PORTLAND HARBOR RI

APPENDIX G
BASELINE ECOLOGICAL RISK ASSESSMENT

ATTACHMENT 14
RECOMMENDED LITERATURE-BASED FISH DIETARY AND WILDLIFE TRVS

DRAFT

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This document is currently under review by US EPA and its federal, state, and tribal partners, and is subject to change in whole or in part.

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1.0 INTRODUCTION

A toxicity reference value (TRV) is a threshold concentration of a particular chemical that represents some level of documented risk (i.e., is the minimum concentration associated with adverse effects or the maximum concentration not associated with adverse effects) to a particular organism. TRVs are concentrations below which adverse effects have not been observed (no-observed-adverse-effect level [NOAEL]) or above which adverse effects have been observed (lowest-observed-adverse-effect level [LOAEL]). This attachment describes the process of recommending literature-based TRVs for use in the Portland Harbor baseline ecological risk assessment (BERA) for assessing risks to specific ecological receptors (i.e., fish, birds, and mammals).

This attachment presents the literature-based dietary and bird egg tissue-residue TRVs that were developed for all COPCs for which toxicological data were available for the following receptor groups and exposure pathways:

- Fish – dietary dose TRVs
- Birds – dietary dose TRVs
- Mammals – dietary dose TRVs
- Birds – egg tissue-residue TRVs

These recommended literature-based TRVs were developed as a tool for evaluating risks to ecological receptors. These TRVs are intended to identify contaminant levels below which no adverse effects are expected and above which adverse effects may be expected.

This attachment is organized as follows:

- Section 2.0 presents methods used to identify and evaluate the available dietary TRV literature for fish and wildlife and methods used to recommend TRVs for these receptor groups.
- Section 3.0 presents the literature-based dietary TRVs recommended for fish, along with a detailed discussion of the basis for the selection of each TRV.
- Sections 4.0 and 5.0 present the literature-based dietary TRVs recommended for wildlife (i.e., birds and mammals, respectively), along with a detailed discussion of the basis for the selection of each TRV. Literature-based bird egg tissue-residue TRVs are also presented.

2.0 TRV SELECTION PROCESS

This section describes the methods and guidelines used to identify relevant toxicological studies for fish and wildlife used to select recommended literature-based TRVs for the BERA.

2.1 IDENTIFICATION OF COPCS

COPCs were identified for each receptor group in the screening step of the BERA. Dietary TRVs were developed for metal or PAH fish COPCs and all bird and mammals COPCs for which toxicological data were available. Bird egg TRVs were developed for specific chemicals of potential concern (COPC) that will be evaluated through a bird egg tissue-residue approach in the BERA. Table 2-1 presents the COPCs for fish, birds, and mammals.

Table 2-1. Summary of COPCs Included in the Dietary TRV Literature Review

COPC	Fish	Birds	Mammals
Metals			
Aluminum	X[a]		
Antimony	X[a]		X
Arsenic		X	
Cadmium	X		
Chromium	X[a]	X	
Copper	X	X	X
Lead	X[a]	X	X
Mercury	X	X	X
Selenium	X[a]	X	X
Thallium		X	
Zinc	X[a]	X	
Butyltins			
Butyltin ion	X		
Dibutyltin ion	X		
Tetrabutyltin	X		
Tributyltin ion	X		
PAHs			
2-Methylnaphthalene	X[a]	X	
Acenaphthene	X	X	
Acenaphthylene	X	X	
Anthracene	X	X	
Benzo(a)anthracene	X	X	
Benzo(a)pyrene	X	X	
Benzo(b)fluoranthene	X	X	
Benzo(g,h,i)perylene	X[a]	X	

Table 2-1. Summary of COPCs Included in the Dietary TRV Literature Review

COPC	Fish	Birds	Mammals
Benzo(k)fluoranthene	X[a]	X	
Chrysene	X	X	
Dibenzo(a,h)anthracene	X[a]	X	
Fluoranthene	X	X	X
Fluorene	X	X	
Indeno(1,2,3-cd)pyrene	X	X	
Naphthalene	X[a]	X	
Phenanthrene	X	X	X
Pyrene	X	X	X
Total HPAHs	X[a]	X	X
Total LPAHs	X	X	X
Total PAHs	X	X	
Phthalates			
BEHP		X	
Di(n)butyl phthalate		X	
PCBs and Dioxins/furans			
Dioxin/furan TEQ		X	X
PCB TEQ		X	X
Total PCBs		X	X
Pesticides			
Aldrin		X	
DDE		X	
Total DDx		X	X

[a] Fish COPC are based on a non-dietary line of evidence (i.e., based on tissue, surface water, or transition zone water concentration exceeding a screening value); however, a dietary TRV was considered for these COPCs when literature was available, for an additional line of evidence for evaluating risks to fish.

BEHP – bis(2-ethylhexyl) phthalate
COPC – chemical of potential concern
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
TEQ – toxic equivalent
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)
TRV – toxicity reference value

2.2 ENDPOINTS EVALUATED

Representative fish, bird, and mammal species were selected as ecological receptors, as presented in the BERA. Fish receptors include largescale sucker, carp, sculpin, peamouth, juvenile Chinook salmon, northern pikeminnow, smallmouth bass, Pacific lamprey ammocoetes, and juvenile white sturgeon. Wildlife receptors include spotted sandpiper, hooded merganser, osprey, bald eagle, mink, and river otter. The assessment endpoints used to develop TRVs for fish, birds, and mammals are also presented in the BERA. These endpoints include survival, growth, reproduction, and behavior related to survival, growth, and reproduction. Only toxicity studies addressing these endpoints were reviewed to recommend the most relevant TRVs for fish and wildlife species. No studies that linked immunoresponse, biochemical and histopathological changes to survival, growth or reproduction were identified in the literature search.

2.3 TRV SELECTION FOR FISH

An extensive toxicological literature search and review was conducted for all fish dietary COPCs identified in the BERA. NOAEL and LOAEL TRVs were recommended based on the available literature. The purpose of these recommended TRVs is to provide appropriately conservative threshold concentrations for use in the BERA. Thus, TRVs were selected to represent the lowest acceptable values (i.e., NOAEL and LOAEL) available from the literature reviewed.

2.3.1 Literature Search and Review

The literature review and prioritization process used to identify the literature evaluated in the fish TRV selection process is presented in this section.

General Database Search

Toxicity studies that relate chemical concentrations in fish food to adverse effects were identified from a search of electronic databases and reference sources, including the following:

- Environmental Residue Effects Database (ERED 2003)
- ECOTOX Database (ECOTOX 2003)
- Jarvinen and Ankley (1999), a compilation of tissue-residue no-observed-effect concentrations (NOECs) and lowest-observed-effect concentrations (LOECs)
- Scientific literature searches through search engines such as BIOSIS and Science Direct

Literature Review and Evaluation for Selecting Recommended Dietary TRVs

The TRV review process for fish was comprehensive, and numerous studies were reviewed for consideration in selecting recommended TRVs. Only toxicological studies in which

relevant endpoints (relating to survival, growth, reproduction, and behavior) were measured were considered in the TRV selection process.

Studies were not considered in the fish TRV selection process for the following reasons:

- Endpoints were not related to growth, reproduction, mortality, or behavior.
- There was no control group for comparison to treated groups in a laboratory study.
- Fish were exposed to more than one chemical in a laboratory study, except for certain mixtures of related chemicals (e.g., mixtures of DDT and its metabolites, or mixtures of polychlorinated biphenyls [PCBs], Aroclors, dioxins/furans, or polycyclic aromatic hydrocarbons [PAHs]).
- Bioaccumulation studies reported tissue concentrations but did not measure or report a toxic effect. Methods in these studies are not designed to measure toxicity and are not useful for the application as threshold toxicity values. If a bioaccumulation study did measure and report a toxic effect, the study was included in the TRV selection process.

Other studies were not included in the TRV selection process if no clear dose-response relationship was reported or when study methods were problematic (e.g., toxicity was attributed to factors other than chemical exposure).

2.3.2 Dietary NOAEL and LOAEL Calculation

Fish dietary TRVs are presented as a daily dose, expressed as mg/kg bw/day. Most studies reported toxicity results as the chemical concentration in food associated with adverse effects, although a few studies presented results as a daily dose. The following approach was used to determine appropriate values for body weight, percent moisture, and food ingestion rate for use in the dose calculation.

Body Weight – Body weight data from the study were used if reported. If body weight data were presented for different times during the exposure period, these data were used to generate an average body weight (i.e., where average body weight [BW] = $BW_{initial}$ + ½ BW gain over duration of exposure) following the convention used in the toxicity literature (e.g., Cockell et al. 1991). If final body weights were not presented, food ingestion rates and IR_{diet} were calculated based on the initial body weight. If body weight data were presented for each dietary concentration level, average body weights were calculated by concentration level, and these weights were used to derive corresponding NOAEL and LOAEL daily dietary dose TRVs. If no body weight data were provided in the study or data provided were not considered representative, body weights were estimated from other literature sources or toxicity studies.

Food Ingestion Rate – Ingestion rate data from the study for the corresponding NOAEL or LOAEL doses were applied, if provided. If only an average for all individuals was provided, this was assumed to be representative and applied. If no ingestion rates were provided in the study, they were estimated from other literature sources for the same

species, or if no literature was available, an ingestion rate of 2% food (dry weight [dw])/ kg bw/day was assumed as a conservative estimate based on the food ingestion rates commonly reported for laboratory toxicity studies.

Percent Moisture – Moisture content of food and the weight basis of the feeding rate is frequently not reported in dietary toxicity studies. The weight basis of ingestion rate and dietary concentration are immaterial to the calculation of daily dietary doses as long as the weight basis is the same. Food concentrations were converted, as necessary, to the corresponding basis of the food ingestion rate, (wet weight [ww] or dw) using percent moisture in food. If the weight basis of the dietary concentration was not reported, a commercial feed or pelleted diet was assumed to approximate a dw concentration, and 80% moisture was assumed when the diet consisted of organism prey (e.g., invertebrate prey).

2.3.3 Process for Selecting Recommended TRVs

NOAEL and LOAEL TRVs were recommended for each COPC from the toxicity studies identified from the literature search and review process (Section 2.3.1). The purpose of these recommended TRVs is to provide appropriately conservative threshold concentrations for use in the BERA. Thus, TRVs were recommended to represent the lowest acceptable values (i.e., NOAEL and LOAEL) available from the literature reviewed. For each COPC, the study reporting the lowest LOAEL was first evaluated to determine if the study was acceptable. If that study was considered to be acceptable, the LOAEL was selected. If that study was not considered to be acceptable, the study reporting the next lowest LOAEL was evaluated and so forth, until the lowest LOAEL reported from an acceptable study was selected.

The acceptability of fish toxicity studies was determined through best professional judgment, taking into account the following:

- Was the observed toxicity a result of a single COPC? Studies using field-collected fish with background chemical concentrations in tissue cannot attribute toxicity to one specific chemical unless there is strong evidence that all other chemicals in the tissue are below toxic levels.
- What is the ecological relevance of the exposure route? For the selection of dietary TRVs, studies in which fish were fed live prey exposed to the COPC instead of being fed a diet treated with chemical salts were preferred, when these studies were available. The natural assimilation of metals or PAHs through live prey is more ecologically relevant and comparable to the exposure of the selected fish receptors in the Portland Harbor BERA.
- What is the ecological relevance of the exposure duration? Chronic studies measuring exposure for 30 days or longer were preferred.
- Did the measured endpoint in the study directly measure the growth, survival, or reproductive success of the test organism? Behavioral studies were considered in the

TRV selection process; however, behavior studies that could not show a correlation between the measured behavioral effect and the effect on growth, survival, or reproductive success were not considered for selection. Behaviors such as inability to capture prey, inability to sense or avoid predators, and courtship behavior are examples of behaviors that may adversely affect growth, survival, or reproduction.

Following the selection of the lowest acceptable LOAEL, a NOAEL was selected using the following hierarchy: 1) from the same study in which the selected LOAEL was reported; or 2) from another study evaluating the same endpoint as the selected LOAEL (growth, survival, reproduction, or behavior). If the NOAEL was selected from a different study than the LOAEL, the acceptability of the study was evaluated using best professional judgment and the process presented above.

When no NOAEL that was lower than the selected LOAEL and based on the same endpoint was available, no NOAEL was selected. If no LOAEL was reported in the reviewed studies (only NOAELs were reported), the highest NOAEL was selected as the NOAEL TRV, and no LOAEL was selected.

A discussion of the uncertainty associated with each recommended TRV is presented for each COPC and receptor group.

2.3.4 Recommended Literature-Based Fish TRVs

A detailed summary of toxicity studies reviewed and the rationale for recommending dietary TRVs for fish are presented in Section 3.0.

2.4 TRV SELECTION FOR WILDLIFE

An extensive toxicological literature search and review was conducted for all bird and mammal dietary COPCs and bird egg COPCs identified in the BERA. NOAEL and LOAEL TRVs were recommended based on the available literature. The purpose of these recommended TRVs is to provide appropriately conservative threshold concentrations for use in the BERA. Thus, TRVs were selected to represent the lowest acceptable values (i.e., NOAEL and LOAEL) available from the literature reviewed in the TRV selection process.

2.4.1 Literature Search and Review

The literature review and prioritization process used to identify the literature evaluated in the fish TRV selection process is presented in the following subsection.

General Database Search

Studies that relate dietary concentrations or bird egg concentrations to adverse effects in wildlife were identified from a search of electronic databases and from a review of original studies identified in the following review sources:

- Agency for Toxic Substances and Disease Registry (ATSDR)
- ECOTOX Database (US Environmental Protection Agency [EPA] electronic database)
- BIOSIS Electronic Database
- TOXNET Database (National Library of Medicine)
- Integrated Risk Information System (IRIS) Database (EPA electronic database)
- US Fish and Wildlife Service (USFWS) Contaminant Review Series Electronic Database
- Oak Ridge National Laboratory database (Sample et al. 1996)

Literature Review and Evaluation for Selecting Dietary TRVs

The TRV review process for wildlife was comprehensive, and numerous studies were reviewed. Only dietary studies measuring relevant endpoints (relating to survival, growth, reproduction, and behavior) were considered in the TRV selection process. All life stages were considered. Various routes of exposure were used in the reviewed studies: dietary, water, injection, and gavage. For bird egg TRVs, the studies considered in the TRV selection process were those in which bird egg residue concentrations and relevant endpoints (relating to survival, growth, reproduction, and behavior) were measured. Two routes of egg exposure were used in the reviewed studies: injection and maternal transfer (to eggs).

Studies that relied on field-collected prey were reviewed along with laboratory studies and used in the development of wildlife TRVs. The uncertainty associated with field studies should be noted due to the fact that the presence of multiple chemicals and other environmental factors may result in adverse effects that complicate the interpretation of field study results (EPA 1993).

Studies were not considered in the wildlife TRV selection process for the following reasons:

- A clearly non-relevant exposure route was used (i.e., inhalation or absorption).
- The study measured the bioaccumulation and distribution of a COPC and did not measure or report a toxic effect. Methods in these studies are not designed to measure toxicity and are not useful for application as threshold toxicity values. If a bioaccumulation study did measure and report a toxic effect, the study was included in the TRV selection process.
- Endpoints were not related to growth, reproduction, mortality, or behavior (endpoints such as immunoresponse or biochemical and histopathological changes were measured instead).
- There was no control group for comparison to treated groups in a laboratory study.

- Birds or mammals were exposed to more than one chemical in a laboratory study, except for certain mixtures of related chemicals (e.g., mixtures of DDT and its metabolites or mixtures of PCB Aroclors, dioxins/furans, or PAHs).
- Data presented in conference proceeding abstracts were not considered sufficient for developing TRVs.

For some wildlife COPCs, no suitable toxicological literature could be found. TRVs were developed for related surrogate chemicals when an appropriate surrogate chemical was available. TRVs could not be derived for some COPCs because no appropriate toxicological studies were found in the literature, and no suitable surrogate chemical was identified. These COPCs will be addressed in the uncertainty section of the BERA.

2.4.2 Dietary NOAEL and LOAEL Calculation

Wildlife dietary TRVs are expressed as a daily dose, expressed as mg/kg bw/day. Most studies reported toxicity results as the chemical concentration in food associated with adverse effects, although some presented results as a daily dose. The daily exposure dose was derived from a food concentration using the animal's body weight (kg) and ingestion rate (kg/day) as reported in the study or using values published elsewhere. The following approach was used to determine appropriate values for body weight, ingestion rate, and percent moisture in food for use in the dose calculation.

Body Weight —Body weight data from the study were used if reported. If body weight data were presented for different times during the exposure period, these data were used to generate an average body weight. If body weight data were presented for each dose level, average body weights were calculated by dose level, and these weights were used to derive corresponding NOAEL and LOAEL TRVs. If no body weight data were provided in the study or data provided were not considered representative, other published body weights were used, primarily from EPA (1993) or Dunning (1993).

Ingestion Rate—Ingestion rate data from the study for the corresponding NOAEL or LOAEL doses were applied if possible. If only an average for all individuals was provided, this was assumed to be representative and applied. If no ingestion rates were provided in the study, ingestion rates were estimated as follows. For birds, ingestion rates were calculated using the allometric equation for the appropriate bird guild or taxa from Nagy (2001). Body weights used in the allometric equation were determined as described in the previous paragraph. For chicks, ingestion rates were determined using National Research Council (NRC) data (1984; 1994). For mammals, ingestion rates were calculated using the allometric equation for all laboratory mammals from EPA (1988) and body weights as previously described. Drinking water ingestion rates were determined using Calder and Braun (1983).

Percent Moisture—In general, food ingestion rates were reported on a ww basis, so concentrations in food were also expressed on a ww basis. Where food ingestion rates were reported on a dw basis, food concentrations were expressed on a dw basis. Food

concentrations were converted, as necessary, to the corresponding basis of the food ingestion rate, (ww or dw) using percent moisture in food. Percent moisture data provided in the study were used, or if not reported in the study, published values were selected for the specific diet type using the NRC series on nutrient requirements (NRC 1994).

In addition, if results were presented separately for males and females, the data for the more sensitive gender were used to derive the TRV.

2.4.3 TRV Selection Process for Dietary TRVs

NOAEL and LOAEL TRVs were recommended for each COPC from the toxicity studies identified through the literature search and review process (Section 2.4.1). The purpose of these recommended TRVs is to provide appropriately conservative threshold concentrations for use in the BERA. Thus, TRVs were recommended to represent the lowest acceptable values (i.e., NOAEL and LOAEL) available from the literature reviewed. For each COPC, the study reporting the lowest LOAEL was first evaluated to determine if the study was acceptable. If that study was considered to be acceptable, the LOAEL was selected. If that study was not considered to be acceptable, the study reporting the next lowest LOAEL was evaluated and so forth, until the lowest LOAEL reported from an acceptable study was selected.

The acceptability of wildlife toxicity studies was determined through best professional judgment, taking into account the following factors:[1]

- Was the observed toxicity a result of a single COPC? Studies using field-collected prey with background concentrations in tissue cannot attribute toxicity to a single chemical present in the tissue, unless there is strong evidence that all other chemicals in the tissue are below toxic levels. However, field studies reporting concentrations based on a pathway (e.g., fish consumption) relevant to the selected ecological receptors (e.g., mink) were considered in the selection of TRVs because these studies may represent the field conditions in the Study Area. If the recommended TRV was based on a field study, the uncertainty of using the study is clearly documented in the uncertainty evaluation of the BERA.
- What is the ecological relevance of the exposure duration? Studies in which effects were measured over a chronic exposure duration were preferred. Chronic exposure is defined as more than 10 weeks for avian receptors and more than 1 year for mammals or during a critical life stage (i.e., reproduction, gestation, or development) for both birds and mammals (Sample et al. 1996). Chronic studies are more representative of long-term exposure conditions for selected receptors in the Study Area.

[1] Note that all of the factors were considered to derive the most appropriate, conservative study and that a strict hierarchical process prioritizing of each of these factors could not be applied across the selection process of TRVs for all the COPCs due to the variation in study methods and availability of toxicological literature.

- What is the ecological relevance of the exposure route? Studies in which exposure was via dietary ingestion were preferred. Studies that used exposure via gavage, oral intubation, or intraperitoneal injection are not directly related to environmental exposures experienced by bird and mammal receptors in the Study Area. In addition, exposure through drinking water is considered a minor pathway (Integral et al. 2004), so dietary ingestion was also preferred over drinking water ingestion. Studies using non-dietary exposure routes were considered in the derivation of TRVs; however, the dietary exposure route was preferred because dietary exposure is the primary route of exposure for selected bird and mammal receptors in the Study Area.
- Did the measured endpoint in the study directly measure the growth, survival, or reproductive success of the test organism? Behavioral studies were considered in the TRV selection process; however, behavior studies that could not show a correlation between the measured behavioral effect and the effect on growth, survival, or reproductive success were not considered for selection. Behaviors such as inability to capture prey, inability to sense or avoid predators, and courtship behavior are examples of behaviors that may adversely affect growth, survival, or reproduction.
- What is the relevance of the test species and the measured endpoint? Domestic (i.e., chickens and Japanese quail) and laboratory (i.e., laboratory rodents) species were considered acceptable test species for TRV selection. However, if the assessment endpoint was egg productivity in a domestic species, such as chickens or Japanese quail, the study was not selected. These species are bred to have unnaturally high egg-laying rates, so comparing toxic threshold effects on egg production in these species to egg production in non-domestic receptors is problematic because of differences in reproductive physiology. Other reproductive endpoints (excluding egg production) for domestic bird species were considered acceptable for TRV selection.
- Did the observed effect represent an adverse effect? Studies in which results were statistically evaluated to identify significant differences from control values were preferred. In addition, a clear dose-response had to be presented in order for a study to be selected.

Following the selection of the lowest acceptable LOAEL, a NOAEL was selected. The NOAEL was selected using the following hierarchy: 1) from the same study in which the selected LOAEL was reported; or 2) from another study that evaluated the same endpoint as the selected LOAEL (growth, survival, reproduction, or behavior). If the NOAEL was selected from a different study than the LOAEL, the acceptability of the study was evaluated using best professional judgment and the process presented above.

When no NOAEL that was lower than the selected LOAEL and based on the same endpoint was available, no NOAEL was selected. If no LOAEL was reported in the reviewed studies (only NOAELs were reported), the highest NOAEL was selected as the NOAEL TRV, and no LOAEL was selected.

A discussion of the uncertainty associated with each recommended TRV is presented for each COPC and receptor group.

2.4.4 TRV Selection Process for Bird Egg TRVs

In addition to the dietary line of evidence, toxicological literature that measured egg concentrations and the associated effects was identified for dioxins/furans, PCBs, mercury, and DDT (as DDE). Bird egg TRVs for these analytes were recommended based on the reviewed literature. The purpose of these recommended TRVs is to provide appropriately conservative threshold concentrations for use in the BERA. Thus, TRVs were recommended to represent the lowest acceptable values (i.e., NOAEL and LOAEL) available from the literature reviewed.

To derive bird egg TRVs for each COPC, the study (laboratory or field study) reporting the lowest LOAEL was selected. Factors used to evaluate the acceptability of dietary TRV studies for birds and mammals (Section 2.4.3) such as relevance of exposure route and exposure duration, were not relevant to egg studies, and the lowest LOAEL of all the toxicity studies reviewed for each COPC was selected as the LOAEL in all cases. Bird egg NOAELs were selected from the same study in which the selected LOAEL was reported. However, if no NOAEL was reported in the selected LOAEL study, the highest NOAEL below the selected LOAEL that was reported in another study was selected. All egg toxicity studies are conducted during a critical life stage (reproduction) and both injection and maternal transfer of chemicals to the egg were considered acceptable routes of exposure. The uncertainty of the presence of multiple chemicals in eggs observed in the field was noted when the selected bird egg LOAEL or NOAEL TRV was based on a field study.

A discussion of the uncertainty associated with each recommended bird egg TRV is presented for each COPC.

2.4.5 Selection of TRVs for DDxs, PAHs, Dioxins/Furans, and PCBs

TRVs were derived from studies that exposed wildlife to single chemicals for all COPCs except those COPCs that consist of a group of related compounds (i.e., DDT and its metabolites, PAHs, PCB Aroclors, dioxins/furans, and PCB congeners). For these chemical groups, NOAELs and LOAELs were derived as follows:

- For 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)]) , wildlife TRVs were compiled from studies based on exposure to a DDT mixture (either technical DDT or a mixture of DDT and its metabolites). However, there were relevant studies reporting effects in birds associated with dietary exposure to individual DDT isomers, specifically DDE. Therefore, in addition to the total DDx TRV, TRVs were recommended for the exposure of birds to individual DDE compounds. Mammal TRVs were not developed for individual DDT isomers.

- For PCB Aroclors, a NOAEL and LOAEL were recommended for the Aroclor mixture with the highest toxicity for comparison to doses of total PCBs.
- For PAHs, toxicity studies using PAH mixtures as well as those using individual PAHs were evaluated. Limited toxicological data on the effects of PAHs on birds or mammals were available. For birds and mammals, the TRVs derived for benzo(a)pyrene will be used to evaluate exposure to individual PAHs because no toxicological data were available for other individual PAHs.
- For dioxins/furans and dioxin-like PCB congeners, TRVs derived for 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) will be compared to TEQ exposure concentrations (calculated separately for dioxins/furans and dioxin-like PCB congeners and summed together as a whole).

2.4.6 Recommended Literature-based Wildlife TRVs

A detailed summary of toxicity studies reviewed and the rationale for the selection of bird and mammal TRVs are presented in Sections 4.0 and 5.0, respectively.

3.0 FISH DIETARY TRVS

Dietary TRVs were recommended for all fish COPCs, where literature was available. Surrogate chemicals were used to develop dietary TRVs for COPCs for which no suitable toxicological data were available.

The following subsections provide a summary of the process used to select recommended TRVs for each COPC. Tables 3-1 through 3-8 presents data from all fish studies evaluated in the TRV selection process, along with the assumptions (e.g., body weight, food ingestion rate, moisture content in food) used to calculate the body-weight-normalized daily dose (NOAEL and LOAEL) from each study.

3.1 METALS

3.1.1 Aluminum

Only one study that measured the toxicity of dietary aluminum to fish (Handy 1993a) was identified from the literature search. Table 3-7 summarizes the feeding rate assumptions and dietary NOAEL calculated from this study. The dietary dose was calculated using the feeding rate reported in the study (5% bw/day). Handy (1993a) measured no effect on survival or body weight maintenance in rainbow trout fish fed 10,000 µg/g dw of aluminum as aluminum sulfate (which rapidly dissociates to Al^{+3}) for 42 days. No data were presented in the study; however, the "absence of toxicity" was reported. The calculated NOAEL TRV of 500 mg/kg bw/day was selected as the NOAEL TRV. No LOAEL was reported, so none was selected.

The selected NOAEL is highly uncertain because it is an unbounded NOAEL based on the most toxic form of aluminum (Al^{+3} ion). The only measurements of aluminum from the Study Area are measurements of total aluminum. The application of a TRV based on the toxicity of ionic aluminum to measured total aluminum concentrations likely overestimates risks associated with aluminum exposure. In addition, only one dose was tested and the sample size was not reported in the selected study.

3.1.2 Antimony

No studies measuring the toxicity of dietary antimony to fish was found. Consequently, no NOAEL or LOAEL TRVs were recommended for antimony.

Table 3-1. Aluminum Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoints	No-Effect Conc. (mg/kg dw)	Effect Conc. (mg/kg dw)	BW (kg)	Ingestion Rate (kg dw/day)	Source
Aluminum sulfate	Rainbow trout	**500**	NA	fed prepared diet for 42 days	no effect on body weight or survival	10,000	NA	0.17	0.0085[a]	Handy (1993a)

[a] Based on observed food ingestion rate was 5% of body weight per day.
bw – body weight
LOAEL – lowest-observed-adverse-effect level
NOAEL – no-observed-adverse-effect level
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

3.1.3 Cadmium

Nine studies measuring the effects of dietary cadmium on fish were evaluated for TRV selection (Baldisserotto et al. 2005; Franklin et al. 2005; Hatakeyama and Yasuno 1982, 1987; Mount et al. 1994; Handy 1993b; Kang et al. 2005; Kim et al. 2004; Szebedinsky et al. 2001). Adverse effects in fish at various life stages were reported (i.e., fry, juvenile, and adult); effects included reduced survival, reduced growth, reduced fry production, and reduced fry survival. Table 3-2 summarizes the feeding rate assumptions, dietary dose calculations, and dietary NOAELs and LOAELs for cadmium based on the reviewed literature.

Eight of the nine studies that measured the effects of dietary cadmium on fish reported either an exposure rate or a feeding rate from which an exposure rate could be calculated (Hatakeyama and Yasuno 1987; Handy 1993b; Mount et al. 1994; Kim et al. 2004; Kang et al. 2005; Franklin et al. 2005; Baldisserotto et al. 2005; Szebedinsky et al. 2001). Insufficient data were presented in Hatekeyama and Yasuno (1982) to calculate an exposure rate or feeding rate, the average feeding rate presented in Hatekeyama and Yasuno (1987) with the same species was assumed.

Dietary dose LOAELs ranged from 0.01 mg/kg bw/day for growth of juvenile rockfish (Kang et al. 2005; Kim et al. 2004) to 68 mg/kg bw/day for mortality of rainbow trout (Handy 1993b). Dietary NOAELs ranged from 2.5 mg/kg bw/day for mortality of juvenile rockfish (Kang et al. 2005; Kim et al. 2004) to 29 mg/kg bw/day for reproduction of guppy (Hatakeyama and Yasuno 1987). The lowest dietary dose LOAEL of 0.01 mg/kg bw/day, for growth of juvenile rockfish was selected as the LOAEL dietary dose TRV for cadmium (Kang et al. 2005; Kim et al. 2004). Kang et al. (2005) and Kim et al. (2004), exposed juvenile rockfish to 0.5, 5, 25, or 125 mg/kg dw of cadmium as cadmium nitrate for 60 days. Significant effects on growth (identified as condition factor, body weight growth rate, and body length growth rate) were reported for fish exposed to all four dietary concentrations. The lowest concentration was administered at a dose of 0.01 mg/kg bw/day. Toxic effects are somewhat uncertain because in one of the two papers where the study is reported, (Kim et al. 2004), the observed growth effect is partially attributed to reduced food intake which may be due to food avoidance rather than toxicological effects.

