reach steady state (lethal body burden of 6 month old fish that died in less than 20 hours was 1.8 to 30 ug/g ww; lethal body burden of fish that died at 100 to 300 hrs was 120 to 749 ug/g ww; 50% variability in lethal body burdens was observed and was related to lipid content; lethal body burden was dependent on time of death; study was uncontrolled; low sample size; no critical body burden was identified in study)
PCB Aroclor mixture	*Salmo salar* (Atlantic salmon)	Behavior	retarded phototropism behavior in alevins	5.59	No	5.59	-	water	48 hours	Fisher et al. 1994	exposed during egg stage, sac fry (and fry concentrations) represent growth dillution	No	LOAEL based on egg concentration; behavior endpoint not directly related to growth, survival, or reproduction
Aroclor 1016, 1221, 1254, 1260 mixture	*Salmo salar* (Atlantic salmon)	Growth	reduced growth	1.1	No	1.1	-	na	na	Meador et al. 2002	see Fisher et al. 1994	No	LOAEL based on fry tissue residues following exposure as eggs; fry represent growth dillution and depuration
Clophen A50	*Salmo trutta* (brown trout)	Behavior	enlarged liver, decreased hemoglobin, sluggish behavior	10	No	10	-	gavage; injection	na	Johansson et al. 1972	exposed via gavage or injection	No	a positive growth effect is reported; bioaccumulation study did not experimentally investigate behavior; behavior endpoint not related to growth, survival, or reproduction
Aroclor 1254	*Salvelinus fontinalis* (brook trout)	Reproduction	reduced hatchability (75%)	77.9	No	77.9	-	water	21 days	Freeman and Idler 1975	adults exposed in water, eggs exposed via maternal transfer; egg data reported	No	LOAEL based on egg concentration
no data	*Salvelinus namaycush* (lake trout)	Behavior	change in temperature preference	26.3	No	26.3	-	diet	na	Dillon 1984	based on anonymous citation (1981) data cannot be validated	No	data cannot be validated; behavior endpoint not clearly linked to growth, mortality, or reproduction
PCB mixture	*Salvelinus namaycush* (lake trout)	Mortality	decreased survivorship of fry	2.69	No	2.69	-	water/ parental transfer	na	Mac et al. 1985	comparison among hatcheries, no controls	No	LOAEL based on field collected egg residues from a contaminated site

Summary of Fish Tissue-based Toxicity Values for PCBs

8.6

COPC form	Species	Endpoint	Endpoint Effect	Whole Body Conc. (mg/kg wet wt.)	ACR Applied?	Final Whole Body Conc. (mg/kg wet wt.)	Final Species LOAEL (mg/kg wet wt.)	Exposure Route	Duration	Reference	Notes	Acceptable for TRV derivation?	Reason not acceptable for TRV derivation
Aroclor 1254	*Salvelinus namaycush* (lake trout)	Mortality	fry mortality	4.5	No	4.5	-	water and diet	48 days	Mac and Seelye 1981a	control fry had tissue burdens up to 5.4 µg/g ww and were approximately equivalent to the treated fry; only a small difference in mortality was reported (16.6 v 12.5%)	No	LOAEL based on field collected egg residues from a contaminated site

na - not applicable; study not acceptable for inclusion in SSD derivation