The lowest LOAEL was two to three orders of magnitude lower than the NOAELs reported in the six other studies (2.5 to 29 mg/kg bw/day) and was two to three orders of magnitude lower than the LOAELs reported in the three other studies that reported LOAELs (4.6 to 68 mg/kg bw/day). As such, although there were few species evaluated, the dose based LOAEL TRV is likely conservative because the majority of the toxicological studies reviewed indicate that the selected LOAEL may overpredict cadmium toxicity (by several orders of magnitude). No NOAEL was available that was lower than the selected LOAEL TRV, so none was recommended.

Table 3-2. Cadmium Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoints	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Cadmium nitrate	rockfish (juvenile)		**0.010**	fed prepared diet for 60 days	reduced body weight and length, growth rate, and condition factor	NA	0.5 (dw)	0.0247	0.000494 (dw)	Kim et al. (2004); Kang et al. (2005)
Cadmium chloride	guppy (adult)	1.2		fed midge larvae per day for 2 months	no effect on number of live fry, fry survival, or premature release of embryos	28 (ww)[a]	NA	0.000859	0.0000372 (ww)	Hatakeyama and Yasuno (1987)
Cadmium chloride	guppy (60 days old)	1.6		fed midge larvae per day for 30 days	no effect on body weight	37 (ww)[a]	NA	0.000859	0.0000372 (ww)	Hatakeyama and Yasuno (1987)
Cadmium nitrate	rockfish	2.5		fed prepared diet per day for 60 days	no effect on survival		NA		0.000494	Kim et al. (2004)
Cadmium chloride	guppy (30 days old)	3.2	4.6	fed live midge larvae per day for 7 months	reduced cumulative number of fry produced	68 (ww)[a]	106 (ww)[a]	0.000779 (NOAEL) 0.000859 (LOAEL)	0.0000372 (ww)	Hatakeyama and Yasuno (1987)
Cadmium chloride	rainbow trout	4.1		fed of live brine shrimp per day for 60 days[b]	no effect on survival	69 (dw)	NA	0.000611	0.00037 (dw)	Mount et al. (1994)
Cadmium nitrate	rainbow trout	5.9		fed prepared diet per day for 15 to 30 days	no effect on specific growth rate, survival	294 (dw)	NA	0.01704	0.000341 (dw)	Baldisserotto et al. (2005)
Cadmium chloride	guppy	1.0		fed M*oina macrocoipa* per day for 10 to 30 days	no effect on growth[c]	23 (ww)[a]	NA	0.000859 Hatakeyama and Yasuno (1987)	0.0000372 (ww) Hatakeyama and Yasuno (1987)	Hatakeyama and Yasuno (1982)

Table 3-2. Cadmium Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoints	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Cadmium nitrate	rainbow trout	9.4		fed prepared diet per day for 28 days	no effect on growth rate or survival	471 (dw)	NA	0.019	0.000380 (dw)	Franklin et al. (2005)
Cadmium chloride	guppy (30 days old)		9.4	fed live midge larvae per day for 7 months	reduced female growth and survival	NA	170 (ww)[a]	0.000659	0.0000364 (ww)	Hatakeyama and Yasuno (1987)
Cadmium nitrate	rainbow trout (juvenile)	16	28	fed prepared diet per day for 36 days	reduced survival	786 (dw)	1,395 (dw)	0.005	0.00010 (dw)	Szebedinsky et al. (2001)
Cadmium sulfate	rainbow trout (juvenile)		68	fed prepared diet per day for 28 days	reduced survival	NA	10,000 (dw)	0.131	0.00089 (dw)	Handy (1992)

[a] Wet weight concentration calculated from dry weight concentration based on 86.7% moisture reported in midge larvae.

[b] Fish were exposed to cadmium in both water and the diet.

[c] A significant effect on growth was observed at day 10; however, growth was recovered by day 20.

bw – body weight

LOAEL – lowest-observed-adverse-effect level

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

3.1.4 Chromium

No relevant literature addressing the toxicity of dietary chromium to fish was found. One study on the toxicity of chromium to fish was reviewed (Walsh et al. 1994), however, the fish tested (gray mullet) were exposed to chromium in field-simulated conditions in which sediment, algae, and clams were treated with chromium and then placed in an aquarium. No effect on growth or survival of gray mullet was reported following exposure, and no dietary concentration could be derived from this study. Consequently, no NOAEL or LOAEL was selected for chromium.

3.1.5 Copper

Thirteen toxicity studies that exposed fish to dietary copper were evaluated for TRV selection (Berntssen et al. 1999a, b; Baker et al. 1998; Handy 1992, 1993b; Kamunde et al. 2001; Kang et al. 2005; Lanno et al. 1985a, b; Lundebye et al. 1999; Miller et al. 1993; Mount et al. 1994; Murai et al. 1981). Adverse effects on growth or survival were reported in four species (Atlantic salmon, channel catfish, rainbow trout, and grey mullet) following exposure to dietary copper. Table 3-3 summarizes the feeding rate assumptions, dietary dose calculations, and dietary NOAELs and LOAELs for copper reported in the reviewed literature.

Ten of the thirteen studies that measured the effects of dietary copper on fish reported either an exposure rate or a feeding rate from which an exposure rate could be calculated (Baker et al. 1998; Berntssen et al. 1999a, b; Handy 1993b; Kamunde et al. 2001; Lanno et al. 1985a, b; Miller et al. 1993; Mount et al. 1994; Handy 1992). Feeding rate data for Murai et al. (1981) were reported in a separate study (Murai and Andrews 1978). Two studies did not report sufficient data to estimate an exposure rate (Lundebye et al. 1999; Miller et al. 1993). A feeding rate of 2.8% bw/day was assumed for Lundebye et al. (1999) based on the average feeding rate for Atlantic salmon fed synthetic diets in 2 toxicity studies (Berntssen et al. 1999a, b). A feeding rate of 1.9% bw/day was assumed for Miller et al. (1993) based on the average feeding rate of rainbow trout fed a synthetic diet in 16 dietary toxicity studies (Baldisserotto et al. 2005; Cockell and Bettger 1993; Cockell and Hilton 1988; Cockell et al. 1991, 1992; Franklin et al. 2005; Galvez and Wood 1999; Handy 1993a, b; Hendricks et al. 1985; Lanno et al. 1985a, b; Kamunde et al. 2001; Macek et al. 1970; Oladimeji et al. 1984; Rodgers and Beamish 1982).

Dietary dose LOAELs ranged from 0.48 mg/kg bw/day for growth of channel catfish fed dietary copper for 16 weeks (Murai et al. 1981) to 60 mg/kg bw/day for growth of Atlantic salmon fry (Baker et al. 1998). Dietary NOAELs ranged from 0.24 mg/kg bw/day for growth of channel catfish (Murai et al. 1981) to 69 mg/kg bw/day for mortality of rainbow trout (Handy 1993b).

The lowest LOAEL and NOAEL TRVs calculated from the reviewed literature (0.48 and 0.24 mg/kg bw/day, respectively) was based on Murai et al. (1981). This LOAEL and NOAEL were selected. In this study, a significant decrease in body weight was reported

for channel catfish fingerlings exposed to 16 mg/kg dw of copper as copper sulfate in a prepared diet for 16 weeks compared to the control group, but a significant reduction in body weight was not observed in fish fed 8 mg/kg dw relative to controls.

There is high uncertainty associated with the selected dietary TRVs for copper because the sensitivity of channel catfish fingerlings documented by Murai et al. (1981) has not been confirmed in subsequent studies using similar exposures and fish of similar age (Erickson et al. 2003; Gatlin and Wilson 1986) and has been characterized as atypical by other studies of copper in fish (Lorentzen et al. 1998). Gatlin and Wilson (1986) attempted to reproduce the exposure conditions used by Murai et al. (1981) using fingerling catfish that were larger (body weight = 5.5 g) than those used in Murai et al. (1981) (body weight = 1 g). Gatlin and Wilson (1986) reported no difference in weight gain in their highest dietary exposure of 40 mg/kg dw. Likewise, Erickson et al. (2003)[2] reported no differences in weight gain following exposure for 30 days to copper-contaminated prey at dietary concentrations of 157 and 246 mg/kg dw using much smaller fingerling channel catfish (0.2 g/fish). These studies help bracket the size of fingerlings tested and confirm that the Murai et al. (1981) study results are anomalous. The next lowest NOAEL and LOAEL TRVs from the toxicity studies reviewed were 1.0 and 2.0 mg/kg bw/d, respectively, based on Kang et al. (2005). At this LOAEL, a reduced growth rate of rockfish was observed following exposure to dietary copper for 60 days.

[2] Erickson (2003) is currently under review for publication but has not yet been published and was not included in the studies evaluated for TRV derivation in Attachment 14.

Table 3-3. Copper Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effects	No-Effect Conc. (mg/kg dw)	Effect Conc. (mg/kg dw)	BW (kg)	Ingestion Rate (kg dw/day)	Source
Copper sulfate	channel catfish (fingerling)	0.24	0.48	fed prepared diet per day for 16 weeks	reduced growth	8	16	0.046 (NOAEL) 0.036 (LOAEL)	0.00137 (NOAEL) 0.00108 (LOAEL)	Murai et al. (1981)
Copper sulfate	rockfish (juvenile)	**1.0**	**2.0**	fed prepared diet for 60 days	reduced growth rate	50	100	0.026	0.00052	Kang et al. (2005)
Copper sulphate	rainbow trout	2.2		fed prepared diet for 32 days	no effect on survival	200	NA	0.14	0.0015	Handy (1992)
Copper sulphate pentahydrate	rainbow trout	6.8		fed prepared diet for 16 weeks	no effect on growth	287	NA	0.014	0.00034	Lanno et al. (1985b)
Copper sulfate	rainbow trout	13		fed prepared diet for 42 days	no effect on growth	684	NA	0.016	0.00030[a]	Miller et al. (1993)
Copper sulphate pentahydrate	Atlantic salmon (parr)	17		fed prepared diet for 4 weeks	no effect on body weight, length, or condition factor	500	NA	0.072	0.0018	Berntssen et al. (1999b)
Copper sulphate pentahydrate	rainbow trout	17		fed prepared diet for 24 weeks	no effect on growth or survival	691.3	NA	0.013	0.00029	Lanno et al. (1985b)
Copper sulphate pentahydrate	rainbow trout	18		fed prepared diet for 8 weeks	no effect on survival	730	NA	0.0075	0.00019	Lanno et al. (1985b)
Copper sulphate pentahydrate	rainbow trout		18	fed prepared diet for 8 weeks	reduced growth	NA	730	0.0075	0.00019	Lanno et al. (1985b)
Copper sulphate pentahydrate	rainbow trout		20	fed prepared diet for 16 weeks	reduced growth[b]	NA	796	0.0091	0.00021	Lanno et al. (1985a)
Cu sulfate pentahydrate	Atlantic salmon (fry)	14	20	fed prepared diet for 3 months	reduced growth	NA	700	0.0041	0.0001134	Lundebye et al. (1999)
Copper sulphate	Atlantic salmon	20	28	fed prepared diet for 3 months	reduced growth	638	868	0.0048	0.00015	Berntssen et al. (1999a)
Copper sulphate pentahydrate	rainbow trout	42		fed prepared diet for 28 days	no effect on growth or survival	1,042	NA	0.0535	0.0021	Kamunde et al. (2001)

Table 3-3. Copper Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effects	No-Effect Conc. (mg/kg dw)	Effect Conc. (mg/kg dw)	BW (kg)	Ingestion Rate (kg dw/day)	Source
Copper chloride	rainbow trout (fry)	26[c]	50[c]	fed brine shrimp for 60 days	reduced survival	440	830	0.00073	0.000044	Mount et al. (1994)
Copper chloride	rainbow trout (fry)	60[c]		fed brine shrimp for 60 days	no effect on body weight and length	1,000	NA	0.00060	0.000036	Mount et al. (1994)
Copper sulphate pentahydrate	grey mullet		60	fed prepared diet for 67 days	reduced growth [d]	NA	2,400	0.016	0.0004	Baker et al. (1998)
Copper sulphate	rainbow trout	69		fed prepared diet for 28 days	no effect on survival	10,000	NA	0.13	0.00091	Handy (1993b)

[a] Feeding rate was estimated as 1.9% body weight per day based on the average feeding rate reported in other dietary toxicological studies were rainbow trout were fed a synthetically prepared diet (i.e., not live prey).

[b] A significant reduction in growth was observed at 16 weeks; however, growth was recovered by 24 weeks.

[c] Fish were exposed to copper in both water and diet.

[d] Observed reduction of growth was associated with a reduction in feeding.

LOAEL – lowest-observed-adverse-effect level

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

3.1.6 Lead

Two studies that measured the toxicity of dietary lead in fish were evaluated for TRV selection (Goettl et al. 1976; Mount et al. 1994). Table 3-4 summarizes the feeding rate assumptions, dietary dose calculations, and dietary NOAELs and LOAELs for zinc reported in the reviewed literature. One of the two studies that measured the effects of dietary lead to fish reported a feeding rate from which an exposure rate could be directly calculated (Mount et al. 1994); the other study did not report sufficient data to estimate a feeding rate or exposure rate (Goettl et al. 1976) so a feeding rate of 1.9% bw/day was assumed for based on the average feeding rate of rainbow trout fed a synthetic diet in 16 dietary toxicity studies (Baldisserotto et al. 2005; Cockell and Bettger 1993; Cockell and Hilton 1988; Cockell et al. 1991, 1992; Franklin et al. 2005; Galvez and Wood 1999; Handy 1993a, b; Hendricks et al. 1985; Lanno et al. 1985a, b; Kamunde et al. 2001; Macek et al. 1970; Oladimeji et al. 1984; Rodgers and Beamish 1982).

No LOAELs were reported. The highest dietary dose NOAEL is 134 mg/kg bw/day for no effect on rainbow trout mortality and growth following exposure to lead in a synthetic diet for 191 days (Goettl et al. 1976). This NOAEL is based on an estimated feeding rate and is unbounded by a LOAEL and is therefore, highly uncertain.

3.1.7 Mercury

Six studies measuring the effects of dietary mercury on fish were evaluated for TRV selection (Friedmann et al. 1996; Hammerschmidt et al. 2002; Matta et al. 2001; Rodgers and Beamish 1982; Webber and Haines 2003; Sandheinrich and Miller 2006). Effects on growth, survival, reproduction, and behavior were reported in five fish species (fathead minnow, golden shiner, walleye, mummichog, and rainbow trout) following exposure to dietary mercury. Table 3-5 summarizes the feeding rate assumptions, dietary dose calculations, and dietary NOAELs and LOAELs for mercury reported in the reviewed literature.

Three of the six dietary toxicity studies presented either exposure rate or feeding rate data from which exposure rates could be directly calculated (Friedmann et al. 1996; Rodgers and Beamish 1982; Webber and Haines 2003). Two studies did not present sufficient information to calculate a feeding rate (Matta et al. 2001; Hammerschmidt et al. 2002). A feeding rate of 2.5% bw/day was assumed for dietary exposure to mummichog in the study by Matta et al. (2001) based on a mummichog feeding rate for a pelletized food diet reported in Gutjahr-Gobell et al. (1999). A feeding rate of 6.0% bw/day was assumed for dietary exposure to fathead minnow in the study by Hammershcmidt et al. (2002) and Sandheinrich and Miller (2006) based on a fathead minnow feeding rate for a pelletized food diet reported in Ogle and Knight (1989).

Table 3-4. Lead Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effects	No-Effect Conc. (mg/kg dw)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg dw/day)	Source
Lead nitrate	rainbow trout	12.6	NA	fed brine shrimp for 60 days	no effect on body weight and length; 100% survival	210	NA	0.00063	0.000038	Mount et al. (1994)
Lead (unspecified form)	rainbow trout	**134**	NA	fed prepared diet for 191 days	no effect on growth	7,040	NA	0.091	0.00173[a]	Goettl (1976)

[a] Feeding rate was estimated as 1.9% body weight per day based on the average feeding rate reported in other dietary toxicological studies were rainbow trout were fed a synthetically prepared diet (i.e., not live prey).

BW – body weight

dw – dry weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

Table 3-5. Mercury Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoint	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Methyl-mercury	golden shiner	NA	0.0091	fed prepared diet for 90 days	altered shoaling behavior after predator exposure	NA	0.455 (ww)	0.009	0.00018 (ww)[a]	Webber and Haines (2003)
Methyl-mercury	golden shiner	0.019	NA	fed prepared diet for 90 days	no effect on growth or survival	0.959 (ww)	NA	0.009	0.00018 (ww)[a]	Webber and Haines (2003)
Methyl-mercuric chloride	mummichog	**0.005**	**0.013**	fed prepared diet for at least 6 weeks	reduced male survival	0.2 (dw)	0.5 (dw)	0.011	0.000275 (dw) (Gutjahr-Gobell et al. 1999)	Matta et al. (2001)
Methyl-mercury	walleye	0.0036[b]	0.026[b]	fed catfish fillets for 6 months	reduced male growth	0.137 (ww)	0.937 (ww)	0.028	0.00073 (ww)	Friedmann et al. (1996)
Methyl-mercury	fathead minnow		0.043	fed dry contaminated fish from juvenile lifestage through spawning	no effect on spawning time or on hypoactivity behavior	NA	0.714 (dw)	0.00606	0.003636 (dw) (Ogle and Knight 1989)	Sandheinrich and Miller (2006)
Methyl-mercury	fathead minnow		0.053	fed prepared diet for multiple generations	reduced spawning success	NA	0.88 (dw)	0.0032	0.000192 (dw) (Ogle and Knight 1989)	Hammerschmidt et al. (2002)
Methyl-mercury	rainbow trout		0.46	fed prepared diet for 12 weeks	reduced body weight in hatchling fish	NA	23.2 (dw)	0.013	0.00025 (dw)	Rodgers and Beamish (1982)
Methyl-mercuric chloride	mummichog	0.14	1.4	fed prepared diet for at least 6 weeks	reduced fertilization success	5.6 (dw)	54 (dw)	0.114	0.00285 (dw) (Gutjahr-Gobell et al. 1999)	Matta et al. (2001)

Table 3-5. Mercury Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoint	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Methyl-mercuric chloride	mummichog	1.4		fed prepared diet for at least 6 weeks	no effect on fertilization success, fecundity, offspring hatchability, survival, or body weight, or on adult female survival	54 (dw)	NA	0.114	0.00285 (dw) (Gutjahr-Gobell et al. 1999)	Matta et al. (2001)
Methyl-mercury	rainbow trout	1.5		fed prepared diet for 12 weeks	no effect on survival	76.5 (ww)	NA	0.009	0.00018 (dw)[b]	Rodgers and Beamish (1982)
Methyl-mercury	rainbow trout		1.5	fed prepared diet for 12 weeks	lethargic behavior and darker appearance of fish	NA	94.8 (dw)	0.0138	0.0002208 (dw)	Rodgers and Beamish (1982)

[a] Food ingestion rate estimated as 2% of body weight per day.

[b] Elevated mortality reported in control group; no replication; high uncertainty associated with estimated dietary dose.

BW – body weight

dw – dry weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

Dietary dose LOAELs ranged from 0.0091 mg/kg bw/day for behavior of golden shiner (Webber and Haines 2003) to 1.5 mg/kg bw/day for behavior of rainbow trout (Rodgers and Beamish 1982). At the lowest LOAEL of 0.0091 mg/kg bw/day, Webber and Haines (2003) reported increased shoal area following exposure to a model predator compared to controls. At this dose, no effects were observed for two other predation avoidance behaviors, shoal height, and time to settling. The authors state that these behaviors may increase the chance of predation but note that this has not been confirmed in wild fish. Because these behavioral effects cannot be tied directly to effects on growth, mortality, or reproduction, this study was not selected to derive TRVs for the BERA. At the next lowest LOAEL of 0.013 mg/kg bw/day, Matta et al. (2001) exposed mummichog to various concentrations of dietary methyl mercury for at least 6 weeks prior to spawning and effects on survival, growth, and reproduction were evaluated. Increased mortality was observed in male mummichog at a dietary dose of 0.013 mg/kg bw/day. This LOAEL was selected because it is the lowest LOAEL where adverse effects on growth, mortality, or reproduction were observed.

Dietary dose NOAELs ranged from 0.0036 mg/kg bw/day for growth and gonadal development of juvenile walleye (Friedmann et al. 1996) to 1.5 mg/kg bw/day for mortality of rainbow trout (Rodgers and Beamish 1982). The NOAEL of 0.005 mg/kg bw/day reported in Matta et al. (2001), where no effect on male mummichog survival was observed was selected as the NOAEL TRV. The selected NOAEL and LOAEL TRVs are uncertain because the dietary doses were based on a FIR for mummichog reported in a dietary toxicity study (Gutjahr-Gobell et al. 1999) that was unrelated to the study that the TRVs were based on (Matta et al. 2001).

3.1.8 Zinc

Two fish studies that measured the toxicity of dietary zinc were evaluated for TRV selection (Mount et al. 1994; Takeda and Shimma 1977). Effects on growth and mortality were reported in all studies following exposure to dietary zinc. Table 3-6 summarizes the feeding rate assumptions, dietary dose calculations, and dietary NOAELs and LOAELs for zinc reported in the reviewed literature.

Only one of the two studies that measured the effects of dietary zinc on fish reported a feeding rate from which an exposure rate could be directly calculated (Mount et al. 1994). Takeda and Shimma (1977) did not report a feeding rate or exposure rate so a feeding rate of 1.9% bw/day was assumed based on the average feeding rate of rainbow trout fed a treated diet in 16 dietary toxicity studies (Baldisserotto et al. 2005; Cockell and Bettger 1993; Cockell and Hilton 1988; Cockell et al. 1991, 1992; Franklin et al. 2005; Galvez and Wood 1999; Handy 1993a, b; Hendricks et al. 1985; Lanno et al. 1985a, b; Kamunde et al. 2001; Macek et al. 1970; Oladimeji et al. 1984; Rodgers and Beamish 1982).

Table 3-6. Zinc Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effects	No-Effect Conc. (mg/kg dw)	Effect Conc. (mg/kg dw)	BW (kg)	Ingestion Rate (kg dw/day)	Source
Zinc (unspecified form)	rainbow trout	**19.0**	**38.0**	fed prepared diet for 6 weeks	reduced growth	1,000	2,000	0.01375	0.00026[a]	Takeda and Shimma (1977)
Zinc chloride	rainbow trout	114.0	NA	fed brine shrimp for 60 days	no effect on body weight and length; 97% survival	1,900	NA	0.00069	0.000041	Mount et al. (1994)

[a] Feeding rate was estimated as 1.9% body weight per day based on the average feeding rate reported in other dietary toxicological studies were rainbow trout were fed a synthetically prepared diet (i.e., not live prey).

BW – body weight

dw – dry weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

Only one LOAEL was reported in the two studies reviewed. Takeda and Shimma (1977) reported a reduction in growth in fingerling rainbow trout following six weeks of dietary dose of 40 mg/kg bw/day and this dietary dose was selected as the LOAEL TRV. The NOAEL TRV of 19 mg/kg bw/day from the same study was selected as the NOAEL TRV. There is high uncertainty associated with the selected TRVs because the literature dataset for the dietary toxicity of zinc to fish is limited to two studies. These TRVs are also uncertain because they are based on an assumed feeding rate of 1.9% bw/day.

3.1.9 Tributyltin

Only one study that measured the toxicity of dietary tributyltin (TBT) to fish (Shimasaki et al. 2003) was reviewed. Table 3-7 summarizes the dietary dose calculations, feeding rate assumptions, and dietary NOAELs and LOAELs from this study. Shimasaki et al. (2003) did not report an exposure rate or feeding rate and no other dietary toxicity studies in which winter flounder, or closely related fish, were fed a synthetic diet were identified so a feeding rate of 2% bw/day was assumed.

Shimasaki et al. (2003) reported the effects on reproductive success of Japanese flounder larvae following exposure to dietary TBT. The flounder larvae that were exposed to TBT were generated from two parents that were genetically female (with XX chromosomes); however, one parent was phenotypically and functionally male, and offspring were generated. All offspring produced were genetically female (XX). The female offspring larvae were exposed to TBT as tributyltin oxide for approximately 65 days at two different doses, and the effects on growth and sex reversal were measured relative to a control. A significant reduction in growth was reported at 100 days at both 0.0021 mg/kg bw/day and 0.020 mg/kg bw/day treatments. The lowest dose at which an effect was observed (0.0021 mg/kg bw/day) was selected as the LOAEL TRV. No NOAEL was reported, so none was selected.

An increase in sex reversal was reported in TBT-exposed fish. The actual impact of TBT on sex reversal is unclear because sex reversal was apparent in the parent fish, prior to TBT exposure; and sex reversal did not appear to affect production of offspring. The ecological significance of the sex reversal endpoint is uncertain. No difference in the concentration was calculated converting the LOAEL TRV for TBT from tributyltin oxide into tributyltin ion (due to significant figures). There is uncertainty associated with the selected TRVs because the literature dataset for the dietary toxicity of TBT to fish is limited to one study. These TRVs are also uncertain because they are based on an assumed feeding rate of 2% bw/day.

Table 3-7. Tributyltin Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoints	No-Effect Conc. (mg/kg dw)	Effect Conc. (mg/kg dw)	BW (kg)	Ingestion Rate (kg dw/day)	Source
Tributyltin oxide	Japanese flounder (larvae)	NA	**0.0021**	fed prepared diet for approximately 65 days	35% reduction in body weight, increased sex reversal	NA	0.1	0.103	0.002068[a]	Shimasaki et al. (2003)

[a] Food ingestion rate estimated as 2% of body weight per day.
BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

3.2 PAHS

Adverse effects in fish resulting from polycyclic aromatic hydrocarbon (PAH) exposure were considered using for individual PAHs and PAH mixtures. Six toxicity studies measuring the effects of dietary PAHs to fish were evaluated for TRV selection. Four of the studies reviewed evaluated the toxicity of benzo(a)pyrene to fish (Hart and Heddle 1991; Hendricks et al. 1985; Rice et al. 2000; Wu et al. 2003) and three of the studies reviewed evaluated the toxicity of a mixture of PAHs to juvenile Chinook salmon (Meador 1997; Palm et al. 2003; Rice et al. 2000). No studies measuring the dietary toxicity of other invidual PAH COPCs to fish was found.

3.2.1 Benzo(a)pyrene

Table 3-8 summarizes the feeding rate assumptions, dietary dose calculations, and dietary NOAELs and LOAELs for benzo(a)pyrene reported in the reviewed literature. Three of the four studies reported either a feeding rate or an exposure rate (Hendricks et al. 1985; Rice et al. 2000; Wu et al. 2003). Hart and Heddle (1991) did not present an exposure rate or feeding rate so a feeding rate of 1.9% body weight/day was assumed based on the average feeding rate of rainbow trout fed a synthetic diet in 16 dietary toxicity studies (Baldisserotto et al. 2005; Cockell and Bettger 1993; Cockell and Hilton 1988; Cockell et al. 1991, 1992; Franklin et al. 2005; Galvez and Wood 1999; Handy 1993a, b; Hendricks et al. 1985; Kamunde et al. 2001; Lanno et al. 1985a, b; Macek et al. 1970; Oladimeji et al. 1984; Rodgers and Beamish 1982). Rice et al.(2000) presented a length but did not present a body weight so the juvenile English sole weight was estimated assuming the length:weight relationship of English sole collected from the Lower Duwamish Waterway in Seattle, Washington (Luxon 2006).

Dietary dose LOAELs ranged from 1.4 mg/kg bw/day for growth of English sole (Rice et al. 2000) to 19 mg/kg bw/day for growth of rainbow trout (Hart and Heddle 1991). At the lowest LOAEL, Rice et al. (2000) exposed juvenile English sole to live polychaete worms that had been previously exposed to sediments spiked with benzo(a)pyrene at two different doses. Reduced daily growth rate was observed at the high dose of 1.4 mg/kg bw/day but not the low dose 0.66 mg/kg bw/day. The LOAEL TRV of 1.4 mg/kg bw/day was selected because this was the lowest LOAEL reported in the reviewed literature. Dietary NOAELs ranged from 0.66 mg/kg bw/day for growth of English sole (Rice et al. 2000) to 12.5 mg/kg bw/day for growth and survival of areolated grouper (Wu et al. 2003). The NOAEL of 0.66 mg/kg bw/day reported in Rice et al. (2000) was selected as the NOAEL TRV. There is uncertainty associated with the selected TRVs because the literature dataset for the dietary toxicity of benzo(a)pyrene to fish is limited to four studies. Estimation of the body weight for English sole does not affect the dose calculation and does not affect the uncertainty of the TRVs.

Table 3-8. Benzo(a)pyrene Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoint	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Benzo(a)pyrene	juvenile English sole	**0.66**	**1.4**	fed contaminated worms for 10 to 12 days	reduced daily growth rate	NA	2.3 (ww)	0.034[a]	0.0020 (ww)	Rice et al. (2000)
Benzo(a)pyrene	juvenile rainbow trout	NA	3.7	fed prepared diet for 53 days	reduced body weight; no effect on survival	NA	NA	NA	NA	Hendricks et al. (1985)
Benzo(a)pyrene	juvenile rainbow trout	1.9	19	fed prepared diet for 18 months	reduced body weight	100 (dw)	1,000 (dw)	0.003	0.00006 (dw)[b]	Hart and Heddle (1991)
Benzo(a)pyrene	grouper	13	NA	force-fed PAH contaminated pellet for 4 weeks	no effect on survival or growth (body weight and total length)	NA	NA	NA	NA	Wu et al. (2003)

[a] Body weight estimated from length using the equation y (g) = 0.7714x (mm)

[b] Feeding rate was estimated as 1.9% body weight per day based on the average feeding rate reported in other dietary toxicological studies were rainbow trout were fed a synthetically prepared diet (i.e., not live prey).

BW – body weight

dw – dry weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

3.2.2 PAH Mixture

Three studies were identified in which fish were exposed to a mixture of PAHs (Rice et al. 2000; Palm et al. 2003; Meador et al. 2006). Adverse effects on growth were evaluated for two species of fish (juvenile English sole and juvenile Chinook salmon). Table 3-9 summarizes the feeding rate assumptions, dietary dose calculations, and dietary NOAELs and LOAELs for PAHs reported in the reviewed literature. All three studies reported a dietary dose or a feeding rate from which a dietary dose could be calculated.

Dietary dose LOAELs ranged from 0.12 mg/kg bw/day for growth of English sole (Rice et al. 2000) to 18 mg/kg bw/day for growth of juvenile Chinook salmon (Meador et al. 2006). At the lowest LOAEL, Rice et al. (2000) exposed juvenile English sole to polychaete worms that had been previously exposed in the lab to 0.1% field contaminated sediments from the Eagle Harbor, Washington, Superfund site mixed with 99% sediments from a reference site. Only PAH concentrations were reported for the sediment and worm tissue, however, other uncharacterized chemicals may also have been present. Fish exposed to contaminated worms at a total PAH dose of 0.12 mg/kg bw/day had a lower daily growth rate than controls. In a second trial of the experiment at the same dietary concentration and a slightly higher feeding rate, a similar trend was observed but the effect on growth was not statistically significant. This LOAEL was not selected because the worms used were exposed to field collected sediments with uncharacterized chemicals.

At the next lower LOAEL, Meador et al. (2006) exposed juvenile Chinook salmon to total PAHs dietary doses of 0.026 (in the control group), 0.7, 2.3, 6.1, 18, or 22.1 mg/kg bw/day for 53 days following smoltification. The mixture was of 21 PAHs based on the mixture of PAHs observed in juvenile Chinook stomach contents from the Duwamish River waterway (Varanasi et al. 1993) Adverse effects on the wet weight of the fish were observed in the highest dose relative to the control and adverse effects on the dry weight of the fish were observed for the two highest concentrations relative to the control. Fish from the two highest doses also had significantly higher ww to dw ratios. Weights of PAH dosed fish at all concentrations were significantly more variable than weights of control fish, however, this effect wasn't dose-responsive. Based on these results, a LOAEL of 18.0 mg/kg bw/day for growth on a dw basis was selected as the LOAEL TRV because this was the only LOAEL reported in the two studies reviewed. The NOAEL of 6.1 mg/kg bw/day for growth on a dw basis from this study was also selected. There is high uncertainty associated with the selected TRVs because the literature dataset for the dietary toxicity of PAH mixtures to fish is limited to three studies.

Table 3-9. PAH Mixture Dietary Toxicity Studies for Fish

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoint	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg/day)	Source
PAH mixture	English sole	NA	0.12	fed contaminated worms for 10-12 days[a]	reduced daily growth rate	NA	2.3	0.034[b]	0.0018 (ww)	Rice et al. (2000)
PAH mixture	juvenile Chinook salmon	5.0	NA	fed prepared diet for 7 weeks	no effect on body weight, length, or condition factor	252	NA	0.0183	0.00037 (dw)	Palm et al. (2003)
PAH mixture	juvenile Chinook salmon	5.0	NA	fed prepared diet for 4 weeks[c]	no impact to disease resistance	252	NA	0.0183	0.00037 (ww)	Palm et al. (2003)
PAH mixture	juvenile Chinook salmon	**6.1**	**18.0**	fed prepared diet for 53 days	reduced body weight (as dry body weight)[d]	NA	NA	NA	NA	Meador et al. (2006)

[a] Worms were exposed to sediments collected from a Superfund site contaminated with PAHs and potentially other chemicals that were not characterized in this study.

[b] Body weight estimated from length using the equation y (g) = 0.7714x (mm)

[c] Fish were exposed to *Listonella anguillarum* following PAH exposure. No difference was observed between PAH-exposed fish and controls in either fish that were vaccinated against the bacterium or those that were not vaccinated.

[d] Effects on growth were not significant at the LOAEL when evaluated on a wet-weight basis.

BW – body weight

dw – dry weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.0 BIRD TRVs

Dietary TRVs were recommended for all bird COPCs, where literature was available. Surrogate chemicals were used to develop dietary TRVs for COPCs for which no suitable toxicological data were available. Bird egg TRVs were developed for dioxins/furans, PCBs, mercury, and 4,4′-DDE.

The following subsections provide a summary of the studies reviewed. Tables 4-1 through 4-23 present data from all bird studies evaluated in the TRV selection process, along with the dietary assumptions used to calculate the body-weight-normalized daily dose (NOAEL and LOAEL) from each study and other details from the reviewed studies.

4.1 METALS

4.1.1 Aluminum

Only two studies on the dietary toxicity of aluminum to birds were evaluated for TRV selection (Carriere et al. 1986; Wolff and Phillips 1990). Table 4-1 summarizes the aluminum NOAELs derived from the studies reviewed. No adverse effects on growth or reproduction (including fertility and hatchability) were reported in either study. NOAELs ranged from 90 mg/kg bw/day for growth of Japanese quail (Wolff and Phillips 1990) to 157 mg/kg bw/day for reproduction and growth of ring doves (Carriere et al. 1986).

No LOAEL was selected because none was reported in the two studies reviewed. The highest NOAEL between the two studies (157 mg/kg bw/day) based on Carriere et al. (1986) was recommended. There is high uncertainty associated with the selected TRV for aluminum because it is based on an unbounded NOAEL and based on exposure to the ionic form of aluminum. Toxicity measured for ionic aluminum is not comparable to the toxicity associated with the colloidal, particulate and complex forms of aluminum present in the environment. The application of a TRV based on the toxicity of ionic aluminum to measured total aluminum concentrations is highly uncertain and will likely overestimate the risks associated with aluminum exposure.

Table 4-1. Aluminum Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg dw)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg dw/day)	Source
Aluminum citrate	Japanese quail	90	NA	diet for 65 days and through reproduction	no effect on body weight[a]	1,667[b]	NA	0.09 (Dunning 1993)	0.00485 (Nagy 2001)	Wolff and Phillips (1990)
Aluminum sulfate	Ring dove	157	NA	diet for 4 months	no effect on growth, fertility, hatchability, or egg permeability	1,111[b]	NA	0.119 (Dunning 1993)	0.0168 (Nagy 2001)	Carriere et al. (1986)

[a] Eggshell thickness was affected in birds fed 120 mg/kg ww; however, no clear dose response was observed.
[b] Concentration in food converted to dry weight assuming 10% moisture in laboratory-prepared food.
BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.1.1 Arsenic

Five studies on the dietary toxicity of arsenic to birds (Stanley et al. 1994; USFWS 1969, 1964; Camardese et al. 1990; Whitworth et al. 1991) were evaluated. Table 4-2 summarizes the arsenic NOAELs and LOAELs derived from the studies included in the TRV selection process. All reviewed studies measured the oral toxicity of arsenic to mallards or cowbirds through diet. Effects on mortality, reproduction, and behavior (including alertness and resting behavior) following arsenic exposure were reported in the literature reviewed. LOAELs ranged from 6.8 mg/kg bw/day for mortality of brown-headed cowbirds [USFWS (1969) as cited in Sample et al. (1996)] to 56 mg/kg bw/day for mortality of young mallards (USFWS 1964). At the lowest LOAEL, 20% mortality in brown-headed cowbirds was reported following dietary exposure to 6.8 mg/kg bw/day arsenic for seven months; however, birds were exposed to a chemical mixture of copper acetoarsenite [USFWS (1969) as cited in Sample et al. (1996)]. At the next lowest LOAEL of 40 mg/kg bw/day, delayed egg laying; depressed egg weight and shell thinning; decrease offspring body weight and production was observed in mallards fed arsenic for over 100 days (Stanley et al. 1994). NOAELs ranged from 2.3 mg/kg bw/day for mortality of brown-headed cowbirds [USFWS (1969) as cited in Sample et al. (1996)] to 40 mg/kg bw/day for growth of mallards (Stanley et al. 1994).

The lowest LOAEL based on a single chemical exposure of 40 mg/kg bw/day was recommended. The NOAEL (10 mg/kg bw/day) reported in the same study was also recommended. The recommended TRVs were reported in the same study and represent the most conservative values calculated from the literature reviewed based exposure to arsenic only.

Table 4-2. Arsenic Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Sodium arsenate	mallard	6.1	NA	diet for 10 weeks	no effect on female growth or survival[a]	300 (ww)	NA	0.6305	0.0128 (ww)	Camardese et al. (1990) as cited in Sample et al. (1996)
Copper acetoarsenite (As^{+3})	brown-headed cowbird	2.3	6.8	diet for 7 months[b]	reduced survival (80%)	12 (dw)[c]	37 (dw)[c]	0.049	0.0090 (dw) (Nagy 2001)	USFWS (1969) as cited in Sample et al.(1996)
Sodium arsenate	mallard	40	NA	diet for up to 128 days	no effect on body weight	400 (ww)		1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Stanley et al. (1994)
Sodium arsenate	mallard	**10**	**40**	diet for up to 128 days	delayed egg laying; depressed egg weight and shell thinning; decrease offspring body weight and production[d]	100 (ww)	400 (ww)	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Stanley et al. (1994)
Sodium arsenate	mallard (birth to 9 weeks)	NA	42	diet for 9 weeks	altered resting and alertness behavior	NA	345 (dw)[c]	0.1 (NRC 1994)	0.0120 (dw) (Nagy 2001)	Whitworth et al. (1991)
Sodium arsenite	mallard (young)	25	50	diet for 154 days	reduced survival (40%)[e]	250 (ww)	500 (ww)	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	USFWS (1964)

[a] Adverse effect on growth was observed; however, growth effect was recovered and does not warrant a LOAEL.
[b] Birds were exposed to multiple chemicals (both copper and arsenic).
[c] Concentration in food converted to dry weight assuming 10% moisture in laboratory-prepared food.
[d] Reproductive effects may have been the result of insufficient food intake.
[e] There was 12 to 31% mortality in controls and 12% mortality at NOAEL.

BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

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4.1.2 Cadmium

Nine laboratory studies on the toxicity of dietary cadmium to birds (Cain et al. 1983; Freeland and Cousins 1973; DiGiulio and Scanlon 1984; Heinz and Haseltine 1983; Leach et al. 1979; Pritzl et al. 1974; Richardson et al. 1974; White and Finley 1978b, a) were evaluated. Table 4-3 presents the cadmium NOAELs and LOAELs calculated from the studies evaluated.

Dietary cadmium exposure resulted in reproductive, growth, and behavior effects in chickens, mallards, and black ducks. LOAELs ranging from 0.40 mg/kg bw/day for avoidance behavior in black duck chicks (Heinz and Haseltine 1983) to 47 mg/kg bw/day for growth of mallards (DiGiulio and Scanlon 1984) were reported in four studies. At the lowest LOAEL avoidance response behavior of offspring was significantly altered (compared with the control group) in mallards fed 4.0 mg/kg cadmium as cadmium chloride prior to and after hatching until chicks were one week old (Heinz and Haseltine 1983). However, in this study, no significant effect on avoidance behavior was observed in mallards fed 10 mg/kg ww, and therefore, no clear dose-response relationship was reported. In the other two studies reviewed, higher LOAELs were calculated. At 2.9 mg/kg bw/day, egg production and eggshell thickness was reduced in leghorn hens (Leach et al. 1979). Egg production in a domestic species is not an appropriate endpoint for TRV selection for assessing risks to Portland Harbor avian receptors; and it is unknown if the degree to which eggshell thinning observed in chickens would affect other non-domestic species and reproductive success.

The next highest LOAEL with a dose-response effect, 4.0 mg/kg bw/day, based on Richardson et al. (1974) represents a more appropriate toxicological threshold for cadmium exposure to evaluate risks to bird receptors in the LWG Study Area, and this LOAEL TRV was recommended. At this dose, growth was affected in Japanese quail chicks. The lowest growth NOAEL of 1.6 mg/kg bw/day (Cain et al. 1983) below this LOAEL also represents a more appropriate no-effects toxicological threshold and was recommended as the NOAEL TRV. The number of acceptable toxicity studies for cadmium toxicity to birds is limited; thus, there is some uncertainty associated with the selected TRVs.

Table 4-3. Cadmium Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Cadmium chloride	black duck	NA	0.40	diet for 4 months prior to egg laying – 1 week after hatching	avoidance response in 7-day-old chicks[a]	NA	4.0 (ww)	1.25 (Dunning 1993)	0.125 (ww) (Heinz et al. 1987)	Heinz and Haseltine (1983)
Cadmium sulfate	chicken	0.73	2.9	diet for 48 weeks	reduced egg production, shell thickness	12.22	48.22 (ww)	0.1019 (NRC 1984)	1.7 (ww) (NRC 1984)	Leach et al. (1979)
Cadmium chloride	mallard (young)	**1.6**	NA	diet for 12 weeks	body weight, femur density	16.2	NA	0.8825	0.0883 (ww) (Heinz et al. 1987)	Cain et al. (1983)
Cadmium chloride	Japanese quail (chicks)	NA	**4.0**	diet for 6 weeks	reduced male body weight	NA	75 (dw)[b]	0.093	0.0050 (dw) (Nagy 2001)	Richardson et al. (1974)
Cadmium chloride	mallard	19	NA	diet for 90 days	no effect on survival	200	NA	1.153	0.110 (ww)	White and Finley (1978b)
Cadmium chloride	mallard	20	NA	diet for 30 to 90 days	no effect on body weight or adult survival	210	NA	1.153	0.110 (ww)	White and Finley (1978a)
Cadmium chloride	chicken (chicks)	NA	24	diet for 21 days	reduced male body weight	NA	75 (dw)[b]	0.138	0.0434 (dw) (NRC 1994)	Freeland and Cousins (1973)
Cadmium chloride	mallard	1.5	20	diet for 30 to 90 days	reduced egg production[c]	15.2	210	1.153	0.110 (ww)	White and Finley (1978a)
Cadmium chloride	chicken (chicks)	NA	40	diet for 20 days	reduced male body weight	NA	400 (dw)[b]	0.574 (NRC 1994)	0.0577 (dw) (NRC 1994)	Pritzl et al. (1974)
Cadmium chloride	mallard	16	47	diet for 42 day	reduced body weight	150	450 (ww)	1.119 (NOAEL, 1.027 (LOAEL)	0.122 (NOAEL), 0.108 (LOAEL)	DiGiulio and Scanlon (1984)

[a] Avoidance response effect was no observed as a clear dose-response (no effect on avoidance response was observed at a higher dose level).
[b] Concentration in food reported in dry weight.
[c] Observed effects were not consistent with a clear dose-response relationship.
BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.1.3 Chromium

Five studies that exposed birds to dietary chromium (Chung et al. 1985; Haseltine et al. unpublished; Jensen and Maurice 1980; Lien et al. 2004; Romoser et al. 1961) were evaluated and one study that exposed birds to chromium via intraperitoneal injection (Burger and Gochfeld 1995b) was reviewed. Table 4-4 presents the chromium NOAELs and LOAELs calculated from the studies evaluated.

Observed adverse effects included mortality in adults and offspring, depressed growth, and altered behavior (including balance, depth perception, thermoregulation, and begging behaviors) were observed in chickens, black ducks, and herring gulls. LOAELs ranged from 5.0 mg/kg bw/day for reproduction of black duck offspring [Haseltine et al. (unpublished) as cited in Sample (1996)] to 465 mg/kg bw/day for growth of chicks (Chung et al. 1985). At the lowest LOAEL of 5.0 mg/kg bw/day, [Haseltine et al. (unpublished) as cited in Sample (1996)] reported a decrease in offspring survival of adult black ducks treated with trivalent chromium over a chronic period (10 months). NOAELs ranged from 0.10 mg/kg bw/day for egg weight and eggshell thickness in chickens (Lien et al. 2004) to 465 mg/kg bw/day for survival of chicks (Chung et al. 1985). At the lowest NOAEL of 0.10 mg/kg bw/day, no effect on eggshell weight and shell thickness was reported in domestic chickens (Lien et al (2004); however, the effect of eggshell thinning on actual reproductive success (e.g., hatchability or offspring viability) was not reported. At the lowest NOAEL of 0.17 mg/kg bw/day, no effect on egg production was reported in domestic chickens; however, egg production in a domestic species is not an appropriate endpoint for assessing risks to Portland Harbor avian receptors. At the next lowest NOAEL of 1.0 mg/kg bw/day, no effect on offspring survival was observed in black ducks [Haseltine et al. (unpublished) as cited in Sample (1996)].

The LOAEL and NOAEL of 5.0 and 1.0 mg/kg bw/day, respectively, were recommended as the TRVs for chromium. The recommended LOAEL TRV was the lowest LOAEL calculated from the literature reviewed, and the recommended NOAEL TRV was the lowest acceptable NOAEL calculated. There is uncertainty associated with the TRV literature dataset for chromium because of the limited number of studies reporting adverse effects and the high variability of these effect levels. In addition, there is uncertainty associated with the recommended TRVs because the original source could not be reviewed.

Table 4-4. Chromium Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg/day)	Source
Chromium picolinate	chicken	0.10	NA	diet for 28 days	no effect on egg weight or shell thickness[a]	1.6	NA	1.7 (NRC 1984)	0.1019 (NRC 1984)	Lien et al. (2004)
Chromium chloride	chicken	0.17	NA	diet for 4 weeks	no effect on egg production or weight, interior egg quality	2.9	NA	1.71 (NRC 1984)	0.0997 (NRC 1984)	Jensen and Maurice (1980)
Chromium potassium sulfate (Cr^{3+})	black duck	**1.0**	**5.0**	diet for 10 months	reduced offspring duckling survival	10	50	1.25 (Dunning 1993)	0.125 (Heinz et al. 1987)	Haseltine et al. unpub as cited in Sample (1996)[b]
Sodium chromate	chicken (chicks)	7.7	NA	diet for 22 days	no effect on survival or adult male body weight	32.1	NA	0.12 (NRC 1994)	0.0286 (NRC 1994)	Romoser et al. (1961)
Chromium nitrate	herring gull (chicks)	NA	22.8	single injection + 48 days untreated	depressed growth and altered behavior (balance, depth perception, thermo-regulation, and begging behavior)	NA	NA	NA	NA	Burger and Gochfeld (1995b)
Potassium chromate (Cr^{6+})	chicken (chicks)	NA	105	diet for 2 weeks	reduced body weight, reduced adult survival	NA	900	0.254 (NRC 1994)	0.0295 (NRC 1994)	Chung et al. (1985)
Chromium sulfate (Cr^{6+})	chicken (chicks)	NA	465	diet for 2 weeks	reduced body weight	NA	4,000	0.254 (NRC 1994)	0.0295 (NRC 1994)	Chung et al. (1985)
Chromium sulfate (Cr^{6+})	chicken (chicks)	465	NA	diet for 2 weeks	no effect on survival	4,000	NA	0.254 (NRC 1994)	0.0295 (NRC 1994)	Chung et al. (1985)

[a] Effect of eggshell thinning on reproductive success (e.g., hatchability or offspring viability) was not reported.

[b] Original paper could not be located.

BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.1.4 Copper

Seven studies on the toxicity of dietary copper to birds (Mehring et al. 1960; Persia et al. 2004; Dozier et al. 2003; Smith 1969; Balevi and Coskun 2004; Lien et al. 2004; Poupoulis and Jensen 1976) were evaluated for TRV selection. Table 4-5 presents the copper NOAELs and LOAELs calculated from the studies evaluated. Three of the reviewed studies that evaluated the dietary toxicity of copper to birds reported impaired growth in young chickens. LOAELs based on reduced chick growth ranged from 29 mg/kg bw/day (Smith 1969) to 66 mg/kg bw/day (Persia et al. 2004). NOAELs based on chick growth ranged from 2.1 mg/kg bw/day (Dozier et al. 2003) to 47 mg/kg bw/day (Mehring et al. 1960). Only one of the studies evaluated the chronic effects (i.e., over 10 weeks) of dietary copper exposure (Mehring et al. 1960).

Thus, the LOAEL and NOAEL of 62 and 47 mg/kg bw/day, respectively, were recommended from Mehring et al. (1960) as the TRVs. The TRVs were recommended from this study because TRVs based on chronic exposures are preferred when data are available. The highest NOAEL and LOAEL were calculated from Mehring et al. (1960); however, growth was affected in the other two studies during a subchronic period (4 weeks), and it is unknown whether the adverse effects on growth would persist over time.

Table 4-5. Copper Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoint	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Copper sulfate	chicken (chicks)	2.1	NA	diet for 17 days	no effect on body weight or survival	18 (dw)	NA	0.254 (NRC 1994)	0.0295 (dw) (NRC 1994)	Dozier et al. (2003)
Copper sulfate	chicken	11.2	NA	diet for 90 days	no effect on damaged egg ratio or egg weight and survival	200 (dw)	NA	1.71 NRC 1994)	0.09585 (dw)	Balevi and Coskun (2004)
Copper sulfate	chicken	15	NA	diet for 28 days	no effect on egg weight or shell thickness	250 (ww)	NA	1.70 (NRC 1984)	0.1019 (ww) (NRC 1984)	Lien et al. (2004)
Copper sulfate	chicken (1 day old)	16	29	diet for 25 days	reduced growth	200 (ww)	350 (ww)	0.534 (EPA 1993)	0.044 (ww) (EPA 1993)	Smith (1969)
Copper sulfate	chicken (chicks)	21	41	diet for 4 weeks	reduced growth, gizzard erosion	250 (ww)	500 (ww)	0.534 (EPA 1993)	0.044 (ww) (EPA 1993)	Poupoulis and Jensen (1976)
Copper oxide	chicken (chicks)	**47**	**62**	diet for 10 weeks	reduced growth and survival	570 (ww)	749 (ww)	0.534 (EPA 1993)	0.044 (ww) (EPA 1993)	Mehring et al. (1960)
Copper chloride	chicken (chicks)	NA	66	diet for up to 22 days	reduced body weight	NA	500 (dw)	0.3845	0.0509 (dw)	Persia et al. (2004)

BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.1.5 Lead

A total of 14 papers on the potential adverse effects of lead on birds (Burger and Gochfeld 1994; Kendall and Scanlon 1982; Edens et al. 1976; Edens and Garlich 1983; Burger and Gochfeld 1988, 1993, 1995b, a; Gochfeld and Burger 1988; Pattee 1984; Finley et al. 1976; Hoffman et al. 1985; Morgan et al. 1975; Burger 1990) were reviewed. Table 4-6 presents the lead NOAELs and LOAELs calculated from the studies reviewed. The mechanisms of exposure included oral intubation, intraperitoneal injection, and dietary ingestion. The injected concentrations that resulted in adverse effects were much higher than dietary doses that resulted in toxicity. Observed adverse effects resulting from oral exposure were reported in Japanese quail, chickens, American kestrel nestlings, herring gulls, and common terns. Various endpoints were measured, including egg production, adult mortality, adult fertility, eggshell thinning, hatchability, growth, and behavior effects such as altered locomotor activity, thermoregulation behavior, balance, feeding behavior, and depth perception.

LOAELs ranged from 0.2 mg/kg bw/day for egg production of Japanese quail (Edens et al. 1976; Edens and Garlich 1983) to 400 mg/kg bw/day for mortality of common tern chicks (Burger and Gochfeld 1988). At the lowest LOAELs, ranging from 0.2 to 3.3 mg/kg bw/day, egg production in Japanese quail and chickens was reduced; however, this endpoint was considered inappropriate for assessing risks to Portland Harbor avian receptors. At the next lowest LOAEL of 20 mg/kg bw/day, hatchability of eggs was affected in Japanese quail fed 20 mg/kg bw/day (Edens et al. 1976). NOAELs ranged from 0.2 mg/kg bw/day for egg production of Japanese quail (Edens and Garlich 1983) to 75 mg/kg bw/day for growth of ringed turtle doves (Kendall and Scanlon 1982).

The LOAEL and NOAEL of 20 and 2.0 mg/kg bw/day, respectively, were recommended as TRVs. The recommended LOAEL was the lowest LOAEL based on an appropriate endpoint (lower LOAELs were reported for egg production in domestic quail). LOAELs reported in all other studies were 100 mg/kg bw/day or greater; thus, the selected LOAEL represents a conservative level based on quail. Domestic species, such as Japanese quail, may have a higher sensitivity to lead, and the selected LOAEL may overestimate risk to the selected avian receptors in Portland Harbor. It appears from the reviewed studies that common terns, herring gulls, and American kestrels are less sensitive to lead, even during chick development. The recommended NOAEL was reported in the same study and represents the lowest acceptable NOAEL reported in the literature reviewed.

Table 4-6. Lead Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Lead acetate	Japanese quail (hatchings)	NA	0.2	diet for 5 weeks	reduced egg production	NA	1.0 (ww)	0.155 (Edens and Garlich 1983)	0.031 (Edens and Garlich 1983)	Edens and Garlich (1983); Edens et al. (1976)
Lead acetate	Japanese quail, (6 weeks old)	0.2	2.0	diet for 5 weeks	reduced egg production	1.0 (ww)	10 (ww)	0.155 (Edens and Garlich 1983)	0.031(Edens and Garlich 1983)	Edens and Garlich (1983)
Lead nitrate	mallard (first year)	2.5	NA	diet for 12 weeks	no effect on survival, or occurrence of pathologic lesions	25 (ww)	NA	1.082 (Dunning 1993)	0.1082 (Heinz et al. 1987)	Finley et al. (1976)
Lead acetate	chicken	1.64	3.3	diet for 4 weeks	reduced egg production	25 (ww)	50 (ww)	1.84 (Edens and Garlich 1983)	0.121 (Edens and Garlich 1983)	Edens and Garlich (1983)
Metallic lead powder	American kestrel	5.82	NA	diet for 5 to 7 months	no effect on survival, fertility, egg production, or eggshell thinning	55.6 (dw)[a]	NA	0.13	0.0136 (dw) Nagy (2001)	Pattee (1984)
Lead acetate	ringed turtle dove	10.9	NA	drinking water for 2 weeks prior to during reproduction	no effect on onset of egg laying, egg production, juvenile body weight, or egg fertility	NA	NA	NA	NA	Kendall and Scanlon (1981)
Lead acetate	Japanese quail	**2.0**	**20**	diet for 12 weeks	reduced egg hatchability	10 (ww)	100 (ww)	0.155 (Edens and Garlich 1983)	0.031 (Edens and Garlich 1983)	Edens et al. (1976)
Lead acetate	Japanese quail (chicks)	5.5	28	diet for 6 weeks	reduced body weight	100 (dw)[b]	500 (dw)[b]	0.0715	0.0040 (dw) Nagy (2001)	Morgan et al. (1975)

Table 4-6. Lead Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Lead acetate	ringed turtle dove	75	NA	oral intubation for 7 days	no effect on growth	100	NA	0.155 (Sample et al. 1996)	0.031 (Edens and Garlich 1983)	Kendall and Scanlon (1982)
Metallic lead powder	American kestrel (nestlings)	25	125	oral intubation for 10 days	reduced growth	NA	NA	NA	NA	Hoffman et al. (1985)
Lead acetate	herring gull (chicks)	50	100	single IP injection + 42 days untreated	altered thermoregulation behavior (increased time to reach shade)	NA	NA	NA	NA	Burger and Gochfeld (1995a)
Lead nitrate	herring gull (chicks)	NA	100	single IP injection + 45 days untreated	altered behavior (righting response, balance, individual recognition, begging, thermoregulation, fish-swallowing speed, and depth perception)	NA	NA	NA	NA	Burger (1990)
Lead nitrate	herring gull (chicks)	NA	100	single IP injection + 18 days untreated	altered behavior (response time, locomotor activity, required longer time to reach food)	NA	NA	NA	NA	Burger and Gochfeld (1993)
Lead acetate	herring gull (chicks)	NA	100	single IP injection + 21 days untreated	depressed growth (temporarily significant) and altered behavior (depressed begging and walking activity, increased error rate in pecking behavior while feeding)	NA	NA	NA	NA	Burger and Gochfeld (1988)

Table 4-6. Lead Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Lead nitrate	common tern (chicks)		200	single IP injection + 21 days untreated	depressed growth and reduced feeding efficiency (ability to manipulate fish)	NA	NA	NA	NA	Gochfeld and Berger (1988)
Lead nitrate	common tern (chicks)		200	two IP injections at day 2 and 7	altered behavior (locomotion, righting response, and depth perception)	NA	NA	NA	NA	Burger and Gochfeld (1988)
Lead nitrate	common tern (chicks)		200	single IP injection + 25 days untreated	depressed growth and altered behavior (locomotion, balance, righting response, feeding tasks, depth perception, and thermoregulation)	NA	NA	NA	NA	Burger and Gochfeld (1985)
Lead nitrate	common tern (chicks)		400	two IP injections at day 2 and 7	reduced survival (20%)	NA	NA	NA	NA	Burger and Gochfeld (1988)

[a] Concentration in food converted to dry weight assuming 10% moisture in laboratory-prepared food

[b] Concentration in food reported in dry weight.

BW – body weight

dw – dry weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

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4.1.6 Mercury

A total of 18 papers on the potential adverse effects of mercury on birds were reviewed. The mechanisms of exposure included gavage, injection, and ingestion (via food or dietary capsule). Field studies that measured mercury residues and considered reproductive effects in wild bird populations were reviewed.

Dietary TRVs

Fourteen studies measuring the toxicity of dietary mercury via injection or oral ingestion (Heinz 1974, 1975, 1979, 1976; Hill and Soares 1987; Peakall and Lincer 1972; Bouton et al. 1999; Heinz 1980; Kreitzer and Heinz 1974; Leander et al. 1977; Scheuhammer 1988; Stoewsand et al. 1971; Spalding et al. 2000; Spann et al. 1986) were reviewed. Table 4-7 presents the mercury NOAELs and LOAELs calculated from the studies reviewed. Observed adverse effects on reproduction (including reduced egg production, hatchability, offspring survival, and eggshell thickness), growth, survival, and behavior (including altered avoidance response, motivation to hunt prey, thermoregulation, maintenance, and learning response behaviors) resulting from dietary exposure were reported in mallards, young great egrets, Japanese quail, zebra finch, bobwhites, and pigeons. LOAELs ranged from 0.064 mg/kg bw/day for egg production and altered behavior in offspring of mallards (Heinz 1975, 1979) to 62 mg/kg bw/day for offspring mortality of Japanese quail (Hill and Soares 1987). NOAELs ranged from 0.064 mg/kg bw/day for offspring survival, altered behavior in offspring of mallards (Heinz 1974, 1976) to 5.24 mg/kg bw/day for eggshell thickness in American kestrels (Peakall and Lincer 1972). At the lowest LOAEL of 0.064 mg/kg bw/day, offspring production was reduced, and avoidance response and maternal response behavior in ducklings was impaired in mallard ducks fed mercury for multiple generations (Heinz 1975, 1979), but no effects on reproduction were reported Heinz (Heinz 1974, 1976).

The LOAEL of 0.064 mg/kg bw/day mercury was selected as the LOAEL. No dietary dose that was lower than this selected LOAEL was calculated from the literature, so no dietary NOAEL TRV was selected. The selected LOAEL represented the most conservative number available from the literature reviewed; however, it is uncertain because the literature did not always report adverse effects at this level. Therefore, the selected LOAEL may or may not always result in an adverse effect.

Table 4-7. Mercury Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Methylmercury dicyandiamide	mallard	NA	**0.064**	diet for multiple generations	reduced avoidance response in 2- and 8-day-old chicks	NA	0.5 (ww)	1.0 (Dunning 1993)[a]	0.128 (ww) (Heinz et al. 1987)[a]	Heinz (1975)
Methylmercury	mallard	NA	**0.064**	diet for three generations	reduced egg and young production, eggshell thinning, duckling avoidance response and reduced response to maternal call behavior	NA	0.5 (ww)	1.0 (Dunning 1993)[a]	0.128 (ww) (Heinz et al. 1987)[a]	Heinz (1979)
Methylmercury chloride	great egret (1 day old)	NA	0.091	diet for 14 weeks	reduced growth	NA	0.5 (ww)	1.02 (Fish 2002)	0.185 (ww) (Kushlan 1978)	Spalding et al. (2000)
Methylmercury chloride	great egret (juvenile)	NA	0.091	gelatin capsule for approx 6 weeks	reduced motivation to hunt prey, tendency to seek shade, altered maintenance behavior and activity	NA	0.5 (ww)	1.02 (Fish 2002)	0.185 (ww) (Kushlan 1978)	Bouton et al. (1999)
Methylmercury dicyandiamide	mallard	0.050	0.30	diet for 12 months through hatching	reduced hatching success, egg production, and reduced duckling survival to 1 week of age	0.5 mg/kg ww	3.0 (ww)	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Heinz (1974)
Methylmercury	mallard	0.050	0.30	diet for 2 years	reduced offspring survival, altered offspring avoidance response behavior	0.5 mg/kg ww	3.0 (ww)	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Heinz (1976)
Methylmercury chloride	Japanese quail	NA	0.30	diet for 8 days treated + 6 days untreated	altered avoidance response behavior (depressed response to stimuli)	NA	5.6 (dw)[b]	0.09 (Dunning 1993)	0.0048 (dw) (Nagy 2001)	Kreitzer and Heinz (1974)
Methylmercury chloride	mallard	0.50	NA	diet for > 60 days	no effect on eggshell thickness	5.0 mg/kg ww	NA	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Heinz (1980)
Methylmercury chloride	Japanese quail	NA	0.9	diet for 5 days	reduced hatchling survival (84%)	NA	17.75 (dw)[b]	0.1 (NRC 1994)	0.0053 (dw) (Nagy 2001)	Hill and Soares (1987)

Table 4-7. Mercury Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
	(chicks)									
Methylmercury chloride	zebra finch	0.72	1.4	diet for 76 days	reduced survival	2.5 mg/kg dw[b]	5 (dw)[b]	0.012 (Dunning 1993)	0.0034 (dw) (Nagy 2001)	Scheuhammer (1988)
Methylmercury chloride	northern bobwhite (12 days old)	0.43	1.6	diet for 6 weeks	reduced survival	5.4 mg/kg ww	20 (ww)	0.19 (EPA 1993)	0.0150 (ww) (EPA 1993)	Spann et al. (1986)
Mercuric chloride	Japanese quail, (1 day old)	0.80	1.6	diet for 10 weeks	reduced eggshell thickness	4 mg/kg ww	8 (ww)	0.155 (Edens and Garlich 1983)	0.031 (ww) (Edens and Garlich 1983)	Stoewsand et al. (1971)
Mercuric chloride	white corneaux pigeon	1.0	3.0	daily (inter-muscular) injections for up to 60 days	decreased learning response[c]	NA	NA	NA	NA	Leander et al. (1977)
Dimethyl mercury	American kestrel	5.24	NA	diet for 3 months	no effect on eggshell thickness	50 mg/kg dwd[d,e]	NA	0.13 (Pattee 1984)	0.0136 (dw) (Nagy 2001)	Peakall and Lincer (1972)
Methylmercury chloride	Japanese quail	NA	6.4	gavage	reduced survival (LC50)	NA	NA	NA	NA	Hill and Soares (1987)
Methylmercury chloride	Japanese quail	NA	8.8	injection	reduced survival (LC50)	NA	NA	NA	NA	Hill and Soares (1987)
Mercuric chloride	Japanese quail	NA	11.1	gavage	reduced survival (LC50)	NA	NA	NA	NA	Hill and Soares (1987)
Mercuric chloride	Japanese quail	NA	19.2	injection	reduced survival (LC50)	NA	NA	NA	NA	Hill and Soares (1987)
Mercuric chloride	Japanese quail	NA	62	diet for 5 days	reduced hatchling survival (88%)	NA	1,160 (dw)[b]	0.1 (NRC 1994)	0.0053 (dw) (Nagy 2001)	Hill and Soares (1987)

Table 4-7. Mercury Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
	(chicks)									

[a] As cited in Sample et al. (1996).

[b] Concentration in food converted to dry weight assuming 10% moisture in laboratory-prepared food

[c] Effect on learning response was inconsistently impaired at lowest dose (NOAEL) and consistently impaired at LOAEL.

[d] Dietary concentration (10 mg/kg) was assumed to be based on a wet weight (ww) basis and was converted into dry weight (dw) to calculate dietary dose assuming 80% moisture in diet of day-old chicks.

[e] Concentration in food converted to dry weight assuming 80% moisture in prey tissue

BW – body weight

dw – dry weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

Egg TRVs

A total of eight laboratory studies and field studies reporting mercury concentrations and associated effects were reviewed. These studies are summarized below. Six laboratory studies reporting mercury concentrations in eggs (Heinz 1974, 1979, 1976; Heinz and Hoffman 2003; Stoewsand et al. 1971; Scott et al. 1975) were reviewed. Table 4-8 presents the egg NOAELs and LOAELs reported in the laboratory studies reviewed. All laboratory studies reported mercury concentrations in eggs laid from adult birds exposed through the dietary pathway (as presented above). In the laboratory, egg LOAELs ranged from 0.7 µg/g ww for eggshell thickness of Japanese quail (Stoewsand et al. 1971) to 40.2 µg/g ww for reproduction of chickens (Scott et al. 1975). At the lowest egg LOAEL of 0.7 µg/g ww, Stoewsand et al. (1971) reported eggshell thinning in Japanese quail; however, no effect on hatchability, fertility, or egg production was measured, indicating that eggshell thinning did not affect overall reproductive success. At the next lowest LOAEL, embryo development of mallards was observed following exposure to dietary methyl mercury chloride during breeding where egg tissue concentrations ranged from 0.74 to 38.0 µg/g ww (Heinz and Hoffman 2003). Egg NOAELs based on laboratory studies ranged from 0.3 µg/g ww for eggshell thickness of Japanese quail (Stoewsand et al. 1971) to 1.05 µg/g ww for reproduction of mallards (Heinz 1976).

In addition to laboratory studies, two field studies that measured mercury concentrations (Wiemeyer et al. 1984; Haseltine et al. 1981) were reviewed. Table 4-8 also presents the egg NOAELs derived from the field studies reviewed. Wiemeyer et al. (1984) suggested an egg threshold concentration of 0.5 µg/g ww as the concentration at which adverse effects on reproduction might be expected in bald eagles. Reproductive success (as measured by hatching success) was unaffected in red-breasted merganser populations with geometric mean concentrations in eggs of 0.51 and 0.52 µg/g ww (Haseltine et al. 1981).

The lowest acceptable LOAEL derived from the laboratory studies was 0.74 µg/g ww mercury (Heinz and Hoffman 2003). This was recommended as the LOAEL TRV for mercury in bird eggs. There is uncertainty associated with the recommended egg LOAEL because the mercury egg concentrations reported in the laboratory varied widely. The highest NOAELs reported below the recommended LOAEL were reported in the two field studies reviewed. A NOAEL of 0.5 µg/g ww was recommended based on Wiemeyer et al. (1984), where adverse effects on bald eagle productivity were not expected. This NOAEL is consistent with the field NOAELs reported in Haseltine et al. (1981), in which hatching success was unaffected in red-breasted merganser eggs with concentrations ranging from 0.51 to 0.52 µg/g ww.

There are uncertainties associated with the recommended NOAEL TRV because it is based on a field study. It is difficult to establish threshold levels for mercury in birds based on field-collected eggs (Giesy et al. 1994b) because mercury concentrations in eggs are often associated with other organochlorine concentrations such as DDE and PCBs (Wiemeyer et al. 1984; Haseltine et al. 1981; Eisler 1987), and the interaction may intensify adverse effects to avian populations. Adverse effects on bald eagle reproduction

Table 4-8. Mercury Bird Egg Toxicity Studies

Chemical Form	Species	NOAEL (µg/g ww)	LOAEL (µg/g ww)	Exposure Conditions	Endpoint Effect	Source
Mercury	bald eagle	**0.50**		14 states, 1969 to 1979	5-year productivity	Wiemeyer et al. (1984)
Mercury	red-breasted merganser	0.52		Lake Michigan, 1977 and 1978	hatching success	Haseltine et al. 1981
Mercuric chloride	Japanese quail (1 day old)	0.30	0.7	laboratory diet for 10 weeks	eggshell thickness	Stoewsand et al. (1971)
Methylmercury chloride	mallard	NA	**0.74** – 38	laboratory diet for reproductive period	impaired embryo development	Heinz and Hoffman (2003)
Methylmercury	mallard	NA	0.83	laboratory diet for three generations	reduced egg and young production, eggshell thinning, duckling response to maternal call, duckling avoidance behavior	Heinz (1979)
Methylmercury chloride	mallard	NA	0.93 – 18	laboratory diet for reproductive period	impaired embryo development	Heinz and Hoffman (2003)
Methylmercury	mallard	0.79 – 1.05	5.46 – 7.39	laboratory diet for 2 years	reduced offspring survival, avoidance response of offspring	Heinz (1976)
Methylmercury dicyandiamide	mallard	1.0	6.0 – 9.0	laboratory diet for through hatching	depressed hatching success, depressed egg production, and reduced duckling survival to 1 week of age	Heinz (1974)
Mercuric sulfate	chicken	NA	29.0	laboratory diet for 8 weeks	reduced hatchability	Scott et al. (1975)
Methylmercury chloride	chicken	NA	40.2	laboratory diet for 8 weeks	reduced egg weight, fertility, hatchability of eggs	Scott et al. (1975)

LOAEL – lowest-observed-adverse-effects level
NOAEL – no-observed-adverse-effects level
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as the TRVs.

were reported in Wiemeyer et al. (1984); however, these effects were attributed primarily to PCBs and DDT, and the effects of mercury were not clear. Thus, the NOAEL TRV for mercury was based on the mercury NOAEL reported in Wiemeyer et al. (1984).

4.1.7 Selenium

Five studies that exposed screech owls, chickens, or mallards to selenium through diet were reviewed and evaluated for TRV selection (Heinz et al. 1988, 1989; Heinz et al. 1987; Choct et al. 2004; Wiemeyer and Hoffman 1996). Table 4-9 presents the selenium NOAELs and LOAELs calculated from the studies evaluated. The mechanism of exposure included dietary ingestion only. Observed adverse effects on offspring survival and growth, embryo development, adult growth, reproductive success, and adult mortality were reported in mallards and screech owls.

LOAELs ranged from 0.82 mg/kg bw/day for reproduction of mallards (Heinz et al. 1989) to 10 mg/kg bw/day for mortality of mallards (Heinz et al. 1988, 1989). NOAELs ranged from 0.025 mg/kg bw/day for growth and survival of chickens (Choct et al. 2004) to 4.6 mg/kg bw/day for mortality of mallards (Heinz et al. 1988). In the study reporting the lowest LOAEL of 0.82 mg/kg bw/day offspring survival and growth was significantly affected for mallards fed selenomethionine for about 100 days (Heinz et al. 1989). The NOAEL reported in this study was 0.42 mg/kg bw/day, where no significant effect on offspring survival and growth was observed (Heinz et al. 1989).

The LOAEL and NOAEL of 0.82 and 0.42 mg/kg bw/day, respectively, were recommended as the LOAEL and NOAEL for dietary selenium in birds. The TRVs are based on the bird species with the highest sensitivity (mallards). The sensitivity of other bird birds is unknown because only mallards and screech owls were considered in the literature reviewed.

Table 4-9. Selenium Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoint	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg/day)	Source
Sodium selenite or sel-plex 50	broiler chicken (chicks)	0.025	NA	diet for approximately 40 days	no effect on body weight	0.25 (dw)	NA	0.993	0.0995 (dw)	Choct et al. (2004)
Seleno-methionine	mallard	**0.42**	**0.82**	diet for approximately 100 days	reduced offspring growth/survival	4.15 (ww)	8.15	1.158 (NOAEL); 1.145 (LOAEL)	0.1158 (NOAEL); 0.1145 (LOAEL) (ww) (Heinz et al. 1987)	Heinz et al. (1989)
Sodium selenite	mallard	0.50	1.0	diet for 7 weeks during reproductive period	embryo abnormalities	5 (ww)	10	1.036 (NOAEL); 1.046 (LOAEL)	0.105 (ww)	Heinz et al. (1987)
Seleno-methionine	mallard	1.6	NA	diet for approximately 100 days	no effect on body weight or survival	10 (ww)	25	1.046 (NOAEL); 0.938 (LOAEL)	0.105 (NOAEL); 0.094 (LOAEL) (ww)	Heinz et al. (1989)
Sodium selenite	mallard	1.0	2.5	diet for 7 weeks during reproductive period	reduced adult growth	16.15 (ww)	NA	1.107	0.1107 (ww) (Heinz et al. 1987)	Heinz et al. (1987)
Seleno-methionine	screech owl	1.0	3.2	diet for approximately 3 months	reduced body weight, hatching success, 5-day offspring survival, clutch size, egg size, and mass[a]	3.7 (ww)	12.1	0.189	0.050 (ww)	Wiemeyer and Hoffman (1996)
Sodium selenite[b]	mallard	4.6	NA	diet for 42 days	no effect on survival	20.1 (ww)	NA	0.326	0.075 (ww)	Heinz et al. (1988)

Table 4-9. Selenium Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoint	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg/day)	Source
Sodium selenite[b]	mallard	2.1	4.6	diet for 42 days	reduced body weight[a]	10.1 (ww)	20.1	0.326	0.075 (ww)	Heinz et al. (1988)
Sodium selenite	mallard	2.5	10	diet for 7 weeks during reproductive period	reduced adult survival (0%)	25 (ww)	100	0.718	0.072 (ww)	Heinz et al. (1987)
Sodium selenite[b]	mallard	NA	10	diet for 42 days	reduced survival	NA	40.1	0.146	0.038 (ww)	Heinz et al. (1988)

[a] Food avoidance also observed and may have affected body weight gain (growth) endpoint.

[b] Selenomethionine was also administered to mallards in the diet; however, this chemical form of selenium was found to be less toxic than sodium selenite.

BW – body weight

dw – dry weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.1.8 Thallium

Only two studies were reviewed on thallium toxicity to birds (Hudson et al. 1984; Bean and Hudson 1976). Table 4-10 presents the thallium NOAELs and LOAELs calculated from the studies reviewed. The mechanisms of exposure included dietary ingestion of oral capsule and oral gavage. Mortality was observed in pheasants, golden eagles, and mallards following exposure to dietary thallium. LOAELs ranged from 24 mg/kg bw/day for mortality of pheasants (Hudson et al. 1984) to 37 mg/kg bw/day for mortality of mallards (Hudson et al. 1984). At the lowest LOAEL, Hudson et al. (1984) reported a lethal concentration where 50% mortality (LC50) was observed in pheasants following exposure to thallium as thallium sulfate via oral gavage. Only one NOAEL of 17 mg/kg bw/day was reported where no effect on mortality was reported in golden eagles given a single dose of 17 mg/kg bw/day of thallium (Bean and Hudson 1976).

The selected LOAEL TRV of 24 mg/kg bw/day was based on Hudson et al. (1984). This was the lowest LOAEL reported in the reviewed literature; however, there is high uncertainty associated with this selected LOAEL because high mortality was observed over a short exposure period (14 days). No NOAEL was reported in the literature reviewed below the selected LOAEL, so none was selected. There is high uncertainty associated with the literature dataset for thallium toxicity to birds due to the paucity of studies available.

Table 4-10. Thallium Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/d)	Source
Thallium sulfate	pheasant	NA	**24**	oral gavage for up to 14 days	reduced survival (LD50)	NA	NA	NA	NA	Hudson et al. (1984)
Thallium sulfate	golden eagle	17	34	gelatin capsule single dose + 21 days observed post-treatment	reduced survival (LD50)	NA	NA	NA	NA	Bean and Hudson (1976)[a]
Thallium sulfate	mallard	NA	37	oral gavage for up to 14 days	reduced survival (LD50)	NA	NA	NA	NA	Hudson et al. (1984)

[a] Study was uncontrolled study and a small sample size (n=3) was tested. Two of three of the birds died following the administration of one single dose and observation over 21 days after treatment.

BW – body weight

LD50 – dose that is lethal to 50% of an exposed population

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.1.9 Zinc

Six studies on zinc toxicity to birds (Dozier et al. 2003; Oh et al. 1979; Persia et al. 2004; Gasaway and Buss 1972; Roberson and Schaible 1960; Stahl et al. 1990) were evaluated. Table 4-11 presents the zinc NOAELs and LOAELs calculated from the studies evaluated. The mechanism of exposure included dietary ingestion only. Adverse effects on growth and survival in young birds (mallards or chicken) were observed in three of the four studies evaluated for TRV selection. LOAELs ranged from 124 mg/kg bw/day for growth of young chickens (Roberson and Schaible 1960) to 659 mg/kg bw/day for mortality and growth of young broiler chickens (Oh et al. 1979). NOAELs ranged from 17 mg/kg bw/day for growth of young chickens (Dozier et al. 2003) to 330 mg/kg bw/day for mortality and growth of young broiler chickens (Oh et al. 1979). In the study from which the lowest LOAEL was calculated, a reduction in white rock chick growth was measured following dietary exposure to zinc for five weeks (Roberson and Schaible 1960).

The lowest LOAEL, 124 mg/kg bw/day, was recommended as the LOAEL TRV, and the NOAEL, 82 mg/kg bw/day, reported in the same study was also recommended. There is uncertainty associated with the recommended LOAEL because the growth effects observed in chicks did not take place over a chronic exposure period or during a critical life stage, and it is unknown whether or not the adverse effect on growth would persist over time. However, none of the studies reporting an effect level concentration was conducted over a chronic exposure or during a critical life stage.

Table 4-11. Zinc Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Zinc sulfate	chicken (chicks)	17[a]	NA	diet for 17 days	no effect on body weight or survival	150 (dw)	NA	0.254 (NRC 1994)	0.0295 (ww) (NRC 1994)	Dozier et al. (2003)
Zinc oxide, zinc sulfate, or zinc carbonate	chicken (chicks)	**82**	**124**	diet for 5 weeks	reduced growth	1,000 (ww)	1,500 (ww)	0.534 (EPA 1993)	0.044 (ww) (EPA 1993)	Roberson and Schaible (1960)
Zinc carbonate	mallard (7 weeks old)	NA	300	diet for 60 days	reduced survival; leg paralysis	NA	3,000 (ww)	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Gasaway and Buss (1972)
Zinc chloride	chicken (chicks)	NA	344	diet for 8 to 22 days	reduced body weight	NA	2,500 (dw)	0.2873	0.0395 (dw)	Persia et al. (2004)
Zinc acetate	chicken (chicks)	330	659	diet for 5 weeks	reduced survival and growth	4,000 (ww)	8,000 (ww)	0.534 (EPA 1993)	0.044 (ww) (EPA 1993)	Oh et al. (1979)
Zinc sulfate	chicken	133		diet for 44 weeks	no effect on egg hatchability	2,028 (ww)	NA	1.9	0.125 (ww)	Stahl et al. (1990)

[a] NOAEL is based on background concentration in prepared food (30 ppm) plus exposure concentration added to food (120 ppm).

BW – body weight

dw – dry weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.1.10 Tributyltin

Two studies on TBT toxicity to birds (Schlatterer et al. 1993; Coenen et al. 1992) were evaluated for TRV selection. Table 4-12 presents the TBT NOAELs and LOAELs calculated from the studies reviewed. A LOAEL of 3.6 mg/kg bw/day was calculated from both studies. At this concentration, reproduction (including reduced hatchability, embryo mortality, and the number of hatched eggs per pair) were reported in Japanese quail fed 60 mg/kg TBT for six weeks (Schlatterer et al. 1993; Coenen et al. 1992). NOAELs ranged from 1.4 mg/kg bw/day for reproduction of Japanese quail (Schlatterer et al. 1993; Coenen et al. 1992) to 22.5 mg/kg bw/day for growth of Japanese quail (Schlatterer et al. 1993).

The LOAEL and NOAEL of 3.6 and 1.4 mg/kg bw/day, respectively, were recommended. There is some uncertainty associated with the recommended TRVs because the literature dataset for TBT toxicity to birds is limited to two studies reporting the effects in Japanese quail only. The sensitivity of other bird species to TBT is unknown.

4.2 PAHS

Adverse effects in birds resulting from polycyclic aromatic hydrocarbon (PAH) exposure were considered using for individual PAHs and PAH mixtures. Sixteen individual PAHs (i.e., acenaphthene, acenaphthylene, anthracene, benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[g,h,i]perylene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, fluoranthene, fluorine, indeno[1,2,3-cd]pyrene, naphthalene, phenanthrene, and pyrene) were identified as bird COPCs in the BERA; however, toxicological studies were only available for benzo(a)pyrene. Three studies on the dietary toxicity of benzo(a)pyrene were reviewed (Hough et al. 1993; Patton and Dieter 1980; Rigdon and Neal 1963).

4.2.1 Benzo(a)pyrene

Two studies on the dietary toxicity of benzo(a)pyrene were reviewed (Hough et al. 1993; Patton and Dieter 1980; Rigdon and Neal 1963). Table 4-13 presents the benzo(a)pyrene NOAELs and LOAELs calculated from the studies evaluated.The only LOAEL reported was 1.4 mg/kg bw/day, where reduced fertility and ovarian appearance was observed in pigeons given weekly injections of benzo(a)pyrene for five months (Hough et al. 1993). The only NOAEL reported was 33 mg/kg bw/day, where no effect on young chicken growth was observed following ingestion of benzo(a)pyrene for 30 days (Rigdon and Neal 1963). No NOAEL was reported below the lowest LOAEL of 1.4 mg/kg bw/day. The LOAEL of 1.4 mg/kg bw/day benzo(a)pyrene was recommended as the LOAEL TRV. This No NOAEL was available below this selected LOAEL, so none was selected.

Table 4-12. TBT Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Effect Endpoint	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Tributyltin oxide	Japanese quail	**2.7**	**6.8**	diet for 6 weeks	reduced number of hatched eggs per pair[a]	24	60	0.15 (Vos et al. 1971)[b]	0.0169 (Nagy 1987)[b]	Schlatterer et al. (1993)
Tributyltin oxide	Japanese quail	**2.7**	**6.8**	diet for 6 weeks	reduced embryo survival in shell, reduced hatchability	24	60	0.15 (Vos et al. 1971)[b]	0.0169 (Nagy 1987)[b]	Coenen et al. (1992)
Tributyltin oxide	Japanese quail	46.9	NA	diet for 6 weeks	no effect on body weight	375	NA	0.15 (Vos et al. 1971)[b]	0.0169 (Nagy 1987)[b]	Schlatterer et al. (1993)

[a] Effects on reproduction were more dramatic at a higher concentration (150 mg/kg in food) where egg production, egg fertility, hatchability, offspring body weight, and 14-day offspring survival were all significantly affected; however, effect on number of hatched eggs/pair was significantly reduced in birds fed 60 mg/kg (LOAEL TRV).

[b] As cited in Sample et al. (1996).

BW – body weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

ww – wet weight

Table 4-13. Benzo(a)pyrene Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Benzo(a)pyrene	pigeon	NA	**1.4**	weekly intramuscular injection for 5 months	reduced fertility, ovarian appearance	NA	NA	NA	NA	Hough et al. (1993)
Benzo(a)pyrene	chicken	33	NA	diet for 30 days	no effect on body weight gain	500	NA	1.84 (Edens and Garlich 1983)	0.121 (Edens and Garlich 1983)	Rigdon and Neal (1963)

BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.
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There is high uncertainty associated with the selected PAH TRVs for birds. There is uncertainty associated with the selected LOAEL due to the route of exposure (intramuscular injection). Injection is not directly relevant to the dietary exposure pathway for birds, and the selected TRVs may not accurately predict dietary PAH toxicity to birds. In addition, there is uncertainty associated with the frequency of exposure (weekly) and the impact of the measured endpoints (fertility and ovarian appearance) on actual reproductive success at the selected LOAEL. It is unknown whether the effects on fertility would reduce the reproductive potential of pigeons at the population level. Finally, there is uncertainty with the literature dataset for PAHs due to the limited number of studies and the high variability of the effect levels reported.

4.2.2 PAH Mixture

One study was reviewed and evaluated for TRV selection on the toxicity of a PAH mixture to birds (Patton and Dieter 1980). Table 4-14 presents the PAH NOAELs and LOAELs calculated from the studies evaluated. Effects on growth, survival and reproduction were measured in chickens, mallards, and pigeons following exposure to PAHs.

At 40 mg/kg bw/day, growth was adversely affected in mallards fed an petroleum hydrocarbon mixture containing PAHs[3] combined with paraffin wax at three months, however, at seven months, growth was recovered and change in body weight was not significantly different than the control group (Patton and Dieter 1980). The reduction observed in growth at three months was attributed to food avoidance of the aromatic hydrocarbon mixture feed because of the noxious odor of the petroleum hydrocarbons. This dose (40 mg/kg bw/day) was recommended as the NOAEL TRV for HPAHs and LPAHs for birds. No LOAEL TRV was reported in this study, and none was recommended.

There is very high uncertainty associated with the recommended LPAH and HPAHs NOAEL TRV for birds based on the limited toxicological data (one study) reviewed. The selected NOAEL TRV is based on exposure to a petroleum hydrocarbon mixture that contained some individual PAHs. Therefore, birds were exposed to a PAH mixture, in addition to other chemicals. In addition, food avoidance was observed in the mixture PAH study and no LOAEL TRV was derived.

[3] Aromatic hydrocarbon mixture contained the following: ethylbenzene, 1,2,3,4-tetrahydronaphthalene, dimethylnaphthalene, 2,3,3-trimethylindolenine, acenaphthylene, acenaphthlene, phenanthrene, 2-methylbenzothiazole, dibenzothiophene, and 2,6-dimethylquinoline.

Table 4-14. PAH Mixture Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Petroleum hydrocarbon mixture including PAHs	mallard	**40**	NA	diet for 7 months[a]	no change in body weight following duration of study[b]	400	NA	1.23	0.123 (ww) (Heinz et al. 1987)	Patton and Dieter (1980)
Petroleum hydrocarbon mixture including PAHs	mallard	400	NA	diet for 7 months[a]	no effect on survival	4,000	NA	1.22	0.0122 (ww) (Heinz et al. 1987)	Patton and Dieter (1980)

[a] Food was dosed with a petroleum hydrocarbon mixture with paraffin wax in food. The aromatic mixture contained only some percentage of PAHs, not including benzo(a)pyrene.

[b] Body weight was significantly decreased at the NOAEL dose for 3 months, but at 7 months, body weight reduction was recovered and body weight change was not significantly different than the control group.

BW – body weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

ww – wet weight

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.3 PCBS

4.3.1 Total PCBs

A total of 40 studies on the potential adverse effects of PCBs on birds were reviewed. The mechanisms of exposure in the evaluated studies included dietary ingestion and egg injection. In addition, both laboratory and field studies were reviewed.

Dietary TRVs

Twenty-four studies considering the oral toxicity of PCB Aroclors to birds via food or capsule ingestion (Ahmed et al. 1978; Britton and Huston 1973; Lowe and Stendell 1991; Haseltine and Prouty 1980; Scott et al. 1975; McLane and Hughes 1980; Risebrough and Anderson 1975; Platonow and Reinhart 1973; Bird et al. 1983; Cecil et al. 1974; Custer and Heinz 1980; Dahlgren et al. 1972; Fernie et al. 2000; Fernie et al. 2001; Fernie et al. 2003a; Fernie et al. 2003b; Fernie et al. 2003c; Fisher et al. 2001; Hill et al. 1975; Kreitzer and Heinz 1974; Stendell 1980; Peakall et al. 1972; Peakall and Peakall 1973a; Stickel et al. 1984; Tori and Peterle 1983) were evaluated.

In the studies reviewed, reproduction (measuring endpoints such as adult fertility, hatchability, eggshell thickness, egg production, eggshell weight, embryo development, courtship behavior, onset of nest initiation, clutch size, and embryo mortality and viability), avoidance behavior, adult growth, and mortality were affected in seven bird species exposed orally to PCB Aroclor mixtures. These endpoints were measured in the following bird species: American kestrels, chickens, turtle doves, mourning doves, pheasants, Japanese quail, mallard ducks, common grackles, red-winged blackbirds, brown-headed cowbirds, and starlings. Table 4-15 summarizes the NOAELs and LOAELs derived from the dietary PCB studies reviewed. LOAELs ranged from 0.35 mg/kg bw/day for reproduction of American kestrels (Lowe and Stendell 1991) to 15 mg/kg bw/day for reproduction of mallards (Haseltine and Prouty 1980). The lowest calculated LOAEL of all studies reviewed was based on the level at which eggshell weight and thickness were affected in American kestrels fed 0.35 mg/kg bw/day Aroclor 1248 (Lowe and Stendell 1991). However, Lowe and Stendell (1991) did not report the overall effect of eggshell thinning on reproductive success (e.g., hatchability, offspring viability) or the critical degree at which eggshell thinning would affect reproductive success (eggshell thickness of the experimental group was 5% different from the control). The next lowest LOAELs were reported in chickens. Britton and Huston (1973) reported reduced hatchability in chickens fed 0.58 mg/kg bw/day PCBs Aroclor 1242 following six weeks of dietary exposure.

NOAELs ranged from 0.054 mg/kg bw/day for mortality, growth, and reproduction of chickens (Ahmed et al. 1978) to 3.9 mg/kg kg/d for reproduction (i.e., egg production and eggshell thinning) of mallards (Risebrough and Anderson 1975). NOAELs below the lowest LOAEL of 0.58 mg/kg bw/day were reported in five studies based on reproduction, growth, and mortality and ranged from 0.054 to 0.49 mg/kg bw/day.

Table 4-15. PCB Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Aroclor 1254	chicken	0.054	NA	diet for 20 weeks	no effect on fertility, hatchability, growth, or survival	40 (ww)	NA	2.56	0.0034 (ww)	Ahmed et al. (1978)
Aroclor 1248	American kestrel	NA	0.35	diet for 5.5 months	reduced eggshell weight and thickness	NA	3.3 (dw)[a]	0.13 (Pattee 1984)	0.0136 (dw) Nagy (2001)	Lowe and Stendell (1991)
Aroclor 1248	screech owl	0.49	NA	diet for two generations	no effect on eggshell thickness, egg production, hatching success, or fledging success	3.3 (dw)[a]	NA	0.181 (Dunning 1993)	0.0266 (dw) Nagy (2001)	McLane and Hughes (1980)
Aroclor 1242	chicken	**0.29**	**0.58**	diet for 6 weeks + 5 weeks untreated	reduced hatchability	5 (ww)	10 (ww)	1.71 (NRC 1984)	0.0997 (ww) (NRC 1984)	Britton and Huston (1973)
Aroclor 1242	Japanese quail	NA	0.60	diet for 45 days	eggshell thinning	NA	11.1 (dw)[a]	0.09 (Dunning 1993)	0.0048 (dw) Nagy (2001)	Hill et al. (1975)
Aroclor 1248	chicken	0.061	0.61	diet for 8 weeks	reduced egg production and egg hatchability	1 (ww)	10 (ww)	1.71 (NRC 1984)	0.105 kg ww/d	Scott et al. (1975)
Aroclor 1232	chicken	NA	1.2	diet for 9 weeks	reduced hatchability, embryo abnormality, and reduced survival		20 (ww)	1.71 (NRC 1984)	0.0997 (ww) (NRC 1984)	Cecil et al. (1974)
Aroclor 1254	ringed turtle dove	NA	1.4	diet for two generations	reduced hatching success in second generation	NA	10.9 (dw)[b]	0.155 (Sample et al. 1996)	0.0202 (dw) Nagy (2001)	Peakall et al. (1972); Peakall and Peakall (1973b)

Table 4-15. PCB Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Aroclor 1254	ring-necked pheasant	NA	1.6	gelatin capsule once per week for 16 weeks	reduced egg hatchability	NA	NA	NA	NA	Dahlgren et al. (1972)
Aroclor 1254	mourning dove	NA	1.6	diet for 42 days	reduced courtship behavior, fewer successful pair bonds formed; delayed onset of nest initiation	NA	11.1 (dw)[a]	0.119 (Dunning 1993)	0.0168 (dw) Nagy (2001)	Tori and Peterle (1983)
Aroclor 1254	mallard	2.5	NA	diet for ~1 month	reproductive success	25 (ww)	NA	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Custer and Heinz (1980)
Aroclor 1254	chicken	0.29	2.9	diet for 39 weeks	reduced hatchability	5 (ww)	50 (dw)	1.71 (NRC 1984)	0.0997 (ww) (NRC 1984)	Platonow and Reinhart (1973)
Aroclor 1254	mallard	3.9	NA	diet for 4 months	no effect on egg production or eggshell thinning	39 (ww)	NA	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Risebrough and Anderson (1975)
Aroclor mixture	American kestrel	NA	5 to 7	diet for 100 days	reduced egg laying in F2 generation; some effect on clutch size and fledgling success	NA	NA	NA	NA	Fernie et al. (2000; 2001)
Aroclor mixture	American kestrel	NA	5 to 7	diet during reproductive period	altered courtship behavior	NA	NA	NA	NA	Fisher et al. (2001)

Table 4-15. PCB Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Aroclor mixture	American kestrel	NA	5 to 7	diet during reproductive period	increase in number of cracked eggs, embryo abnormalities, reduced offspring survival (48%), reduced offspring growth rate in F2 generation.	NA	NA	NA	NA	Fernie et al. (2003a; 2003b; 2003c)
Aroclor 1254	American kestrel	NA	9.5	diet for 62 to 69 days	decreased sperm count and sperm concentration	NA	NA	NA	NA	Bird et al. (1983)
Aroclor 1254	Japanese quail	NA	12.0	diet for 8 days	avoidance response	NA	222.2 (dw)	0.09 (Dunning 1993)	0.0048 (dw) (Nagy 2001)	Kreitzer and Heinz (1974)
Aroclor 1242	mallard	NA	15	diet for 12 weeks	reduced hatchability, embryo survival, egg viability; embryo abnormalities	NA	150 (ww)	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Haseltine and Prouty (1980)

[a] Concentration in food converted to dry weight assuming 10% moisture in laboratory-prepared food.
[b] Concentration in food converted to dry weight based on 9% moisture in laboratory-prepared food, as reported in study.
BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

(Ahmed et al. 1978; Britton and Huston 1973; Scott et al. 1975; McLane and Hughes 1980; Platonow and Reinhart 1973). At the highest NOAEL of 0.49 mg/kg bw/day, no effects on eggshell thickness, egg production, hatching success, and fledging success were reported in screech owls exposed to dietary PCBs for two generations (McLane and Hughes 1980).

The lowest LOAEL calculated for chickens of 0.58 mg/kg bw/day from Britton and Huston (1973) was recommended as the LOAEL TRV. The lowest LOAEL of 0.35 mg/kg bw/day, calculated from Lowe and Stendell (1991), was not selected because the impact of eggshell thinning on kestrel reproductive success was not reported, whereas reproductive success of chickens measured in Britton and Huston (1973) is clearly impaired because significant effects on hatchability were observed in the treated group compared to the control group. It should be noted that there is not a large difference between the calculated LOAELs reported in these two studies (i.e., 0.58 vs. 0.35 mg/kg bw/day). The NOAEL of 0.29 mg/kg bw/day, calculated from the same study as the recommended LOAEL, was recommended as the NOAEL. Hatchability was not affected in chickens at this dietary concentration, or at a lower concentrations reported in Ahmed et al. (1978) and Scott et al. (1975).

As in the case with dioxins/furans, chickens appear to have a higher sensitivity to PCBs than do other avian species in the laboratory and may not be representative of Portland Harbor avian receptors. Thus, there is some uncertainty associated with the selected TRVs for PCBs in birds. However, the selected TRVs represent conservative values reported in the available literature.

Egg TRVs

Twenty-eight laboratory studies and field studies reporting PCB concentrations and associated effects were reviewed. The most sensitive endpoint for PCB toxicity in birds is reproductive impairment associated with egg residues (Hoffman et al. 1996).

Thirteen laboratory toxicological studies that measured PCB concentrations in eggs (Platonow and Reinhart 1973; Custer and Heinz 1980; Fernie et al. 2000; Fernie et al. 2001; Fisher et al. 2001; Stendell 1980; Peakall et al. 1972; Peakall and Peakall 1973a; Scott et al. 1975; Gilman et al. 1978; Britton and Huston 1973; Haseltine and Prouty 1980; McLane and Hughes 1980) were reviewed. Table 4-16 summarizes the egg NOAELs and LOAELs reported in the laboratory studies reviewed. One egg injection study was reviewed (Gilman et al. 1978); all other studies reported PCB concentrations in eggs laid by an adult bird exposed through the dietary pathway (as presented above). Egg concentrations and reproductive parameters (including eggshell thickness, egg production, hatching success, fledging success, and embryo and chick mortality) were measured in six bird species (including screech owls, chickens, American kestrels, ringed turtle dove, mallard, and herring gulls). Egg LOAELs in the laboratory ranged from 3.1 µg/g ww for reproduction in chickens (Scott et al. 1975) to 34.1 µg/g ww for reproduction success of American kestrels (Fernie et al. 2000; Bondy et al. 2000).

Table 4-16. PCB Bird Egg Toxicity Studies

Chemical Form	Species	NOAEL (ng/kg ww)	LOAEL (ng/kg ww)	Exposure Conditions	Endpoint Effect	Source
Total PCBs	double-crested cormorant	NA	4.4 – 14.8	five regional areas of the Great Lakes, 1986 to 1988	reduced reproductive success	Tillitt et al. (1992)
Total PCBs	great blue heron	0.474 – 2.842	NA	Lower Columbia River and Willamette River, 1994 to 1995	nest attendance and visitation, fledging, reproductive success	Thomas and Anthony (1999; 2003)
Aroclor mixture	osprey	0.69	NA	Willamette River, 1993	productivity	Henny et al. (2003)
Aroclor 1248	screech owl	3.32 and 7.12	NA	laboratory diet for two generations	eggshell thickness, egg production, hatching success, fledging success	McLane and Hughes (1980)
Aroclor 1248	chicken	0.41	3.1	laboratory diet for 8 weeks	reduced egg production and egg hatchability	Scott et al. (1975)
Total PCBs	double-crested cormorant	NA	3.6 – 7.3	Upper Great Lakes, May to August 1988	incidence of embryo malformations	Yamashita et al. (1993)
Total PCBs	black-crowned night heron	NA	4.1	Bair Island, San Francisco Bay National Wildlife Refuge, 1983	reduced embryonic growth	Hoffman et al. (1986)
Total PCBs	Caspian tern	NA	4.2 – 18	Upper Great Lakes, May to August 1988	increased incidence of embryo malformations	Yamashita et al. (1993)
Total PCBs	bald eagle	<4.5	**4.5** – < 10	14 states, 1969 to 1979	5-year productivity	Wiemeyer et al. (1984)
Total PCBs	brown pelican	4.75	NA	South Carolina, 1969 to 1973	reproductive success	Blus et al. (1977)
Total PCBs	bald eagle	**3.0** – < 5.6	5.6 – < 13	15 states, 1980 to 1984	5-year productivity	Wiemeyer et al. (1993)
Aroclor 1248	American kestrel	NA	5.6	laboratory diet for 5.5 months	reduced eggshell weight and thickness	Lowe and Stendell (1991)
Total PCBs	Forster's tern	7.0		Green Bay, Lake Michigan, 1988	hatching success	Harris et al. (1993a)
Total PCBs	bald eagle	NA	12.7	Columbia River estuary, 1980 to 1987	reduced productivity, eggshell thinning	Anthony et al. (1993)
Aroclor 1254	chicken	< 5	> 15	diet for 39 weeks (14 weeks for 50 ppm group)	reduced hatchability	Platonow and Reinhart (1973)

Table 4-16. PCB Bird Egg Toxicity Studies

Chemical Form	Species	NOAEL (ng/kg ww)	LOAEL (ng/kg ww)	Exposure Conditions	Endpoint Effect	Source
Aroclor 1254	ringed turtle dove	NA	16	diet for two generations	reduced hatchability, reduced embryo survival	Peakall et al. (1972); Peakall and Peakall (1973b)
Total PCBs	red-breasted merganser	20	NA	Lake Michigan, 1977 and 1978	hatching success	Haseltine et al. (1981)
Aroclor 1254	mallard	23	NA	laboratory diet for approximately 1 month	number hens laying, time to first hatch, clutch size, egg fertility, egg hatchability, duckling survival to 3 weeks	Custer and Heinz (1980)
Total PCBs	Forster's tern	NA	22.2	Green Bay, Lake Michigan, during 1983 nesting season	impaired reproductive success	Kubiak et al. (1989)
Total PCBs	double-crested cormorant	NA	23.8	Lake Huron, 1972 to 1973	impaired reproductive success	Weseloh et al. (1983)
Aroclor mixture	American kestrels	NA	34.1	laboratory diet for 100 days until eggs hatched	impaired reproductive success of parents exposed *in ovo*	Fernie et al. (2000; 2001)
Aroclor mixture	American kestrels	34.1	NA	laboratory diet for 1 month prior to mating through mating period	courtship behavior	Fisher et al.(2001)
Aroclor 1242	mallard	105	NA	laboratory diet for 12 weeks	hatchability, reduced embryo survival, egg viability, embryo abnormalities	Haseltine and Prouty (1980)
PCBs	herring gulls	142	NA	single injection in laboratory	reduced embryo and chick survival	Gilman et al. (1978)

LOAEL – lowest-observed-adverse-effects level
NA – not applicable
NOAEL – no-observed-adverse-effects level
PCB – polychlorinated biphenyl
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as the TRVs.

In the study in which the lowest LOAEL was reported, egg production and reduced hatchability were reported in chickens fed Aroclor 1248 and the egg concentration of Aroclor 1248 was 3.1 µg/g ww. Egg NOAELs in the laboratory ranged from 0.41 µg/g ww for egg production and hatchability in chickens (Scott et al. 1975) to 105 µg/g ww for embryonic and chick survival of herring gulls (Gilman et al. 1978).

In addition to the laboratory egg studies, fourteen of field studies that measured PCB concentrations in eggs in avian field populations (Henny et al. 2003; Thomas and Anthony 1999, 2003; Anthony et al. 1993; Wiemeyer et al. 1984; Yamashita et al. 1993; Tillitt et al. 1992; Hoffman et al. 1986; Haseltine et al. 1981; Blus et al. 1977; Weseloh et al. 1983; Wiemeyer et al. 1993; Harris et al. 1993a; Kubiak et al. 1989) were reviewed. Table 4-16 also summarizes the egg NOAELs and LOAELs derived from the field studies reviewed. Generally, adverse effects on avian reproduction were associated with lower PCB concentrations in field-collected eggs than in laboratory eggs. Impaired reproductive success, reduced productivity, and effects on embryo survival, growth, and development in nine bird species (double-crested cormorant, great blue heron, osprey, black-crowned night heron, Caspian tern, bald eagle, brown pelican, Forster's tern, red-breasted merganser) have all been associated with PCB concentrations in field-collected eggs.

Egg LOAELs for PCBs based on field studies ranged from 3.6 µg/g ww for frequency of embryo malformations of upper Great Lakes double-crested cormorants (Yamashita et al. 1993) to 23.8 µg/g ww for overall reproductive success of Lake Heron double-crested cormorants (Weseloh et al. 1983). In the study in which the lowest LOAEL was observed, the incidence of live deformities in double-crested cormorants in the upper Great Lakes was elevated where egg concentrations of PCBs ranged from 3.6 to 7.3 µg/g ww (Yamashita et al. 1993). It was noted in the study that the incidence of malformations may have been attributable to both PCBs and dioxins/furans that were present in the egg, thus there is some uncertainty associated with the reported egg LOAEL. Four studies reported egg LOAELs ranging from 4.1 to 4.5 µg/g ww where reproduction (including embryonic growth) was impaired in double-crested cormorants and Caspian terns of the Great Lakes, San Francisco Bay black-crowned night herons, and bald eagles from 14 states in the United States (Wiemeyer et al. 1984; Yamashita et al. 1993; Tillitt et al. 1992; Hoffman et al. 1986). There is general uncertainty associated with the egg PCB LOAELs reported in the field literature, because concentrations of PCBs are frequently closely correlated with concentrations of DDE (Giesy et al. 1994a), and it is difficult to separate the adverse reproductive effects of PCBs from those of DDE (Wiemeyer et al. 1984). Nearly all field studies reviewed reported levels of both PCBs and DDE associated with adverse effects on bird populations.

Egg NOAELs for PCBs based on field studies ranged from 0.474 µg/g ww for breeding behavior and reproductive success of Lower Columbia River and Willamette River great blue herons (Thomas and Anthony 1999, 2003) to 20 µg/g ww for hatching success of Lake Michigan red-breasted mergansers (Haseltine et al. 1981). In the study in which the lowest NOAEL was observed, no effects on breeding behavior (including nest attendance

and nest visitation behavior) and fledging and hatching success were measured in field populations of great blue herons where PCB egg concentrations collected near pulp and paper mills ranged from 0.474 to 2.842 µg/g ww.

It appears that avian species have a varying degree of sensitivity to PCBs. The LOAEL of 3.1 µg/g ww was recommended as the LOAEL TRV for PCBs in bird eggs. Field-collected egg concentrations less than 4.5 µg/g ww have been associated with impaired reproduction in five species (including bald eagles, double-crested cormorants, black-crowned night herons, and Caspian terns). In the laboratory, at chicken egg concentrations of 3.1 µg/g ww, hatchability was reduced (Scott et al. 1975). Thus, an egg LOAEL TRV of 3.1 µg/g ww was recommended, because this was the lowest value reported in the reviewed literature. Scott et al. (1975) also reported a NOAEL of 0.41 µg/g ww. This NOAEL was selected as the NOAEL TRV for PCBs in bird eggs and was the lowest NOAEL reported in the reviewed toxicological literature. This NOAEL is consistent with the field-based NOAELs of 0.474 and 0.69 µg/g ww reported for reproductive effects in herons and osprey, respectively (Henny et al. 2003; Thomas and Anthony 1999, 2003).

The recommended LOAEL and NOAEL TRVs may overestimate risks to the selected avian receptors in Portland Harbor (i.e., bald eagle, osprey, hooded merganser, and spotted sandpiper), which may be less sensitive to PCBs than are chickens. Adverse reproductive effects in the field have been associated with slightly higher PCB egg concentrations. The use of a LOAEL based on wild species more closely related to the Portland Harbor receptors may represent a more realistic but less conservative TRV for the selected Portland Harbor receptors. However, the LOAEL and NOAEL TRVs were recommended because they were the most conservative values available in the literature reviewed. In addition, in a hazard assessment conducted in the Great Lakes, a NOAEL of 4.0 µg/g ww total PCBs was recommended (based on multiple field studies) as a reasonable estimate of the concentration required to cause effects in bird eggs (Giesy et al. 1994a). NOAELs recommended by Giesy et al. (1994a) for use in wildlife hazard assessments ranged from 3.5 to 5.0 µg/g ww and were based on wild species. Based on the above information, the selected LOAEL and NOAEL for total PCBs in bird eggs represent very conservative threshold values.

4.4 DIOXINS AND FURANS

4.4.1 2,3,7,8-TCDD

Exposure from dioxins/furans and dioxin-like PCB congeners will be evaluated in the BERA using a toxic equivalent concentration (TEQ) approach. In this approach, a TEQ value is calculated using measured concentrations of dioxins/furans and dioxin-like PCB congeners, and WHO-derived TEFs for birds. The TEQ sum for dioxins/furans and dioxin-like PCB congeners will be compared with TRVs based on 2,3,7,8-TCDD toxicity. Therefore, the TRV for 2,3,7,8-TCDD will be used to evaluate dioxins/furans and dioxin-like PCB congeners.

A total of nineteen papers on the adverse effects of TCDD and dioxin-like PCB congeners on birds were reviewed. The mechanisms of exposure included gavage, intraperitoneal injection, and egg injection. In addition, both laboratory and field studies were reviewed.

Dietary TRVs

Two studies in which birds were exposed to 2,3,7,8-TCDD via daily oral intubation (Schwetz et al. 1973) and weekly intraperitoneal injections (Nosek et al. 1992b) were reviewed. Table 4-17 presents the NOAELs and LOAELs derived from the two studies reviewed. LOAELs ranged from 0.14 µg/kg bw/day for growth, mortality, and reproduction in ring-necked pheasants (Nosek et al. 1992b) to 1.0 µg/kg bw/day for mortality of chickens (Schwetz et al. 1973). In the study reporting the lowest LOAEL, Nosek et al. (1992b) measured a reduction in survival, body weight, egg production, and embryo survival in ring-necked pheasants given ten weekly injections of 1.0 µg/kg 2,3,7,8-TCDD over a critical life stage (reproduction). The calculated daily dose from this study was 0.14 µg/kg/d. NOAELs ranged from 0.014 µg/kg bw/day for growth, mortality, and reproduction in ring-necked pheasants (Nosek et al. 1992b) to 1.0 µg/kg bw/day for growth of chickens (Schwetz et al. 1973).

The LOAEL and NOAEL of 0.14 and 0.014 µg/kg bw/day, respectively, were recommended as the dietary TRVs for 2,3,7,8-TCDD in birds because they represent the lower-effect-level concentration of the two studies considered. In addition, the selected TRVs are based on a study measuring adverse effect over a chronic exposure (10 weeks) during a critical life stage; the other study reviewed (Schwetz et al. 1973) was not conducted during a critical life stage or over a chronic period. However, there is high uncertainty associated with the selected TRVs because they are based on injection exposure. Intraperitoneal injection is not directly relevant to the dietary exposure pathway for birds, and the selected TRVs may not accurately predict dietary dioxin/furan toxicity.

Table 4-17. 2,3,7,8-TCDD Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (µg/kg bw/day)	LOAEL (µg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
2,3,7,8-TCDD	ring-necked pheasant	**0.04**	**0.14**	weekly IP injection for 10 weeks	body weight loss; reduced adult survival, egg production, and embryo survival	NA	NA	NA	NA	Nosek et al. (1992b)
2,3,7,8-TCDD	chicken	0.1	1.0	oral intubation for 20 to 21 days	reduced survival (8 out of 10 died)	NA	NA	NA	NA	Schwetz et al. (1973)
2,3,7,8-TCDD	chicken	1.0		oral intubation for 20 to 21 days	no effect on growth	NA	NA	NA	NA	Schwetz et al. (1973)

BW – body weight
IP – intraperitoneal
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
TCDD – tetrachlorodibenzo-*p*-dioxin
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

Egg TRVs

In addition to the two studies reviewed on the toxicity of dioxins/furans to adult birds, 17 egg studies were reviewed. Both egg injection studies and field studies reporting egg residues and associated effects on embryo survival and development were reviewed. These endpoints (embryo survival and development) appear to be the most sensitive effects resulting from dioxins/furans and dioxin-like exposure seen in birds, and are clearly related to reproductive success in avian populations (EPA 2003; Hoffman et al. 1996).

Eight laboratory egg injection studies were reviewed in which 2,3,7,8-TCDD concentration or the TEQ of PCB 126 or PCB 77 was injected into eggs (Henshel et al. 1993; Henshel et al. 1997; Hoffman et al. 1998; Powell et al. 1997; Powell et al. 1998; Powell et al. 1996; Nosek et al. 1992a; Janz and Bellward 1996). Table 4-18 presents the egg NOAELs and LOAELs derived from the laboratory studies reviewed. The effects of injected dioxins/furans on embryo mortality, embryo growth, or hatchability were measured in eggs in seven bird species (chickens, double-crested cormorants, ring-necked pheasants, pigeons, great blue heron, common tern, and American kestrels). LOAELs (as injected concentrations) for 2,3,7,8-TCDD or TEQ concentrations ranged from 10 ng/kg 2,3,7,8-TCDD for frequency of embryo malformations in chickens (Henshel et al. 1993) to 40,000 ng/kg 2,3,7,8-TCDD for embryo mortality in double-crested cormorants (Powell et al. 1997). In the study in which the lowest LOAEL was reported, Henshel et al. (1993) reported an increase in the occurrence of embryo abnormalities in chicken eggs following a single injection of 2,3,7,8-TCDD in the egg yolk or air-sac during intubation. NOAELs for 2,3,7,8-TCDD or TEQ concentrations ranged from 60 ng/kg for reproduction in chickens (Hoffman et al. 1998) to 20,000 ng/kg 2,3,7,8-TCDD for embryo mortality in double-crested cormorants (Powell et al. 1997). No NOAEL that was less than the lowest LOAEL of 10 ng/kg was reported in the reviewed laboratory literature.

In addition to laboratory egg injection studies, nine field studies that measured dioxin/furan concentrations (Thomas and Anthony 2003, 1999; White and Seginak 1994; Henny et al. 2003; Anthony et al. 1993; Kubiak et al. 1989; Tillitt et al. 1992; Yamashita et al. 1993; Woodford et al. 1998) were reviewed. Table 4-18 also presents the egg NOAELs and LOAELs derived from the field studies reviewed. Egg concentrations of 2,3,7,8-TCDD or the TEQ equivalent have been associated with the impaired reproductive success (including reduced offspring productivity, nesting success, offspring growth, and hatchability, altered breeding behavior, and increased occurrence of embryo malformations) of wood duck, bald eagle, Forster's tern, osprey, and double-crested cormorant field populations. Egg LOAELs for 2,3,7,8-TCDD or TEQ ranged from 20 ng/kg ww for reproductive success of wood ducks (White and Seginak 1994) to 2,800 ng/kg ww for frequency of embryo malformations in Caspian terns (Yamashita et al. 1993). The lowest LOAEL was reported in White and Seginak (1994). Wood ducks were most sensitive to dioxins/furans in the reviewed field literature. Reduced reproductive success was reported in wood duck populations from Bayou Meto in central Arkansas, where egg residues ranged from 20 to 50 ng/kg ww TEQ (White and Seginak 1994). Egg

NOAELs for 2,3,7,8-TCDD or TEQ concentrations were reported in three studies and ranged from 2.3 ng/kg ww for productivity of Willamette River osprey (Henny et al. 2003) to 7.42 ng/kg ww for breeding behavior and reproductive success of Lower Columbia and Willamette River great blue herons (Thomas and Anthony 2003, 1999).

Field studies generally reported lower LOAELs in eggs; however, the lowest egg LOAEL of 10 ng/kg from the studies reviewed was reported in chickens (Henshel et al. 1993). This LOAEL was recommended as the TRV for 2,3,7,8-TCDD in bird eggs. No NOAEL was reported for chickens below this selected LOAEL. Field-based NOAELs lower than the selected LOAEL ranged from 2.3 to 7.42 ng/kg ww (Thomas and Anthony 2003, 1999; White and Seginak 1994; Henny et al. 2003). The highest NOAEL in these field studies, 7.42 ng/kg ww, was recommended as the NOAEL. At this concentration, breeding behavior, fledging success, and reproductive success were unaffected in herons from the Lower Columbia and Willamette Rivers (Thomas and Anthony 2003, 1999).

The recommended LOAEL and NOAEL TRVs for dioxins/furans in bird eggs represent conservative thresholds for dioxins/furans and dioxin-like chemicals. Field-based NOAELs were limited because most field studies measured PCB egg concentrations that were associated with effects, and the highest field-based NOAEL was selected as the NOAEL TRV. Actual field-based NOAELs may range higher; however, data are not available for many field bird species. The selected LOAEL is based on the high chicken sensitivity to dioxins/furans and may overestimate risks to the selected avian receptors in Portland Harbor (i.e., bald eagle, osprey, hooded merganser, and spotted sandpiper), which may be less sensitive to dioxins/furans. Adverse reproductive effects in the field have been associated with slightly higher dioxin/furan residues (2,3,7,8-TCDD or the TEQ equivalent) ranging from 20 to 136 ng/kg ww in wood duck, bald eagle, Forster's tern, and osprey eggs. The use of a LOAEL TRV based on wild species more closely related to the Portland Harbor receptors may represent a more realistic but less conservative TRV for the selected Portland Harbor receptors. However, the LOAEL TRV was selected because it was the most conservative LOAEL available in the literature reviewed. In addition, EPA (2003) recommends the inclusion of chicken data in deriving NOAELs and LOAELs for dioxins/furans due to the wide range of sensitivities within bird species and the fact that there is no inherent mechanistic difference between the toxicity of dioxins/furans and dioxin-like chemicals in chickens and other birds that would preclude the possibility that some species of wild birds are equally or more sensitive.

Table 4-18. 2,3,7,8-TCDD and TEQ Bird Egg Toxicity Studies

Chemical Form	Species	NOAEL (ng/kg ww)	LOAEL (ng/kg ww)	Exposure Conditions	Endpoint Effect	Source
2,3,7,8-TCDD	osprey	**2.3**	NA	Willamette River, 1993	productivity	Henny et al. (2003)
2,3,7,8-TCDD	great blue heron	2.57 – 7.42	NA	Lower Columbia River and Willamette River, 1994 to 1995	breeding behavior reproductive success, fledging	Thomas and Anthony (1999; 2003)
2,3,7,8-TCDD	chicken	NA	10	single injection in laboratory	reduced reproductive success	Henshel et al. (1993)
TEQ	wood duck	5	20 – 50	Bayou Meto, central Arkansas wetland, 1987	nesting success, hatchability, duckling production	White and Seginak (1994)
TEQ	chicken	NA	30	single injection in lab on day 4	reduced hatching weight without yolk sac, embryo and hatching malformation	Hoffman et al. (1998)
2,3,7,8-TCDD	bald eagle	NA	**31.98**	Columbia River estuary, 1980 to 1987	reduced productivity, eggshell thinning	Anthony et al. (1993)
2,3,7,8-TCDD	Forster's tern	NA	> 37.3	Green Bay, Lake Michigan during 1983 nesting season	increased incubation period, reduced hatchability, lower offspring body weight, and edema occurrence	Kubiak et al. (1989)
2,3,7,8-TCDD	osprey	NA	78	Wisconsin River, downstream from bleach kraft mills, 1992 to 1996	reduced chick growth	Woodford et al. (1998)
TEQ	double-crested cormorant	NA	85 – 344	five regional areas of the Great Lakes, 1986 to 1988	reduced reproductive success	Tillitt et al. (1992)
2,3,7,8-TCDD	chicken	NA	122	single injection in laboratory	reduced embryo survival (LC50)	Henshel et al. (1997)
TEQ	osprey	NA	136	Wisconsin River, downstream from bleach kraft mills, 1992 to 1996	reduced chick growth	Woodford et al. (1998)
2,3,7,8-TCDD	chicken	NA	150	single injection in laboratory	embryo abnormality and reduced survival (LC50)	Powell et al. (1996)
2,3,7,8-TCDD	chicken	80	160	single injection in laboratory	reduced embryo survival, embryo deformities	Powell et al. (1996)

Table 4-18. 2,3,7,8-TCDD and TEQ Bird Egg Toxicity Studies

Chemical Form	Species	NOAEL (ng/kg ww)	LOAEL (ng/kg ww)	Exposure Conditions	Endpoint Effect	Source
TEQ	chicken	NA	230	single injection in laboratory	reduced embryo survival (LC50)	Powell et al. (1996)
2,3,7,8-TCDD	chicken	100	300	single injection in laboratory	reduced embryo survival and hatching body weight	Henshel et al. (1997)
TEQ	chicken	60	300	single injection in laboratory	reduced hatching success, embryo malformation	Hoffman et al. (1998)
TEQ	chicken	160	320	single injection in laboratory	reduced embryo survival, embryo deformities	Powell et al. (1996)
TEQ	double-crested cormorant	322		field exposure	reduced embryo survival, gross abnormalities, body weight	Powell et al. (1997)
TEQ	double-crested cormorant	NA	350 – 1,300	Upper Great Lakes from May to August 1988	incidence of embryo malformations	Yamashita et al. (1993)
2,3,7,8-TCDD	ring-necked pheasant	100	1,000	single injection in laboratory	reduced embryo survival	Nosek et al. (1992b)
2,3,7,8-TCDD	pigeon	NA	1,000	single injection in laboratory	reduced hatchability	Janz and Bellward (1996)
TEQ	Caspian tern	NA	1,300 – 2,800	Upper Great Lakes from May to August 1988	increased incidence of embryo malformations	Yamashita et al. (1993)
2,3,7,8-TCDD	great blue heron	NA	2,000	single injection in laboratory	reduced hatchability	Janz and Bellward (1996)
TEQ	Forster's tern	NA	2,175	Green Bay, Lake Michigan during 1983 nesting season	increased incubation period, reduced hatchability, lower offspring body weight, and edema occurrence	Kubiak et al. (1989)
2,3,7,8-TCDD	double-crested cormorant	NA	4,000	single injection in laboratory	reduced embryo survival	Powell et al. (1997)
2,3,7,8-TCDD	double-crested cormorant	NA	4,000	single injection in laboratory	reduced embryo survival	Powell et al. (1998)

Table 4-18. 2,3,7,8-TCDD and TEQ Bird Egg Toxicity Studies

Chemical Form	Species	NOAEL (ng/kg ww)	LOAEL (ng/kg ww)	Exposure Conditions	Endpoint Effect	Source
TEQ	common tern	NA	4,400	single injection on day 4 in laboratory	reduced embryo survival, hatching success	Hoffman et al. (1998)
TEQ	American kestrel	NA	5,000	single injection on day 6	reduced embryo survival, hatching success, embryo malformation	Hoffman et al. (1998)
2,3,7,8-TCDD	double-crested cormorant	1,300	5,400	single injection in laboratory	reduced embryo survival	Powell et al. (1998)
2,3,7,8-TCDD	ring-necked pheasant	1,000	10,000	single injection in laboratory	reduced embryo survival	Nosek et al. (1992b)
TEQ	double-crested cormorant	NA	16,000	single injection in laboratory	reduced embryo survival	Powell et al. (1997)
TEQ	double-crested cormorant	7,000	17,500	single injection in laboratory	reduced embryo survival	Powell et al. (1998)
TEQ	double-crested cormorant	NA	17,700	single injection in laboratory	reduced embryo survival	Powell et al. (1998)
TEQ	American kestrel	2,300	23,000	single injection on day 6 in laboratory	reduced hatchability	Hoffman et al. (1998)
TEQ	double-crested cormorant	20,000	40,000	single injection in laboratory	reduced embryo survival	Powell et al. (1997)

LC50 – concentration that is lethal to 50% of an exposed population
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
TCDD – tetrachlorodibenzo-*p*-dioxin
TEQ – toxic equivalent
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.5 PESTICIDES

4.5.1 Aldrin

Two studies that measured the toxicity of aldrin to birds (DeWitt 1956; Hall et al. 1971) were reviewed and evaluated. Table 4-19 presents the aldrin NOAELs and LOAELs calculated from the studies reviewed. Adverse effects on growth or survival of domestic species (quail and pheasant) were observed following oral exposure to aldrin. LOAELs ranged from 0.04 mg/kg bw/day for mortality of quail (DeWitt 1956) to 92 mg/kg bw/day for mortality of pheasant chicks (Hall et al. 1971). At the lowest LOAEL, 97.5% mortality was observed after 127 days in quails following dietary exposure of aldrin. Only one NOAEL of 10 mg/kg bw/day was derived from the reviewed studies. At this NOAEL, no effect on pheasant chicks growth was observed following seven weekly exposure doses of a gelatin capsule treated with aldrin.

The lowest LOAEL calculated from the reviewed literature of 0.04 mg/kg bw/day was recommended as the TRV for aldrin. There were no NOAELs lower than the selected LOAEL reported in the literature reviewed, so none was recommended. There is some uncertainty associated with the selected LOAEL TRV because the literature dataset for aldrin toxicity in birds is limited to two studies reporting the effects in domestic species only, with high variability in the dose levels resulting in adverse effects. The sensitivity of other bird species to aldrin is unknown.

Table 4-19. Aldrin Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Aldrin	quail	NA	**0.04**	diet for 5 months	reduced survival (2.5%) in 127 days	NA	0.56 (dw)[a]	0.09 (Dunning 1993)	0.0048 (dw) (Nagy 2001)	DeWitt (1956)[b]
Aldrin	pheasant	NA	0.7	diet for 16 to 20 weeks	0% survival in 46 days	NA	5.6	1.135 (Dunning 1993)	0.0464 (dw) (Nagy 2001)	DeWitt (1956)
Aldrin	pheasant (chicks)	10	20	gelatin capsule for 7 weeks[b]	reduced growth	NA	NA	NA	NA	Hall et al. (1971)
Aldrin	pheasant (chicks)	NA	92	gelatin capsule for 7 weeks[c]	64% survival	NA	NA	NA	NA	Hall et al. (1971)

[a] Concentration in food converted to dry weight assuming 10% moisture in laboratory-prepared food.
[b] Birds were given one dose of a treated gelatin capsule per week. Effects were observed through 9 weeks following exposure period.
[c] Birds were given one dose of a treated gelatin capsule three times per week.
BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.5.2 DDE

The best documented response to DDE is eggshell thinning in birds, which can result in embryo mortality and decreased hatchling survival (Heath et al. 1969; Lincer 1975). Overall avian sensitivity is highly variable. Raptors, waterfowl, passerines, and non-passerine ground birds have been documented to be more susceptible to eggshell thinning than are domestic fowl and other gallinaceous birds, and DDE appears to have been a more potent inducer of eggshell thinning than DDT (EPA 2007b). The leading hypothesis for DDE-induced thinning involves an inhibition by 4,4′-DDE (but not by 2,4′-DDE, or DDD or DDT isomers) of prostaglandin synthesis in the shell gland mucosa (EPA 2007b; Lundholm 1997). TRVs for DDE have been based on dietary studies and on studies of eggs. Both are discussed below.

Dietary TRV

Eighteen studies evaluating dietary DDE toxicity to birds (Gill et al. 1970; Lincer 1975; Peakall et al. 1975; Peakall et al. 1973; Davison et al. 1976; Wiemeyer and Porter 1970; Mendenhall et al. 1983; Longcore and Samson 1973; Longcore et al. 1971; Haegele and Hudson 1973, 1974; Heath et al. 1969; Kreitzer and Heinz 1974; Kolaja 1977; Porter and Wiemeyer 1972; Pritchard et al. 1972; Risebrough and Anderson 1975; Stickel et al. 1970) were evaluated for TRV selection. Table 4-20 presents the DDE NOAELs and LOAELs calculated from the studies included in the TRV selection process. Adverse effects on eggshell thinning, offspring mortality, hatchability, egg production, clutch size, adult mortality, and avoidance response behavior were measured in seven bird species (barn owls, American kestrels, mallards, black ducks, ring doves, Japanese quail, and cowbirds). LOAELs ranged from 0.32 mg/kg bw/day for reproduction of barn owls (Mendenhall et al. 1983) to 71 mg/kg bw/day for mortality of pheasants (Gill et al. 1970). At the lowest LOAEL, eggshell thinning, reduced eggshell strength, and nestling mortality was observed in barn owls fed 2.83 mg/kg ww DDE in their diet for two years (Mendenhall et al. 1983). NOAELs ranged from 0.12 mg/kg bw/day for eggshell thinning in American kestrels (Lincer 1975) to 24 mg/kg bw/day for reproduction and growth of Japanese quail (Davison et al. 1976). The NOAEL of 0.12 mg/kg bw/day was the only NOAEL calculated below the lowest LOAEL. At this concentration, no effect on eggshell thinning was reported in field-collected kestrels fed a DDE mixture for approximately five months (Lincer 1975).

The lowest LOAEL of 0.32 mg/kg bw/day [calculated from Mendenhall et al. (1983)] was recommended. The recommended LOAEL is a conservative threshold effect level based on the most sensitive species tested in the reviewed literature. Only one dose level was administered in Mendenhall et al. (1983); thus, the NOAEL was selected from another study. The NOAEL of 0.12 mg/kg bw/day calculated from Lincer (1975) was recommended as the NOAEL. This was the only NOAEL reported below the recommended LOAEL TRV.

Table 4-20. DDE Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
"DDE"	barn owls	NA	**0.32**	diet for 2 years (two nestings)	increase in eggshell breakage/thickness; reduced nestling survival	NA	3.1 (dw)	0.524 (Dunning 1993)	0.0539 (dw) (Nagy 2001)	Mendenhall et al. (1983)
"DDE"	barn owls[b]	0.32	NA	diet for 2 years (two nestings)	no effect on adult survival	3.1 (dw)	NA	0.524 (Dunning 1993)	0.0539 (dw) (Nagy 2001)	Mendenhall et al. (1983)
"DDE"	American kestrel	NA	0.35	diet for 14 days	reduced shell thickness and egg permeability	NA	3.3 (dw)[c]	0.13 (Pattee 1984)	0.0136 (dw) (Nagy 2001)	Peakall et al. (1973)
p,p′-DDE	mallard	NA	0.90	diet for 2 years	increased percentage of cracked eggs, reduced hatchling survival /production, and shell thickness	NA	9 (ww)	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Heath et al. (1969)
p,p′-DDE	black duck	NA	1.0	diet for 7 months	reduced shell thickness, egg weight, and hatchability; reduced duckling survival	NA	10 (ww)	1.25 (Dunning 1993)	0.1250 (ww) (Heinz et al. 1987)	Longcore and Samson (1973)
DDE	mallard	NA	1.0	diet for 30 days	eggshell thinning	NA	10 (ww)	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Kolaja (1977)
DDE	Black duck	NA	1.0	diet during reproductive period	eggshell thinning and cracking, reduced embryo and duckling survival	NA	10 (ww)	1.25 (Dunning 1993)	0.1250 (ww) (Heinz et al. 1987)	Longcore et al. (1971)
DDE mixture	American kestrel[d]	**0.12**	1.2	diet for approximately 5 months	reduced eggshell thickness	1.13 (dw)[e]	11.3 (dw)[e]	0.13 (Pattee 1984)	0.0136 (dw) (Nagy 2001)	Lincer (1975)

Table 4-20. DDE Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
p,p′-DDE	American kestrel	NA	1.0	diet for 1 year (2 clutches)	reduced eggshell thickness	NA	10 (dw)	0.13 (Pattee 1984)	0.0136 (dw) (Nagy 2001)	Wiemeyer and Porter (1970); Porter and Wiemeyer 1972
"DDE"	ring dove	NA	1.6	diet for 14 days	eggshell thinning, egg permeability	NA	11.1 (dw)[c]	0.119 (Dunning 1993)	0.0168 (dw) (Nagy 2001)	Peakall et al. (1973)
DDE	Japanese quail	2.99	NA	diet for 8 days treated + 6 days untreated	no effect on avoidance response	55.56 (dw)[c]	NA	0.09 (Dunning 1993)	0.0048 (dw) (Nagy 2001)	Kreitzer and Heinz (1974)
"DDE"	white pekin duck	NA	3.1	diet for 14 days	eggshell thinning, egg permeability	NA	44.4 (dw)[c]	5.5 (Peakall et al. 1975)	0.3895 (dw) (NRC 1994)	Peakall et al. (1973)
p,p′-DDE	white pekin duck	NA	3.1	diet for 2 to 3 weeks	reduced eggshell thickness, breakage shell permeability, and egg yolk/shell gland weight	NA	44.4 (dw)[c]	3.63	0.257 (dw)	Pritchard et al. (1972)
p,p′-DDE	mallard	NA	4.0	diet for 96 days	reduced eggshell thickness (first and second reproductive season)	NA	40 (ww)	1.082 (Dunning 1993)	0.1082 (ww) (Heinz et al. 1987)	Haegele and Hudson (1974)
p,p′ DDE	mallard	NA	5.9	diet for 4 months	reduced eggshell thickness	NA	36.5 (dw)	1.082 (Dunning 1993)	0.174 (dw) (Heinz et al. 1987)	Risebrough and Anderson (1975)
p,p′-DDE	ring dove	NA	6.3	diet for 126 days	reduced egg production, shell thickness, survival of young, and clutch size	NA	44.4 (dw)[c]	0.119 (Dunning 1993)	0.0168 (dw) (Nagy 2001)	Haegele and Hudson (1973)

Table 4-20. DDE Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
"DDE"	white Pekin duck	NA	9.1	diet for 10 days	eggshell thinning	NA	NA	NA	NA	Peakall et al. (1975)
p,p′-DDE	Japanese quail	24	NA	diet for 13 weeks	reduced body weight, egg production, eggshell thickness, egg weight, calcium content in eggshell;, and number and length of clutch	200 (ww)	NA	0.116	0.014 (ww)	Davison et al. (1976)
p,p′-DDE	ring-necked pheasant	NA	71	diet for 8 days	reduced survival (LC50)	NA	1,086 (dw)	0.0398	0.023 (dw) (Nagy 2001)	Gill et al. (1970)

[a] A chronic NOAEL was extrapolated from the chronic LOAEL using a UF of 5.
[b] Three birds in the treated group died; however, the causes of two of the deaths were unknown and not related to DDE exposure.
[c] Concentration in food converted to dry weight assuming 10% moisture in laboratory-prepared food.
[d] Field-collected birds were used in this controlled laboratory experiment.
[c] Concentration in food converted to dry weight based on 73% moisture reported in laboratory diet.
BW – body weight
dw – dry weight
LC50 – concentration that is lethal to 50% of an exposed population
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

Egg TRVs

A total of 32 laboratory and field studies reporting DDE or DDT concentrations in eggs and associated reproductive effects were reviewed.

Twelve laboratory studies where DDE or DDT concentrations in eggs were reported were reviewed. Eggs were either injected with DDE or DDT concentrations, or were exposed through maternal transfer following dietary exposure (Longcore and Samson 1973; Genelly and Rudd 1956b; Lincer 1975; Wiemeyer and Porter 1970; Mendenhall et al. 1983; Dunachie and Fletcher 1969; Bryan et al. 1989; Gilman et al. 1978; Haegele and Hudson 1974; Longcore et al. 1971; Scott et al. 1975; Smith et al. 1970). Table 4-21 summarizes the egg NOAELs and LOAELs reported in the laboratory studies reviewed. Reproductive effects (including eggshell thinning, offspring mortality, hatchability and reproductive behavior) of DDE and DDT exposure to bird eggs were measured in seven bird species (barn owls, mallards, herring gulls, American kestrels, black ducks, chickens, and Japanese quail).

Effect level concentrations in eggs were lower in birds exposed to DDE than DDT in the laboratory. DDE LOAELs ranged from 12 µg/g ww for eggshell thickness and nestling mortality of barn owls (Mendenhall et al. 1983) to 84.5 µg/g dw for eggshell thickness in American kestrels (Lincer 1975). At the lowest LOAEL, eggshell thinning, reduced eggshell strength, and nestling mortality were observed in barn owls fed 2.81 mg/kg ww DDE in their diet for two years where the egg concentration of DDE was 12 µg/g (Mendenhall et al. 1983). DDE NOAELs ranged from 1.9 µg/g for eggshell thickness of American kestrels (Lincer 1975) to 22.6 µg/g for embryonic and chick mortality of herring gulls (Gilman et al. 1978). DDT LOAELs ranged from 100 µg/g ww for offspring survival of chickens (Dunachie and Fletcher 1969) to 658 µg/g ww for reproductive behavior of Japanese quail (Bryan et al. 1989).

In addition to laboratory egg studies, 24 field studies that measured DDE egg concentrations and the associated reproductive effects (Wiemeyer et al. 1984; Wiemeyer et al. 1993; Wiemeyer et al. 1988; Thomas and Anthony 1999, 2003; Nygard 1983; Ambrose et al. 1988; Anthony et al. 1993; Blus et al. 1977; Blus et al. 1985; Custer et al. 1983; Custer et al. 1999; Elliott and Martin 1994; Elliott et al. 1988; Elliott et al. 1996; Fox 1976; Haseltine et al. 1981; Henny et al. 2003; King et al. 1991; Klaas et al. 1980; Krantz et al. 1970; Littrell 1986; White et al. 1984; Weseloh et al. 1983) were reviewed. Table 4-21 also summarizes the egg NOAELs and LOAELs reported in the field studies reviewed. It should be noted that the effects of DDE and PCBs are closely correlated, and separating the effects of each of these chemicals is difficult (Wiemeyer et al. 1984), particularly in field-collected eggs. Generally, in the field, much lower DDE egg concentrations are associated with adverse reproductive effects than are in the laboratory.

Adverse effects reported in the field (including productivity, brood size, hatching success, and eggshell thinning) were associated with elevated concentrations of DDE in seven bird species (bald eagles, osprey, common tern, black skimmers, double-crested cormorants, northern gannets, and peregrine falcons). Field egg LOAELs ranged from 3.5 µg/g ww

for productivity in bald eagles (Wiemeyer et al. 1984) to 43 ww µg/g for eggshell thinning in peregrine falcons (Nygard 1983). At the lowest LOAELs, Wiemeyer et al. (1984; 1993) reported bald eagle egg concentrations of 3.5 and 3.6 µg/g ww DDE that were associated with a level of mean five-year productivity that was less than the productivity level necessary to maintain a stable population. NOAELs were reported for 13 bird species (great blue heron, osprey, clapper rails, brown pelicans, bald eagles, black-crowned night heron, Forster's terns, long-billed curlews, Cooper's hawks, black skimmers, sharp-shinned hawks, red-breasted mergansers, and peregrine falcons). Field egg NOAELs ranged from 0.331 µg/g ww, associated with breeding behavior of adult great blue herons (Thomas and Anthony 1999, 2003), to 10.72 µg/g ww for reproductive success of bald eagles (Krantz et al. 1970).

An bird egg TRV was recommended for 4,4′-DDE only because birds appear to be most sensitive to DDE. The recommended LOAEL of 3.5 mg/kg ww DDE was based on (Wiemeyer et al. 1984). This was the lowest LOAEL reported in both field and laboratory studies. At this egg concentration (reported in field-collected bald eagle eggs), offspring productivity was below the level necessary to maintain a stable population (Wiemeyer et al. 1984). Reproductive success was impaired in osprey and common tern populations where DDE concentrations in eggs were only slightly higher (between 3.5 and 4.0 mg/kg ww); however, other bird species (such as long-billed curlews, hawks, black skimmers, red-breasted mergansers, and peregrine falcons) appear to be less sensitive to DDE, and egg concentrations greater than 4.0 mg/kg ww DDE are not associated with adverse reproductive effects or critical levels of eggshell thinning. Thus, the recommended LOAEL of 3.5 mg/kg ww DDE represents a conservative effect threshold based on the most sensitive bird species measured in the literature reviewed. All egg residues reported in laboratory studies are greater than this recommended LOAEL. Wiemeyer et al. (1984) also reported a NOAEL of 1.3 µg/g ww. This NOAEL was recommended as the NOAEL TRV for DDE in bird eggs. This NOAEL was lower than nearly all of the NOAELs reported in the field literature and thus also represents a conservative no-effect threshold.

Table 4-21. DDE and DDT Bird Egg Toxicity Studies

Chemical Form	Species	NOAEL (ng/kg ww)	LOAEL (ng/kg ww)	Exposure Conditions	Endpoint Effect	Source
p,p′-DDE	great blue heron	0.331 – 1.432	NA	Lower Columbia River and Willamette River, 1994 to 1995	nest attendance and visitation, fledging, reproductive success	Thomas and Anthony (1999; 2003)
DDE	osprey	0.82 – 22	NA	Eagle Lake, California, 1973 to 1979 and 1983 to 1984	eggshell thinning	Littrell (1986)
DDE	clapper rail	1.3	NA	eastern and southern United States, 1972 to 1974	eggshell thinning	Klaas et al. (1980)
DDE	brown pelican	2.09	NA	South Carolina, 1969 to 1973	reproductive success	Blus et al. (1977)
DDE	bald eagle	2.17 – 3.3	NA	Pacific Coast of Canada- Fraser River (near bleached kraft paper mills) 1990 to 1992	eggshell thinning	Elliott et al. (1996)
DDE	osprey	2.3	NA	Willamette River in 1993	productivity	Henny et al. (2003)
DDE	bald eagle	**1.3**	**3.5**	14 states, 1969 to 1979	reduced 5-year productivity	Wiemeyer et al. (1984)
DDE	bald eagle	< 2.2 – < 3.6	3.6 – < 6.3	15 states, 1980 to 1984	reduced 5-year productivity	Wiemeyer et al. (1993)
DDE	black-crowned night heron	3.9	NA	New England and North Carolina	reproductive success	Custer et al. (1983)
DDE	double-crested cormorant	3.9	NA	field exposure: Green Bay, Lake Michigan, 1994 and 1995	hatching success	Custer et al. (1999)
DDE	osprey	2.9	3.9	14 states, 1970 to 1979	reduced brood size	Wiemeyer et al. (1988)
DDE	common tern	NA	3.98	Buffalo Lake, Alberta, Canada, May to August 1972	reduced reproductive success	Fox (1976)
DDE	bald eagle	NA	4	15 states, 1980 to 1984	eggshell thinning	Wiemeyer et al. (1993)
DDE	osprey	NA	4.2 – 8.7	14 states, 1970 to 1979	eggshell thinning	Wiemeyer et al. (1988)
DDE	long-billed curlew	4.26	NA	Umatilla National Wildlife Refuge, 1978 to 1979	eggshell thinning	Blus et al. (1985)
DDE	cooper's hawk	4.48	NA	South-central Ontario 1986 - 1989	eggshell thinning	Elliott and Martin (1994)

Table 4-21. DDE and DDT Bird Egg Toxicity Studies

Chemical Form	Species	NOAEL (ng/kg ww)	LOAEL (ng/kg ww)	Exposure Conditions	Endpoint Effect	Source
DDE	black skimmer	6.5	NA	three sites along south Texas coast, 1979 to 1981	eggshell thinning	White et al. (1984)
DDE	black skimmer	3.2	7.0	Lavaca Bay, Texas, April to July 1984	reduced hatching success	King et al. (1991)
DDE	sharp-shinned hawk	7.23	NA	South-central Ontario 1986 to 1989	eggshell thinning	Elliott and Martin (1994)
DDE	red-breasted merganser	7.4 – 7.6	NA	Lake Michigan 1977 and 1978	hatching success	Haseltine et al. (1981)
DDE	peregrine falcon	9.3 and 10.6	NA	Alaska 1960s to 1980s	reproductive success	Ambrose et al.(1988)
p,p′-DDE	bald eagle	NA	9.7	Columbia River estuary, 1980 to 1987	eggshell thinning, reduced productivity	Anthony et al. (1993)
"DDE"	barn owls	NA	12 - 41	laboratory diet for 2 years	eggshell breakage, reduced shell thickness, reduced nestling survival	Mendenhall et al. (1983)
DDE	double-crested cormorants	NA	14.5	Lake Huron, 1972 to 1973	reduced reproductive success and eggshell thinning	Weseloh et al. (1983)
p,p′-DDE	mallard	NA	15.4	laboratory diet for 96 days	reduced eggshell thickness	Haegele and Hudson (1974)
DDE	northern gannet	NA	18.5	eastern Canada, 1968 to 1984	eggshell thinning	Elliott et al. (1988)
p,p′-DDE	bald eagle	10.72 and 4.76	21.8, 18	Maine (area with poor nesting success), 1968	reduced reproductive success	Krantz et al.(1970)
DDE	herring gull	22.6	NA	single injection in the laboratory	reduced embryo and chick survival	Gilman et al. (1978)
p,p′-DDE	American kestrel	3.09	32.4	laboratory diet for 1 year	eggshell thickness	Wiemeyer and Porter (1970)
DDT mixture, mainly DDE	peregrine falcon	NA	43	Norway, 1976 to 1979	eggshell thinning	Nygard (1983)

Table 4-21. DDE and DDT Bird Egg Toxicity Studies

Chemical Form	Species	NOAEL (ng/kg ww)	LOAEL (ng/kg ww)	Exposure Conditions	Endpoint Effect	Source
DDE	black duck	NA	46.3	diet for reproductive period	eggshell thinning and cracking, reduced embryo survival, reduced duckling survival	Longcore et al. (1971)
commercial DDT	chicken	53 – 62		laboratory diet for 8 weeks	egg production, egg hatchability, and egg strength	Scott et al. (1975)
p,p′-DDE	black duck		64.9	laboratory diet for 7 months	reduced hell thickness, egg weight, hatchability, reduced duckling survival	Longcore and Samson (1973)
DDE mixture	American kestrel	1.9 – 7.88	84.5	laboratory diet for approximately 5 months	eggshell thickness	Lincer (1975)
DDT	chicken	50	100	single injection	reduced chick survival	Dunachie and Fletcher (1969)
"DDT" – likely a mixture	ring-necked pheasant		162	diet for 8 weeks	offspring survival	Genelly and Rudd (1956a)
p,p′-DDT	Japanese quail	105	184	single injection in the laboratory	reduced hatchability of eggs from in ovo treated birds	Bryan et al. (1989)
o,p′-DDT	Japanese quail	105	526	single injection in the laboratory	hatchability of eggs from in ovo treated birds, survival to 5 weeks	Bryan et al. (1989)
p,p′-DDT	Japanese quail	658		single injection in the laboratory	reproductive behavior	Bryan et al. (1989)
o,p′-DDT	Japanese quail	184	658	single injection in laboratory	impaired reproductive behavior	Bryan et al. (1989)

BW – body weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as the TRVs.

4.5.3 Total DDx

Nine studies that measured the dietary toxicity of technical DDT or some other mixture of DDT and its metabolites (DDx) to birds (Davison and Sell 1974; Gill et al. 1970; DeWitt 1956; Genelly and Rudd 1956b; Greichus and Hannon 1973; Shellenberger 1978; Scott et al. 1975; Scott 1977; Stickel et al. 1966) were evaluated for TRV selection. Table 4-22 presents the total DDx NOAELs and LOAELs calculated from the studies included in the TRV selection process. Observed adverse effects included decreased eggshell thickness and weight, increased mortality, reduced offspring survival, and reduced fertility and hatchability. Growth appeared to be the endpoint least affected by DDx exposure in avian species. LOAELs ranged from 1.8 mg/kg bw/day for reproduction in mallards (Davison and Sell 1974) to 61 mg/kg bw/day for mortality of pheasants (Gill et al. 1970). In the study reporting the lowest LOAEL, Davison and Sell (1974) reported statistically significant eggshell thinning in mallards fed technical DDT for 11 months. NOAELs ranged from 0.18 mg/kg bw/day for reproduction in mallards (Davison and Sell 1974) to 21 mg/kg bw/day for growth of pheasants (DeWitt 1956). In the study reporting the lowest NOAEL, Davison and Sell (1974) reported no statistically significant change in eggshell thickness in mallards fed technical DDT for 11 months.

The lowest LOAEL, 1.8 mg/kg bw/day, was calculated from the results of Davison and Sell (1974) and was recommended as the LOAEL TRV for total DDx. The NOAEL of 0.18 mg/kg bw/day, based on the same study, was recommended as the NOAEL TRV. There is uncertainty associated with the recommended TRVs for total DDx because the impact of eggshell thinning on reproductive success at a population level is unknown. Eggshell thinning was statistically different from the control group with a difference of about 6% (Davison and Sell 1974). Reproductive effects on field populations of birds have been documented when eggshell thinning has reached 15 to 20% [(Anderson and Hickey (1972) as cited in White et al. (1984)]; (Lincer 1975; Peakall et al. 1975). This recommended LOAEL represents a very conservative threshold value and may overestimate risk to birds at the population level.

Table 4-22. Total DDx Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
DDT mixture	double-crested cormorant	1.3	NA	diet for 9 weeks	no effect on survival	5 (ww)	NA	1.56	0.4 (ww)	Greichus and Hannon (1973)
tech DDT	mallard	**0.18**	**1.8**	diet for 11 months	reduced eggshell weight and thickness	2 (ww)	20 (ww)	1.22 (NOAEL), 1.17 (LOAEL)	0.111 (ww) (NOAEL), 0.104 (LOAEL)	Davison and Sell (1974)
tech DDT	mallard	1.8	NA	diet for 11 months	reduced female survival (> 95%)	20 (ww)	NA	1.17	0.104 (ww)	Davison and Sell (1974)
"DDT" (likely a mixture)	pheasant	2.3	NA	diet for approximately 9 months	no effect on egg production	55.6 (dw)[a]	NA	1.135 (Dunning 1993)	0.0464 (dw) (Nagy 2001)	DeWitt (1956)
tech DDT	Japanese quail	3.0	NA	diet for four generations	no effect on adult survival and body weight	55.6 (dw)[a]	NA	0.09 (Dunning 1993)	0.0048 (dw) (Nagy 2001)	Shellenberger (1978)
tech DDT	Bald eagle[b]	0.30	3.0	diet for 112 days	reduced survival (50%)	NA	NA	NA	NA	Stickel et al. (1966)
tech DDT	Japanese quail	NA	3.0	diet for four generations	reduced fertility and hatchability	NA	55.6 (dw)[a]	0.09 (Dunning 1993)	0.0048 (dw) (Nagy 2001)	Shellenberger (1978)
DDT mixture	double-crested cormorant	NA	3.1	diet for 9 weeks	reduced survival	NA	12.5 (ww)	1.59	0.4 (ww)	Greichus and Hannon (1973)
"DDT" (likely a mixture)	pheasant	NA	3.5	diet for approximately 8 months	reduced survival	NA	NA	NA	NA	DeWitt (1956)
"DDT" (likely a mixture)	ring-necked pheasant	NA	4.5	diet for 8 weeks	reduced offspring survival	NA	90 (ww)	1.135 (Dunning 1993)	0.0572 (ww)	Genelly and Rudd (1956a)

Table 4-22. Total DDx Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
commercial DDT	white leghorn chicken	5.8	NA	diet for 15 weeks	no effect on egg reproduction, hatchability, or strength	100 (ww)	NA	1.71 (NRC 1984)	0.0997 (ww) (NRC 1984)	Scott et al. (1975); Scott et al. 1977
"DDT" (likely a mixture)	quail	6	NA	diet for approximately 9 months	no effect on fertility	111.1 (dw)[a]	NA	0.09 (Dunning 1993)	0.0048 (dw) (Nagy 2001)	DeWitt (1956)
DDT mixture	double-crested cormorant	6.7	NA	diet for 9 weeks	no effect on body weight	25 (ww)	NA	1.49	0.4 (ww)	Greichus and Hannon (1973)
"DDT" (likely a mixture)	quail	7.2	NA	diet for approximately 8 months	no effect on body weight	NA	NA	NA	NA	DeWitt (1956)
"DDT" (likely a mixture)	quail	NA	8.9	diet for approximately 8 months	reduced survival	NA	NA	NA	NA	DeWitt (1956)
tech DDT	mallard	16	NA	diet for 11 weeks	no effect on body weight or female survival;	200 (ww)	NA	0.98	0.0795 (ww)	Davison and Sell (1974)
tech DDT	mallard	16	NA	diet for 11 months	no effect on body weight	200 (ww)	NA	1.247	0.102 (ww)	Davison and Sell (1974)
tech DDT	mallard	NA	16	diet for 11 months	reduced female survival (> 95%)	NA	200 (ww)	1.247	0.102 (ww)	Davison and Sell (1974)
"DDT" (likely a mixture)	pheasant	21	NA	diet for approximately 8 months	no effect on body weight	NA	NA	NA	NA	DeWitt (1956)
tech DDT	ring-necked pheasant	NA	61	diet for 8 days	reduced survival (LC50)	NA	1,038.9 (dw)[a]	0.03975	0.0023 (dw) (Nagy 2001)	Gill et al. (1970)

[a] Concentration in food converted to dry weight assuming 10% moisture in laboratory-prepared food.

[b] Field-collected birds were used in this controlled laboratory experiment and small sample size was used.
BW – body weight
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
dw – dry weight
LC50 – concentration that is lethal to 50% or an exposed population
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
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)
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

4.6 OTHER SVOCS

4.6.1 Bis(2-ethylhexyl) Phthalate

Three studies on the toxic effects of dietary BEHP on birds were reviewed and evaluated (Peakall 1974; O'Shea and Stafford 1980; Ishida et al. 1982). Only one LOAEL of 329 mg/kg bw/day was calculated where egg production ceased in domestic chickens following 230 days of exposure (also during a critical life stage) (Ishida et al. 1982). Table 4-23 presents the BEHP NOAELs and LOAELs calculated from the studies reviewed. NOAELs ranged from 1.11 mg/ kg bw/day for reproduction of ringed doves (Peakall 1974) to 71.5 mg/kg bw/day for growth in starlings (O'Shea and Stafford 1980). At the lowest NOAEL, O'Shea and Stafford (1980) did not report an effect on eggshell thickness in turtle doves exposed to dietary BEHP for four weeks.

The only calculated LOAEL of 329 mg/kg bw/day was recommended as the LOAEL TRV. The reproductive NOAEL, 1.11 mg/kg/day, from Peakall (1974) was recommended as the NOAEL TRV because it was based on the same endpoint (reproduction) as the selected LOAEL. There is a large difference between the selected NOAEL and LOAEL, and there is uncertainty associated with both of these values because the literature dataset for BEHP toxicity to birds is limited to three studies using highly variable dose concentrations.

4.6.2 Dibutyl Phthalate

No studies reporting the dietary toxicity of dibutyl phthalate to birds were identified. BEHP was recommended as the surrogate for dibutyl phthalate.

Table 4-23. BEHP Dietary Toxicity Studies for Birds

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
BEHP	ringed dove	**1.11**	NA	diet for 4 weeks	no effect on eggshell thickness	11.1 (dw)[a]	NA	0.155 (Sample et al. 1996)	0.0173 (dw) (Nagy 2001)[b]	Peakall (1974)
BEHP	European starling	67.8	NA	diet for 30 days	no effect on growth or food consumption	260 (ww)	NA	0.828 (Cabe 1993)	0.0216 (ww)	O'Shea and Stafford (1980)
BEHP	chicken	NA	**329**	diet for 230 days	cessation of egg laying, abnormal ovaries	NA	5,000 (ww)	1.84 (Edens and Garlich 1983)	0.121(Edens and Garlich 1983)	Ishida et al. (1982)

[a] Concentration in food converted to dry weight assuming 10% moisture in laboratory-prepared food.
[b] As cited in Sample et al. (1996).
BEHP – bis(2-ethylhexyl) phthalate
BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

5.0 MAMMAL DIETARY TRVs

Dietary TRVs were recommended for all mammal COPCs, where literature was available. Surrogate chemicals were used to develop dietary TRVs for COPCs for which no suitable toxicological data were available.

The following subsections provide a summary of the studies reviewed. Tables 5-1 through 5-9 present data from all the mammal studies evaluated in the TRV selection process and the assumptions (e.g., body weight, food ingestion rate, moisture content in food) used to calculate the body-weight normalized daily dose (NOAEL and LOAEL) from each study.

5.1 METALS

5.1.1 Aluminum

Eleven studies on the toxicity of aluminum to mammals (Domingo et al. 1987a; Domingo et al. 1987b; Domingo et al. 1989; Golub and Keen 1999; Golub et al. 1987; Gomez et al. 1990; Llobet et al. 1995; Ondreicka et al. 1966; Paternain et al. 1988; Schroeder and Mitchener 1975; Yokel 1985) were evaluated for TRV selection. Table 5-1 presents all of the NOAELs and LOAELs calculated for aluminum from the literature reviewed. The mechanisms of exposure included dietary ingestion, drinking water ingestion, gavage, intraperitoneal injection, and subcutaneous injection. Effects on adult growth, and reproduction were measured in laboratory rats and mice exposed to aluminum. LOAELs ranged from 3.6 mg/kg bw/day for growth of rats exposed via intraperitoneal injection (Llobet et al. 1995) to 75.8 mg/kg bw/day for growth and mortality of mice exposed through dietary ingestion (Golub et al. 1987). NOAELs ranged from 0.70 mg/kg bw/day for growth and mortality of rats exposed via drinking water (Schroeder and Mitchener 1975) to 275 mg/kg bw/day for growth and reproduction of rats exposed via gavage (Gomez et al. 1990). Only three dietary studies were reviewed.

Dietary exposure is preferred for TRV selection when studies are available because drinking water and gavage exposure is not directly relevant to the dietary pathway being evaluated for Portland Harbor wildlife receptors. The only dietary LOAEL of 75.8 mg/kg bw/day was recommended as the LOAEL. At this concentration, maternal and offspring body weight and length were significantly reduced following dietary exposure to aluminum to adult mice during gestation (Golub et al. 1987). The highest dietary NOAEL (34.4 mg/kg bw/day) below the selected LOAEL was selected based on Ondreicka et al. (1966). No effect on on body weight, the number of litters, or number of offspring per litter was observed in mice aluminum for multiple generations.

Table 5-1. Aluminum Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Aluminum potassium sulfate	mouse	0.70	NA	drinking water for lifespan[a]	no effect on survival, increase in growth	5 (ww)	NA	0.03 (EPA 1993)	0.0042 (EPA 1993)	Schroeder and Mitchener (1975)
Aluminum nitrate	rat	NA	3.6	IP injection 5 times per week for 4 weeks[d]	reduced male body weight	NA	NA	NA	NA	Llobet et al. (1995)
Aluminum nitrate	rat	3.6	7.2	IP injection 5 times per week for 4 weeks[d]	reduction in number of pregnancies, reduced sperm count	NA	NA	NA	NA	Llobet et al. (1995)
Aluminum lactate	white rabbit	10.8	NA	subcutaneous injections during gestation	no effect on offspring body weight	NA	NA	NA	NA	Yokel (1985)
Aluminum nitrate	rat	NA	13.0	gastric gavage during gestation	reduced offspring body weight and length	NA	NA	NA	NA	Domingo et al. (1987a)
Aluminum nitrate	rat	NA	13.0	gastric gavage during gestation	reduced number of live fetuses and maternal body weight	NA	NA	NA	NA	Paternain et al. (1988)
Aluminum chloride	mouse	NA	19.3	drinking water for multiple generations	reduced body weight in second and third generations	NA	NA	NA	NA	Ondreicka et al. (1966)
Aluminum nitrate	rat	13.0	25.9	gastric gavage during gestation and lactation	reduced offspring body weight and newborn survival	NA	NA	NA	NA	Domingo et al. (1987b)
Aluminum chloride	mouse	**34.3**	NA	diet for multiple generations	no effect on body weight, number of litters, or number of offspring per litter	355 (ww)	NA	0.20 (EPA 1993)	0.019 (Calder and Braun 1983)	Ondreicka et al. (1966)
Aluminum lactate	mouse	NA	**75.8**	diet during gestation	reduced maternal and offspring body weight and length	NA	412.7 (ww)	0.03 (EPA 1993)	0.0055 (Calder and Braun 1983)	Golub et al. (1987)

Table 5-1. Aluminum Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Aluminum hydroxide	rat	95.3	NA	gastric gavage during gestation	no effect on maternal body weight, number of implantations / resorptions, fetal survival, fetal growth, or fetal abnormalities	NA	NA	NA	NA	Domingo et al. (1989)
Aluminum lactate	mouse	137	NA	diet for 8 weeks	no effect on body weight and length	1,000 (ww)	NA	NA	NA	Golub and Keen (1999)
Aluminum hydroxide	rat	275	NA	gavage during gestation	no effect on maternal body weight, implantation loss, litter survival, fetal growth, fetal abnormalities	NA	NA	NA	NA	Gomez et al. (1990)

[a] Drinking water contained other metals (i.e., 5 mg/kg chromium, 50 mg/kg zinc, 5 mg/kg copper, and 10 mg/kg magnesium).
[b] Males were exposed and mated with untreated females.
BW – body weight
dw – dry weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

There is high uncertainty associated with the selected TRVs for aluminum because they are based on exposure to the ionic form of aluminum. Toxicity measured for ionic aluminum is not comparable to the toxicity associated with the colloidal, particulate and complex forms of aluminum present in the environment. The application of a TRV based on the toxicity of ionic aluminum to measured total aluminum concentrations is highly uncertain and will likely overestimate the risks associated with aluminum exposure.

5.1.1 Antimony

Five studies on the toxicity of antimony to laboratory rats (Hext et al. 1999; Rossi et al. 1987; Poon et al. 1998; Schroeder et al. 1970; Schroeder et al. 1968) were evaluated for TRV selection. Table 5-2 presents all of the NOAELs and LOAELs calculated for antimony from the literature reviewed. In the studies considered for TRV selection, the mechanisms of exposure included drinking water and dietary ingestion. Adverse effects, including reduced growth, survival, and offspring body weight were observed in rats and mice exposed to antimony. LOAELs ranged from 0.060 mg/kg bw/day for growth of rats (Rossi et al. 1987) to 43.9 mg/kg bw/day for growth of rats (Poon et al. 1998). NOAELs ranged from 0.35 mg/kg bw/day for survival of mice (Schroeder et al. 1968) to 1,489 mg/kg bw/day for growth and mortality of rats (Hext et al. 1999). Only one dietary study was reviewed (Hext et al. 1999). Hext et al. (1999) reported no effect on growth or mortality in rats fed 1,489 mg/kg bw/day antimony as antimony oxide for 90 days.

The only dietary NOAEL of 1,489 mg/kg bw/day was recommended as the NOAEL. Dietary exposure is preferred for TRV selection when studies are available because drinking water exposure is not directly relevant to the dietary pathway being evaluated for Portland Harbor wildlife receptors. No LOAEL was selected because no dietary studies reporting LOAELs were available. There is high uncertainty associated with the selected unbounded NOAEL because the literature dataset for the dietary toxicity of antimony to mammals is limited to one study in which no toxicity was observed.

Table 5-2. Antimony Dietary Toxicity Studies for Mammal

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Antimony chloride	rat	NA	0.060	drinking water for 39 days	reduced maternal body weight	NA	0.533	0.282	0.032 (Calder and Braun 1983)	Rossi et al. (1987)
Antimony potassium tartrate	rat	NA	0.57	drinking water for lifetime	reduced survival	NA	5	0.263	0.030 (Calder and Braun 1983)	Schroeder et al. (1970)
Antimony potassium tartrate	mouse	0.35	NA	drinking water for lifetime	no effect on lifespan	5	NA	0.0418	0.0029 (Calder and Braun 1983)	Schroeder et al. (1968)
Antimony chloride	rat	0.060	0.60	drinking water for 39 days	reduced offspring body weight	0.53	5.3	0.277	0.031 (Calder and Braun 1983)	Rossi et al. (1987)
Antimony potassium tartrate	mouse	0.35	NA	drinking water for lifetime	no effect on body weight	5	NA	0.282	0.0029 (Calder and Braun 1983)	Schroeder et al. (1968)
Antimony potassium tartrate	rat	0.57	NA	drinking water for lifetime	no effect on body weight	5	NA	0.0418	0.030 (Calder and Braun 1983)	Schroeder et al. (1970)
Potassium Antimony potassium tartrate	rat	5.86	43.9	drinking water for 13 weeks	reduced body weight	20	500	NA	NA	Poon et al. (1998)
Antimony oxide	rat	**1,489**	NA	diet for 90 days	no effect on growth rate; small increase in body weight	16,702	NA	NA	NA	Hext et al. (1999)

BW – body weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

5.1.2 Copper

Three studies on the toxic effects of dietary copper to mammals were reviewed and evaluated for TRV selection (NTP 1993; Aulerich et al. 1982; Dodds-Smith et al. 1992). Table 5-3 presents all of the NOAELs and LOAELs calculated for copper from the literature reviewed. The mechanism of exposure included dietary ingestion only. Effects on reproduction, mortality, and growth were measured in mink, rats, and mice. LOAELs ranged from 26 mg/kg bw/day for reproduction of mink (Aulerich et al. 1982) to 467 mg/kg bw/day for growth of mice (NTP 1993). NOAELs ranged from 18 mg/kg bw/day for reproduction of mink (Aulerich et al. 1982) to 749 mg/kg bw/day for mortality and growth of mice (NTP 1993). In the study reporting the lowest LOAEL, 38% kit mortality (as compared to 12% in the control group) and reduced litter mass were reported in the offspring of adult mink fed 26 mg/kg bw/day dietary copper as copper sulfate following one year of exposure during a critical life stage (Aulerich et al. 1982). No effect was reported on mink reproduction following exposure to 18 mg/kg bw/day (Aulerich et al. 1982).

The LOAEL and NOAEL of 26 and 18 mg/kg bw/day copper derived from Aulerich et al. (1982) were recommended as the TRVs for copper. The recommended TRVs for copper in mammals represents concentrations protective of the most sensitive mammal species measured in the literature review (mink), which is also a selected receptor species for Portland Harbor. There is some uncertainty associated with the recommended TRVs because the literature dataset for the dietary toxicity of copper to mammals is limited to three studies.

Table 5-3. Copper Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Copper sulfate	mink	**18**	**26**	diet for 357 days	reduced offspring kit survival, litter mass[a]	110.5	160.5	1.071 (NOAEL), 1.088 (LOAEL)	0.18 (Bleavins and Aulerich 1981)	Aulerich et al. (1982)
Copper sulfate	mink	43	NA	diet for 153 to 657 days	no effect on body weight	260.5	NA	1.056	0.18 (Bleavins and Aulerich 1981)	Aulerich et al. (1982)
Copper sulfate	rat	137	NA	diet for 13 weeks	100% survival	NA	NA	NA	NA	NTP (1993)
Copper sulfate	rat	67	137	diet for 13 weeks	reduced body weight	NA	NA	NA	NA	NTP (1993)
Copper sulfate	rat	93	197	diet for 2 weeks	reduced body weight	NA	NA	NA	NA	NTP (1993)
Copper sulfate	shrew	267	NA	diet for 12 weeks	no effect on body weight	NA	NA	NA	NA	Dodds-Smith et al. (1992)
Copper sulfate	rat	305	NA	diet for 2 weeks	100% survival	NA	NA	NA	NA	NTP (1993)
Copper sulfate	mouse	467	NA	diet for 13 weeks	100% survival	NA	NA	NA	NA	NTP (1993)
Copper sulfate	mouse	227	467	diet for 13 weeks	reduced body weight	NA	NA	NA	NA	NTP (1993)
Copper sulfate	mouse	749	NA	diet for 2 weeks	100% survival, no effect on growth	NA	NA	NA	NA	NTP (1993)

[a] At LOAEL, 38% kit mortality was observed. In mink from NOAEL and control groups, 12% and 19% mortality were observed, respectively.

BW – body weight
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
NTP – National Toxicity Program
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

5.1.3 Lead

Eleven studies on the toxicity of lead to mammals were evaluated for TRV selection (Angell and Weiss 1982; Azar et al. 1973; Overmann 1977; Odenbro and Kihlstrom 1977; Reiter et al. 1975; Hammond et al. 1990; Hackett et al. 1982; Kimmel et al. 1980; Schroeder and Mitchener 1971b; Sharma and Kanwar 1985; Zenick et al. 1979). Table 5-4 presents all of the NOAELs and LOAELs calculated for lead from the literature reviewed. The mechanisms of exposure in the studies considered for TRV selection included dietary ingestion, drinking water ingestion, and oral gavage. LOAELs ranged from 0.55 mg/kg bw/day for behavior of rats exposed via drinking water (Reiter et al. 1975) to 120 mg/kg bw/day for growth and behavior of mice exposed via drinking water (Angell and Weiss 1982). NOAELs ranged from 0.5 mg/kg bw/day for reproduction of mice exposed via gavage (Odenbro and Kihlstrom 1977) to 49.2 mg/kg bw/day for growth of rats exposed via gavage (Overmann 1977). Only one dietary study that measured the toxicity of lead on rats (Azar et al. 1973) was reviewed. Azar et al. (1973) reported reduced body weight and kidney damage in offspring of parents fed 90 mg/kg bw/day lead as lead acetate over a chronic period (two years). No effect on growth was reported in rats fed 11 mg/kg bw/day.

The LOAEL and NOAEL of 90 and 11 mg/kg bw/day, respectively, were recommended from the one dietary study (Azar et al. 1973) because dietary exposure is the preferred exposure route for TRV recommendation. Exposure routes in the other three studies varied (i.e., oral gavage, intravenous injection, drinking water, or a combination of drinking water and dietary exposure). These exposure routes are not directly relevant to the dietary exposure pathway being measured for the wildlife ecological receptors in Portland Harbor. There is some uncertainty associated with the recommended TRVs because the literature dataset for the dietary toxicity of lead is limited to one study only.

The selected dietary LOAEL and NOAEL are higher than the effect levels reported in the studies that used drinking water, though drinking water effect levels were widely variable (LOAELs ranged from 3.3 to 120 mg/kg bw/day lead for growth and reproduction). However, because drinking water ingestion involves a method of uptake and absorption that is different than the selected dietary pathway for wildlife receptors in the ERA, none of the drinking water studies were used to calculate the selected TRVs. LOAELs calculated from gavage studies are also lower (LOAELs range from 1.5 to 5.5 mg/kg bw/day for behavior and reproduction). Thus the selected TRVs may underestimate risk to mammals; however, the study used to calculate the TRVs is based on a dietary pathway, the most applicable exposure route.

Table 5-4. Lead Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Lead acetate	rat	NA	0.55	drinking water for multi-generational	change in reflex develop-ment in offspring, reduced locomotor activity in adults	NA	5	0.35 (EPA 1993)	0.0385 (Calder and Braun 1983)	Reiter et al. (1975)
Triethyl lead chloride	mouse	0.5	1.5	gavage (water) for day 3 to 5 after mating	decreased frequency of implanted ova	NA	NA	NA	NA	Odenbro and Kihlstrom (1977)
Soluble lead	rat	NA	3.3	food and drinking water for three generations	reduced offspring survival, increased number of runts	NA	NA	0.35 (EPA 1993)	NA	Schroeder and Mitchener (1971b)
Lead acetate	rat		5.5	intubation for 18 days	altered operant behavior	NA	NA	NA	NA	Overmann (1977)
lead acetate	rat	5.5		drinking water for multiple generations	no effect on body weight	50	NA	0.35 (EPA 1993)	0.0385 (Calder and Braun 1983)	Reiter et al. (1975)
Soluble lead	mouse	NA	6.3	food and drinking water for three generations	reduced offspring survival, increased number of runts, discontinuation of breeding	NA	NA	0.03 (EPA 1993)	NA	Schroeder and Mitchener (1971b)
Lead acetate	rat	4.7	8.9	drinking water for 12 weeks	reduced growth of females through pregnancy and lactation	NA	NA	NA	NA	Kimmel et al. (1980)
Lead nitrate	rat	3.1	15.6	injection (IV) on day 9 or 15 of gestation, monitor for 11 or 5 days	decrease in percent body weight gain in pregnant rat	NA	NA	NA	NA	Hackett et al. (1982)
Lead acetate	rat	NA	31.5	drinking water for 12 days	reduced growth	250	NA	0.09	0.0113 (Calder and Braun 1983)	Hammond et al. (1990)

Table 5-4. Lead Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Lead acetate	rat	44	NA	drinking water for gestation through nursing	no effect on maternal care (nursing, pup retrieval), offspring reflex development, maternal body weight	100	NA	0.35 (EPA 1993)	0.0385 (Calder and Braun 1983)	Zenick et al. (1979)
Lead acetate	rat	49.2		intubation for 18 days	reduced body weight	NA	NA	NA	NA	Overmann (1977)
Lead acetate	rat	**11**	**90**	diet for 2 years	reduced offspring weight, kidney damage	141	1,160	0.35 (EPA 1993)	0.028 (EPA 1993)	Azar et al. (1973)
Lead acetate	mouse	NA	112	drinking water for 11 weeks	reduced pup weight and survival	NA	800	0.03 (EPA 1993)	0.00422 (Calder and Braun 1983)	Sharma and Kanwar (1985)
Lead acetate	rat	NA	120	drinking water for age 3 days to age 133 days	altered operant behavior, reduced body weight	NA	1,090	0.35 (EPA 1993)	0.0385 (Calder and Braun 1983)	Angell and Weiss (1982)

bw – body weight
BW – body weight
IV – intravenous
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

5.1.4 Mercury

Seven toxicity studies on dietary mercury using mink and laboratory rodents were evaluated for TRV selection (Aulerich et al. 1974; Dansereau et al. 1999; Verschuuren et al. 1976; Hughes and Annau 1976; Wobeser et al. 1976a, b; Schroeder and Mitchener 1975). Table 5-5 presents all of the NOAELs and LOAELs calculated for mercury from the literature reviewed. In the literature evaluated for TRV selection, observed adverse effects of mercury exposure included increased mortality, depressed growth, altered offspring behavior, and reproductive effects. The mechanisms of exposure included dietary ingestion, drinking water ingestion, and injection. LOAELs ranged from 0.0084 mg/kg bw/day for growth of rats (Verschuuren et al. 1976) to 3.0 mg/kg bw/day for reproduction and offspring behavior of mice (Hughes and Annau 1976). At the lowest LOAEL, growth was reduced in rats fed 0.0084 mg/kg bw/day mercury as mercuric chloride for three generations (Verschuuren et al. 1976). The next lowest LOAELs (ranging from 0.07 to 0.12 mg/kg bw/day) were calculated from Dansereau et al. (1999) where mink were fed a diet for several generations made up of 20% mink feed, 40% eviscerated chicken carcasses (contaminant free), and 40% field-collected fish from the Robert Bourassa Reservoir, Quebec. There is some uncertainty associated with the LOAELs reported in Dansereau et al. (1999) because the field-collected fish contained other organic chemicals that could have contributed to the reproductive toxicity reported in mink; however, the field-collected fish made up only a portion of the mink diet, so the uncertainty is likely to be low. LOAELs for reduced whelping success and adult mortality were 0.07 and 0.12 mg/kg bw/day mercury, respectively (Dansereau et al. 1999). NOAELs reported in the reviewed literature ranged from 0.02 mg/kg bw/day for reproduction of mink (Dansereau et al. 1999) to 2.0 mg/kg bw/day for reproduction and offspring behavior of mice (Hughes and Annau 1976).

The LOAEL and NOAEL of 0.07 and 0.02 mg/kg bw/day, respectively, were recommended as the TRVs for mercury. They were the lowest TRVs reported for mink. A lower LOAEL (0.0084 mg/kg bw/day) was reported in Verschuuren et al. (1976); however, this study was not used to derive the selected TRV because low-effect doses were reported in Dansereau et al. (1999), in which mink, one of the selected mammal receptors in Portland Harbor, were exposed over a chronic duration for multiple generations through an ecologically relevant exposure (via partial fish consumption). The NOAEL was the lowest NOAEL calculated from the reviewed studies.

There is uncertainty associated with the recommended TRVs because the field-collected fish (making up 40% of the prepared diet) may have contained other, uncharacterized organic chemicals that could have contributed to the reproductive toxicity reported in mink. However, the selected mammal TRVs for mercury were based on the only study reporting the reproductive, chronic toxicity of mercury to mink. The use of TRVs based on studies in which diet was comprised partially of field-collected fish will be revisited in the Round 2 Comprehensive Report and the BERA.

Table 5-5. Mercury Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg/day)	Source
Methylmercuric chloride	rat	NA	0.0084	diet for three generations	reduced growth	NA	0.0799	0.16	0.016 (EPA 1993)	Verschuuren et al. (1976)
Methylmercuric chloride	ranch mink	0.051	NA	diet for 145 days[a]	no effect on adult survival (91% survival)	0.33	NA	0.87 (Bleavins and Aulerich 1981)	0.18 (Bleavins and Aulerich 1981)	Wobeser et al. (1976a)
Methylmercuric chloride	ranch mink	0.043	NA	diet for 145 days	no effect on juvenile growth	0.33	NA	1.34 (Bleavins and Aulerich 1981)	0.18 (Bleavins and Aulerich 1981)	Wobeser et al. (1976a)
Mercury (chemical form unknown)	mink	**0.02**	**0.07**	diet for multiple generations[b]	reduced number of females whelped	0.12	0.56	1.34 (Bleavins and Aulerich 1981)	0.18 (Bleavins and Aulerich 1981)	Dansereau et al. (1999)
Mercury (chemical form unknown)	mink	0.07	0.12	diet for multi-generational[b]	reduced adult survival	0.5	0.9	1.34 (Bleavins and Aulerich 1981)	0.18 (Bleavins and Aulerich 1981)	Dansereau et al. (1999)
Methylmercuric chloride	rat	0.19	NA	diet for three generations	no effect on survival or reproduction	1.997	NA	0.20	0.019 (EPA 1993)	Verschuuren et al. (1976)
Methylmercuric chloride	mink	0.16	0.25	diet for 93 days	reduced growth, reduced survival (60%)	1.2	1.9	1.34 (Bleavins and Aulerich 1981)	0.18 (Bleavins and Aulerich 1981)	Wobeser et al. (1976b)
Methylmercury	mink	NA	0.64	diet for 2 months	reduced growth and survival (0%)	NA	5	1.2	0.15	Aulerich et al. (1974)

Table 5-5. Mercury Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg/day)	Source
Mercury chloride and methylmercury acetate	mouse	0.70	NA	drinking water for lifetime	no effect on growth or survival	5	NA	0.031	0.0044 (Calder and Braun 1983)	Schroeder and Mitchener (1975)
Methylmercury hydroxide	mouse	2.0	3.0	single injection (gestation day 8)	reduced pup survival and body weight, altered offspring avoidance behavior	NA	NA	NA	NA	Hughes and Annau (1976)

[a] Mink were exposed to field-collected fish.

[b] Mink prepared diet consisted of 40% freshwater field-collected fish and 60% prepared chicken carcasses.

[a] Concentration in food converted to dry weight assuming 10% moisture in laboratory-prepared food

BW – body weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

ww – wet weight

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

5.1.5 Selenium

Eight laboratory studies on the toxicity of selenium to mammals were evaluated for TRV selection (Halverson et al. 1966; Ferm et al. 1990; Behne et al. 1992; Jia et al. 2005; Julius et al. 1983; Rosenfeld and Beath 1954; Schroeder and Mitchener 1971a, 1972). Table 5-6 presents all of the NOAELs and LOAELs calculated for selenium from the literature reviewed. The mechanisms of exposure included dietary ingestion, drinking water ingestion, gavage, and intravenous injection. Adverse effect on growth, mortality, and reproduction were reported in laboratory rats, mice, and hamsters. LOAELs ranged from 0.08 mg/kg bw/day for growth of rats (Halverson et al. 1966) to 8.69 mg/kg bw/day for growth of hamsters (Ferm et al. 1990). NOAELs ranged from 0.055 mg/kg bw/day for growth of rats (Halverson et al. 1966) to 7.9 mg/kg bw/day for growth of hamsters (Ferm et al. 1990). The lowest LOAEL and NOAEL were derived from Halverson et al. (1966). Growth was significantly reduced in rats fed 0.08 mg/kg bw/day selenium as sodium selenite or seleniforous wheat for six weeks, and no effect on growth was reported in rats fed 0.055 mg/kg bw/day (Halverson et al. 1966).

The LOAEL and NOAEL of 0.08 and 0.055 mg/kg bw/day, respectively, were recommended as the TRVs for selenium. These were the lowest TRVs calculated in the literature reviewed. There is some uncertainty associated with the recommended TRVs because the study was conducted over a subchronic (six-week) period. However, no dietary study reviewed was conducted over a chronic period (i.e., one year) or during a critical life stage. Ferm et al. (1990) exposed hamsters via oral gavage during a critical life stage (gestation) and reported much higher LOAELs (ranging from 7.1 to 8.7 mg/kg bw selenium). Thus, the selected TRVs may overestimate chronic risk to mammals exposed to selenium.

Table 5-6. Selenium Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Sodium selenite or seleniferous wheat	rat	0.055	0.08	diet for 6 weeks	reduced body weight	3.2	4.8	0.139 (NOAEL), 0.129 (LOAEL)	0.00238 (NOAEL), 0.00215 (LOAEL)	Halverson et al. (1966)
Sodium selenite or seleniferous wheat	rat	0.13	0.14	diet for 6 weeks	reduced survival	8.0	9.6	0.129 (NOAEL), 0.1255 (LOAEL)	0.00215 (NOAEL), 0.00186 (LOAEL)	Halverson et al. (1966)
Selenomethionine	rat	NA	0.16	diet for 110 days	reduced body weight	NA	2	0.34	0.027 (EPA 1993)	Behne et al. (1992)
Selenite	rat	0.16	NA	diet for 110 days	body weight	2	NA	0.34	0.027 (EPA 1993)	Behne et al. (1992)
Potassium sodium selenite	rat	0.16	0.27	drinking water for 1 year	reduced pup growth, number weaned	1.5	2.5	0.35 (EPA 1993)	0.0385 (Calder and Braun 1983)	Rosenfeld and Beath (1954)
Sodium selenite, Nano-Se, or organic selenium	rat	0.17	0.28	diet for 13 weeks	reduced body weight	NA	NA	NA	NA	Jia et al. (2005)
Selenomethionine	hamster	0.36	NA	diet for 21 days	body weight	5.1	10.1	0.092 (NOAEL), 0.091 (LOAEL)	0.00655 (NOAEL), 0.0068 (LOAEL)	Julius et al. (1983)
Sodium selenate	mouse	0.42	NA	drinking water for multiple generations	no effect on survival	3	NA	0.03 (EPA 1993)	0.0385 (Calder and Braun 1983)	Schroeder and Mitchener (1971b)

Table 5-6. Selenium Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Sodium selenate	mouse	NA	0.43	drinking water for multiple generations	reduced offspring survival, number of runts, breeding failure	NA	3.06	0.03 (EPA 1993)	0.0385 (Calder and Braun 1983)	Schroeder and Mitchener (1971b)
Sodium selenate	mouse	NA	0.43	drinking water for lifetime	reduced survival, body weight	NA	3.06	0.03 EPA 1993)	0.0385 (Calder and Braun 1983)	Schroeder and Mitchener (1972)
Selenomethionine	hamster	NA	0.76	diet for 21 days	reduced body weight	NA	10.1	0.091	0.0068	Julius et al. (1983)
Sodium selenite	hamster	NA	0.87	single IV injection during gestation	reduced maternal body weight	NA	NA	NA	NA	Ferm et al. (1990)
Sodium selenite	hamster	1.82	NA	single IV injection during gestation	no effect on number of abnormal litters	NA	NA	NA	NA	Ferm et al. (1990)
Sodium selenate	hamster	2.21	2.68	single IV injection during gestation	reduced maternal body weight, increase in number of abnormal litters	NA	NA	NA	NA	Ferm et al. (1990)
Sodium selenite	hamster	NA	3.4	21days	reduced body weight	NA	40.25	0.074	0.0062	Julius et al. (1983)
Sodium selenite	hamster	NA	5.8	21 days	reduced female survival	NA	80.24	0.062	0.0045	Julius et al. (1983)
Sodium selenate	hamster	NA	7.11	4 days of gestation	reduced fetal body length	NA	NA	NA	NA	Ferm et al. (1990)

Table 5-6. Selenium Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Sodium selenite	hamster	7.11	7.90	4 days of gestation	increase in number of abnormal litters, reduction in fetal body length	NA	NA	NA	NA	Ferm et al. (1990)
Sodium selenate	hamster	7.90	8.69	4 days of gestation	reduced maternal body weight	NA	NA	NA	NA	Ferm et al. (1990)

BW – body weight
dw – dry weight
IV – intravenous
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

Bold identifies the NOAEL and LOAEL selected as the TRVs.

5.2 PAHS

Adverse effects in mammals resulting from polycyclic aromatic hydrocarbon (PAH) exposure were considered using for individual PAHs and PAH mixtures. Three individual PAHs (i.e., fluoranthene, phenanthrene, and pyrene) were identified as mammal COPCs in the BERA; however, toxicological studies were not available for these inidvidiual PAHs. Three studies were available on the dietary toxicity of benzo(a)pyrene (MacKenzie and Angevine 1981; Rigdon and Neal 1965; Neal and Rigdon 1967).

5.2.1 Benzo(a)pyrene

Three studies on the toxicity of benzo(a)pyrene to mice were evaluated for TRV selection (MacKenzie and Angevine 1981; Rigdon and Neal 1965; Neal and Rigdon 1967). The mechanisms of exposure included dietary ingestion and gavage. Table 5-7 presents all of the NOAELs and LOAELs calculated for benzo(a)pyrene from the literature reviewed. Only one LOAEL was reported in the studies reviewed. A significant decrease in pup body weight and adult male testes weight was observed in pregnant mice exposed to 10 mg/kg bw/day benzo(a)pyrene via gavage for 10 days of gestation (MacKenzie and Angevine 1981). NOAELs ranged from 33.3 mg/kg bw/day for mortality of mice (Neal and Rigdon 1967) to 199 mg/kg bw/day for growth and reproduction of mice (Rigdon and Neal 1965). Both NOAELs were based on dietary studies. No NOAEL was reported below the only LOAEL reported for benzo(a)pyrene.

The LOAEL of 10 mg/kg bw reported in MacKenzie and Angevine (1981) was recommended as the LOAEL TRV. This was the only LOAEL reported in the reviewed literature, and this study was conducted over a critical life stage (during pregnancy). There is some uncertainty associated with the recommended LOAEL because gavage is not a preferred exposure route; however, no LOAELs were reported in the two dietary studies that were reviewed. There is additional uncertainty associated with the selected TRVs because the literature dataset for benzo(a)pyrene toxicity in mammals is limited to three studies using laboratory mice, and only one study reports an effect-level concentration. No NOAEL was reported in MacKenzie and Angevine (1981), so none was recommended.

Table 5-7. Benzo(a)pyrene Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Benzo(a)pyrene	mouse	NA	**10**	gavage for 10 days during gestation	reduced pup body weight, testes weight	NA	NA	NA	NA	MacKenzie and Angevine (1981)
Benzo(a)pyrene	mouse	33.3	NA	diet for up to 115 days	no effect on survival[a]	250 (ww)	NA	0.03 (EPA 1993)	0.004 (ww) (EPA 1993)	Neal and Rigdon (1967)
Benzo(a)pyrene	mouse	199	NA	diet for prior to or following mating	no effect on adult body weight, embryonic development, fertility, and occurrence of embryonic malformations[b]	900 (ww)	NA	0.0175	0.004 (ww) (EPA 1993)	Rigdon and Neal (1965)

[a] Stomach tumor frequency increased at lower doses.

[b] No statistics – results not clearly presented in paper, overall conclusions taken from paper; decreased body weight attributed to decreased ingestion rat (not toxicity).

BW – body weight

LOAEL – lowest-observed-adverse-effect level

NA – not applicable

NOAEL – no-observed-adverse-effect level

ww – wet weight

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

5.2.3 PAH mixture

No relevant studies on the toxicity of PAH mixtures to mammals were identified in the scientific literature.

5.3 PCBS

A total of fourteen papers on the potential adverse effects of PCBs on mammals were reviewed (Aulerich and Ringer 1977; Aulerich et al. 1985; Bleavins et al. 1980; Heaton et al. 1995; Hornshaw et al. 1983; Restum et al. 1998; Brunström et al. 2001; Harris et al. 1993b; Jensen et al. 1977; Kihlstrom et al. 1992; Ringer 1983; Tillitt et al. 1996; Wren et al. 1987). The mechanism of exposure included dietary ingestion of laboratory or exposed field-collected diets. The most comprehensive studies of PCB toxicity in a wildlife mammalian species have been conducted with mink, and only mink studies were reviewed for PCBs. Mink also appears to be one of the most sensitive mammalian species tested (Fuller and Hobson 1986) and is therefore a good surrogate for the assessment of risk to other mammals. Monkeys also are highly sensitive to PCBs; however, effect levels from mink studies only were reviewed for the Portland Harbor BERA because mink are a selected receptor for Portland Harbor and have a greater taxonomic similarity to river otter, the other selected mammalian receptor for Portland Harbor, than do monkeys.

Table 5-8 presents all of the NOAELs and LOAELs calculated for PCBs from the literature reviewed. Adverse effects on maternal growth, kit growth, kit survival, and gestation length, whelping success, and reproductive failure were measured in mink following exposure to PCBs. LOAELs ranged from 0.037 mg/kg bw/day for reproduction in mink (Restum et al. 1998) to 2,000 mg/kg bw/day for growth of rats (Harris et al. 1993b). NOAELs ranged from 0.070 mg/kg bw/day for reproduction in mink (Hornshaw et al. 1983) to 480 mg/kg bw/day for growth of rats (Harris et al. 1993b). The lowest LOAELs, ranging from 0.037 to 0.077 mg/kg bw/day PCBs, were reported in studies in which adverse reproductive effects (including reduced kit body weight, delay in the onset of estrus, and reduced whelping success) were observed in mink fed field-collected carp from the Great Lakes region over a chronic period (Hornshaw et al. 1983; Restum et al. 1998). In the studies mink were fed a prepared diet containing various percentages of field-collected fish; thus, these study only have quantitative relevance to mink exposed to chemical mixtures similar those found in the Great Lakes fish. In addition, there is uncertainty associated with these LOAELs because the field-collected fish contained other organic chemicals (e.g., dioxins/furans, DDE, DDD, chlordane) that likely could have contributed to the reproductive toxicity reported in mink. The next lowest LOAEL of 0.089 mg/kg bw/day was reported in Brunström et al. (2001) in which offspring growth was reduced in mink fed a Clophen A50 PCB mixture for 18 months (Brunström et al. 2001).

The lowest LOAELs (ranging from 0.037 to 0.077 mg/kg bw/day were reported in studies where mink were exposed to field-collected fish (Hornshaw et al. 1983; Restum et al. 1998); the uncertainties of these studies are presented above. These studies report

LOAELs only slightly lower than the LOAEL of 0.089 mg/kg bw/day, calculated from Brunström et al. (2001), where mink were fed PCBs under controlled, laboratory conditions in which reproductive effects could be attributed exclusively to PCB exposure. Chronic, controlled studies with relevant exposure pathways were preferred in the TRV selection process. While the studies of mink fed field-collected fish (Hornshaw et al. 1983; Restum et al. 1998) contain uncertainties because the field-collected fish contain other organic chemicals that could have contributed to the reproductive toxicity reported, the mink studies represent chronic exposure over multiple generations and ecologically relevant exposure (via fish consumption) to an ecological receptor (mink) being selected for evaluation in the risk assessment. Therefore, the lowest mink LOAEL of 0.037 mg/kg bw/day calculated from Restum et al. (1998) was recommended as the LOAEL TRV. No NOAEL that was lower than the selected LOAEL was reported in any reviewed study that exposed mink to PCBs, so none was recommended.

The selected LOAEL TRV represents a conservative threshold effect value for mink, one of the selected mammal receptors for Portland Harbor. There is uncertainty associated with using a study relying on field-collected fish. The recommended mammal TRVs for PCBs were selected because they represent the most conservative values reported in the literature based on a chronic mink study in which a relevant dietary fish exposure was used.

Table 5-8. PCB Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Total PCBs	mink		**0.037**	diet for multiple generations[a]	reduced offspring kit body weight, onset of estrus, decrease in females whelping	NA	0.25 (ww)	1.34 (Bleavins and Aulerich 1981)	0.20 (ww)	Restum et al. (1998)
Aroclor 1254	mink		0.074	diet for 290 days[a]	reduced offspring kit survival to 4 weeks (0%)	NA	NA	1.34 (Bleavins and Aulerich 1981)	NA	Hornshaw et al. (1983)
Aroclor 1254	mink	0.070	0.077	diet for 250 days[a]	reduced offspring kit body weight	NA	NA	1.34 (Bleavins and Aulerich 1981)	NA	Hornshaw et al. (1983)
Clophen A50	mink		0.089	diet for 18 months	reduced offspring kit growth	NA	0.1 mg/day	1.12	NA	Brunström et al. (2001)
Aroclor 1254	mink		0.13	diet for 6 months	reduced offspring kit growth rate	NA	1 (ww)	1.34 (Bleavins and Aulerich 1981)	0.18 (ww) (Bleavins and Aulerich 1981)	Wren et al. (1987)
Total PCBs	mink		0.13	diet for 182 days during reproductive period[a]	reduced offspring kit body weight at 3 and 6 weeks, gestation length, kit survival	NA	NA	NA	NA	Heaton et al. (1995); Tillitt et al. (1996)
Aroclor 1254	mink	0.077	0.17	diet for 250 days[a]	reduced offspring kit survival at birth (0%)	NA	NA	1.34 (Bleavins and Aulerich 1981)	NA	Hornshaw et al. (1983)
Aroclor 1254	mink	NA	0.22	diet for 4 and 9 months prior to giving birth	reduced number of offspring per female, decrease in offspring body weight	NA	2 (ww)	1.34 (Bleavins and Aulerich 1981)	0.15	Ringer (1983)

Table 5-8. PCB Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Aroclor 1254	mink	0.13	0.26	diet for 4 months	reduced number of kits born alive (0% at 4 weeks)	1 (ww)	2 (ww)	1.34 (Bleavins and Aulerich 1981)	0.18 (Bleavins and Aulerich 1981)	Aulerich and Ringer (1977)
Clophen A50	mink	0.27	NA	diet for 18 months	no effect on maternal body weight	0.3	NA	1.12	NA	Brunström et al. (2001)
Total PCBs	mink	0.26	0.32	diet for 182 days during reproductive period[a]	reduced maternal body weight	NA	NA	NA	NA	Heaton et al. (1995)
Aroclor 1254	mink	NA	0.39	diet for 88 to 102 days	reduced number of kits whelped and born alive (0%)	NA	2.5 (ww)	0.87 (Bleavins and Aulerich 1981)	0.13 (Bleavins and Aulerich 1981)	Aulerich et al. (1985)
PCB mixture (composition not reported)	mink	NA	0.51	diet for 66 days	reduced number of kits born alive	NA	3.3 (ww)	0.87 (Bleavins and Aulerich 1981)	0.13 (Bleavins and Aulerich 1981)	Jensen et al. (1977)
Aroclor 1242	mink	NA	0.65	diet for 8 months	reproductive failure	NA	5 (ww)	1.34 (Bleavins and Aulerich 1981)	0.18 (Bleavins and Aulerich 1981)	Bleavins et al. (1980)
Aroclor 1254	mink	NA	1.31	diet for 4 weeks	reduced body weight gain in adults	NA	10 (ww)	1.34 (Bleavins and Aulerich 1981)	0.18 (Bleavins and Aulerich 1981)	Hornshaw et al. (1986)
Aroclor 1254	mink	NA	1.64	diet for 3 months	all whelps stillborn	NA	NA	NA	NA	Kihlstrom et al. (1992)
Aroclor 1254	mink	1.2	1.8	diet for 28 days	reduced female growth	NA	NA	NA	NA	Aulerich et al. (1986)

Table 5-8. PCB Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
Clophen A50	mink	NA	2.0	diet for 3 months	all whelps stillborn	NA	NA	NA	NA	Kihlstrom et al. (1992)
Aroclor 1254	mink	1.5	2.4	diet for 28 days	reduced male and female growth	NA	NA	NA	NA	Aulerich et al. (1986)
Aroclor 1016	mink	NA	2.6	diet for 8 months	reduced birth weight and growth rate of offspring kits, and reduced adult female survival (75%)	NA	20 (ww)	1.34 (Bleavins and Aulerich 1981)	0.18 (Bleavins and Aulerich 1981)	Bleavins et al. (1980)
Aroclor 1232	rat	480	2,000	single IP injection + 14 days untreated	reduced body weight gain	NA	NA	NA	NA	Harris et al. (1993b)

[a] Mink were exposed to field-collected fish contaminated with dioxins/furans, PCBs, and other unknown contaminants.

BW – body weight
dw – dry weight
IP – intraperitoneal
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
PCB – polychlorinated biphenyl
ww – wet weight
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

5.4 DIOXINS AND FURANS

Exposure from dioxins/furans and dioxin-like PCB congeners will be evaluated in the BERA using a toxic equivalent concentration (TEQ) approach. In this approach, a TEQ value is calculated using measured concentrations of dioxins/furans and dioxin-like PCB congeners and WHO-derived TEFs for mammals. The TEQ sum for dioxins/furans and dioxin-like PCB congeners can be compared with TRVs based on 2,3,7,8-TCDD toxicity.

A total of eleven papers on the potential adverse effects of TCDD and dioxin-like PCB congeners on mammals (Heaton et al. 1995; Tillitt et al. 1996; DeCaprio et al. 1986; Murray et al. 1979; Hochstein et al. 1998; Aulerich et al. 1988; Kociba et al. 1978; Van Birgelen et al. 1994; Olson et al. 1980; Chapman and Schiller 1985; Brunström et al. 2001). Table 5-9 presents all of the NOAELs and LOAELs calculated for dioxins/furans from the literature reviewed. Adverse effects on adult growth, adult mortality, kit growth, kit survival, gestation length, and litter size were measured in mink, guinea pigs, rats, hamsters, and mice following exposure to dioxins/furans. Dioxin/furan LOAELs (as 2,3,7,8-TCDD or TEQ concentration) ranged from 2.24 ng/kg bw/day for reproduction of mink (Tillitt et al. 1996) to 1,370,000 ng/kg bw/day for growth of mice (Chapman and Schiller 1985). NOAELs ranged from 0.65 ng/kg bw/day for growth of guinea pigs (DeCaprio et al. 1986) to 190,000 ng/kg bw/day for growth of mice (Chapman and Schiller 1985).

The lowest LOAELs, ranging from 2.24 to 3.6 ng/kg bw/day 2,3,7,8-TCDD or TEQ were reported in studies where adverse reproductive effects (including reduced kit body weight and kit survival) were observed in mink fed field-collected carp from Saginaw Bay, Lake Huron for 182 days (Tillitt et al. 1996; Heaton et al. 1995). In these studies, mink were fed a prepared diet containing various percentages of field-collected carp (10%, 20%, and 40%). Effects on reproduction were observed in all mink fed any percentage of the field-collected carp; therefore, this study only has quantitative relevance to mink exposed to chemical mixtures similar those found in the Saginaw Bay fish. In addition, there is uncertainty associated with these LOAELs because the field-collected carp likely contained other uncharacterized, organic chemicals that could have contributed to the reproductive toxicity reported in mink. Field-collected carp also had reported concentrations of total PCBs (Tillitt et al. 1996; Heaton et al. 1995). Brunstrom et al. (2001) report essentially the same effect threshold (2.34 ng/kg bw/d) for reduced number of surviving mink kits per adult female following dietary exposure of adult mink to a laboratory mixture of PCBs in food for 18 months.

Therefore, the lowest mink LOAEL of 2.24 ng/kg bw/day calculated from Tillitt et al. (1996) was recommended as the LOAEL TRV. No NOAEL that was lower than the selected LOAEL was reported in any reviewed study that exposed mink to dioxins/furans, so none was recommended.

Table 5-9. TEQ Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
TEQ	mink	NA	**0.00000224**	diet for 182 days including reproduction[a]	reduced offspring kit body weight, kit survival	NA	NA	NA	NA	Tillitt et al. (1996)
TEQ	mink	NA	0.00000236	diet for 18 months	reduced litter surviving litter size	NA	2.9 mg/day	1.12	NA	Brunström et al. (2001)
TEQ	mink	NA	0.0000036	diet for 182 days including reproduction[a]	reduced offspring kit body weight at 3 and 6 weeks, gestation length, and kit survival	NA	NA	NA	NA	Heaton et al. (1995)
2,3,7,8-TCDD	guinea pig	0.00000065	0.0000049	diet for 90 days	reduced body weight	1.0×10^{-5}	7.6×10^{-5}	NA	NA	DeCaprio et al. (1986)
TEQ	mink	0.0000107	0.0000068	diet for 182 days including reproduction[a]	reduced maternal body weight; ingestion rate also significantly reduced	1.6×10^{-5}	5.3×10^{-5}	1.089 (NOAEL), 1.054 (LOAEL)	0.18 (Bleavins and Aulerich 1981)	Heaton et al. (1995)
2,3,7,8-TCDD	rat	0.0000010	0.000010	diet for three generations	reduced litter size and F2 postnatal survival	NA	NA	NA	NA	Murray et al. (1979)
2,3,7,8-TCDD	guinea pig	0.0000049	0.0000285	diet for 90 days[b]	reduced survival (60%)	7.6×10^{-5}	4.3×10^{-4}	NA	NA	DeCaprio et al. (1986)
2,3,7,8-TCDD	mink	0.0000049	0.000049	diet for 125 days	reduced body weight, reduced adult survival (50%)[c]	1.0×10^{-4}	1.0×10^{-3}	0.8776 (NOAEL), 0.8183 (LOAEL)	0.049 (NOAEL) 0.050 (LOAEL)	Hochstein et al. (1998)
2,3,7,8-TCDD	mink	NA	0.0001	IP injection for 12 days	reduced male body weight, reduced kit survival	NA	NA	NA	NA	Aulerich et al. (1988)
2,3,7,8-TCDD	rat	0.00001	0.0001	diet for 2 yrs	reduced female survival; reduced body weight	NA	NA	NA	NA	Kociba et al. (1978)

Table 5-9. TEQ Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg)	Effect Conc. (mg/kg)	BW (kg)	Ingestion Rate (kg/day)	Source
2,3,7,8-TCDD	rat	NA	0.00032	diet for 13 weeks	reduced body weight	NA	NA	NA	NA	Van Birgelen et al. (1994)
2,3,7,8-TCDD	rat	0.00010	NA	diet for three generations	no effect on body weight	NA	NA	NA	NA	Murray et al. (1979)
2,3,7,8-TCDD	hamster	NA	0.500	single IP injection/gavage + 50 days untreated[d]	reduced body weight	NA	NA	NA	NA	Olson et al. (1980)
2,3,7,8-TCDD	mouse	0.19	1.37	single gavage + 30 days untreated[d]	reduced body weight	NA	NA	NA	NA	Chapman and Schiller (1985)

[a] Mink were exposed to field-collected fish contaminated with dioxins/furans, PCBs, and other unknown contaminants.
[b] Guinea pigs were exposed to dioxins/furans through dietary and water exposure. The LOAEL TRV is based on the dietary exposure only.
[c] Body weight loss at LOAEL may be related to food suppression. A 20% loss in body weight was observed in the control group.
[d] Lab animals were exposed to a single exposure dose, and no intubation control group was reported.

BW – body weight
IP – intraperitoneal
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
TCDD – tetrachlorodibenzo-*p*-dioxin
TEQ – toxic equivalent
Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

5.5 PESTICIDES

5.5.1 DDTs

TRVs were recommended only for total DDx based on studies that used any mixture or technical grade of DDT. Investigations that addressed separate exposures to isomers of DDT, DDD, and DDE were found, but insufficient data were available from the literature to derive separate TRVs for DDD, DDE, and DDT.

Total DDx

Thirteen studies that measured the toxicity of technical DDT or some other mixture of DDT and its metabolites to mammals were evaluated (Duby et al. 1971; Ware and Good 1967; Ottoboni et al. 1977; Ottoboni 1972, 1969; Nickerson and Sniffen 1973; Wolfe et al. 1979; Fitzhugh 1948; Jonsson et al. 1976; Banerjee et al. 1996; Cannon and Holcomb 1968; Rossi et al. 1983; Shabad et al. 1973; Tomatis et al. 1974; Turusov et al. 1973). Table 5-10 presents the NOAELs and LOAELs calculated for total DDx from the reviewed studies. Reproduction was adversely affected in mice and rats exposed to technical DDT or another mixture of DDT via dietary ingestion or oral gavage. LOAELs ranged from 1.3 mg/kg bw/day for reproduction of mice (Ware and Good 1967) to 333 mg/kg bw/day for mortality and reproduction of mice (Shabad et al. 1973). At the lowest LOAEL of 1.3 mg/kg bw/day, litter size was reduced in mice fed a DDT mixture during a critical life stage (gestation) over 120 days (Ware and Good 1967). NOAELs ranged from 0.8 mg/kg bw/day for reproduction of rats (Fitzhugh 1948) to 113 mg/kg bw/day for mortality of hamsters (Rossi et al. 1983). Two NOAELs (0.8 and 1.2 mg/kg bw/day) that were lower than the lowest LOAEL of 1.3 mg/kg bw/day were calculated. At 0.8 mg/kg bw/day, Fitzhugh (1948) observed no effect on offspring survival in rats fed DDT for two years, however effects were not statistically evaluated. At the NOAEL of 1.2 mg/kg bw/day, Duby et al. (1971) reported no effects on litter size, weight, or uterine involution in rats fed technical DDT over two generations.

The lowest LOAEL of 1.3 mg/kg bw/day, as calculated from Ware and Good (1967) was recommended as the LOAEL for total DDx. The selected LOAEL represents the most conservative effect-level concentration reported in all of the literature reviewed. No NOAEL was reported in Ware and Good (1967), so the recommended NOAEL was based on another study. The highest calculated NOAEL that was below the recommended LOAEL was derived from Duby et al (1971). This NOAEL of 1.2 mg/kg bw/day was selected as the NOAEL TRV. A lower NOAEL of 0.8 mg/kg bw/day was calculated from Fitzhugh (1948); however, the higher NOAEL is preferred below the recommended LOAEL. There is some uncertainty associated with the recommended TRVs because the NOAEL and LOAEL were selected from different studies.

Table 5-10. Total DDx and DDx Mixture Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Technical DDT	rat	1.2	NA	diet for two generations	reduced litter size and weight	15	NA	0.35 (EPA 1993)	0.028 (EPA 1993)	Duby et al. (1971)
"DDT" mixture	mouse	1.3	NA	diet for 120 days	reduced survival	7	NA	0.03 (EPA 1993)	0.006 (EPA 1993)	Ware and Good (1967)
"DDT" mixture	mouse	**0.26**[a]	**1.3**	diet for 120 days	reduced litter size	NA	7	0.03 (EPA 1993)	0.006 (EPA 1993)	Ware and Good (1967)
Technical DDT	rat	1.6	NA	diet for 23 months	reduced adult survival, reduced growth, reduced viable litter size, reproductive life-span	20	NA	0.35 (EPA 1993)	0.028 (EPA 1993)	Ottoboni (1972)
Technical DDT	rat	NA	2.0	diet for 7.5 weeks	reduced fertility	NA	NA	NA	NA	Nickerson and Sniffen (1973)
Technical DDT	mouse	2.4	NA	diet for 15 months	reduced adult survival, reduced litter size, litters per pair	17.8	NA	0.015	0.002	Wolfe et al. (1979)
"DDT" mixture	rat	0.8	4.0	diet for 2 years	reduced number of young surviving to weaning	10	50	0.35 (EPA 1993)	0.028 (EPA 1993)	Fitzhugh (1948)
Technical DDT	rat	6.7	13.4	diet for 36 weeks	reduced litter size, mating and reproductive success	75	150	0.25	0.022 (EPA 1993)	Jonsson et al. (1976)
Technical DDT	dog (beagle)	10	NA	gavage for three generations	gestation length, fertilization, pregnancy, litter size; reduced pup survival, viability, growth, sex; lactation ability	NA	NA	NA	NA	Ottoboni et al. (1977)
Technical DDT	rat	13	NA	diet for 37 weeks	reduced survival	150	NA	0.25	0.022 (EPA 1993)	Jonsson et al. (1976)

Table 5-10. Total DDx and DDx Mixture Dietary Toxicity Studies for Mammals

Chemical Form	Test Species	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Exposure Conditions	Endpoint Effect	No-Effect Conc. (mg/kg ww)	Effect Conc. (mg/kg ww)	BW (kg)	Ingestion Rate (kg ww/day)	Source
Technical DDT (DDD, DDE, DDT)	rat	16	NA	diet for three generation	reduced adult survival, growth, fertility, viability, stillbirths, litter size, abnormalities, pup survival	200	NA	0.35 (EPA 1993)	0.028 (EPA 1993)	Ottoboni (1969)
pp′-DDT, p,p′-DDD, p,p′-DDE	rat	21	NA	diet for 6 weeks	reduced survival, body weight (males only)	200	NA	0.16	0.016	Banerjee et al. (1996)
"DDT" mixture	mouse	NA	37	two generations	reduced survival	NA	200	0.03 (EPA 1993)	0.006 (EPA 1993)	Cannon and Holcomb (1968)
p,p′-DDD and p,p′-DDE	mouse	NA	42	diet for 123 weeks	reduced male growth	NA	250	0.040	0.007	Tomatis et al. (1974)
Technical DDT	mouse	9.2	46	diet for six generations	reduced lifespan, pup survival	50	250	0.03 (EPA 1993)	0.006 (EPA 1993)	Turusov et al. (1973)
"DDT" mixture	mouse	55	NA	two generations	reduced body weight	300	NA	0.03 (EPA 1993)	0.006 (EPA 1993)	Cannon and Holcomb (1968)
Technical DDT	hamster	113	NA	diet for lifetime	reduced survival	1,000	NA	0.13	0.014	Rossi et al. (1983)
Technical DDT	hamster	NA	113	diet for lifetime	reduced body weight	NA	1,000	0.13	0.014	Rossi et al. (1983)
Technical DDT	mouse	NA	333	gavage for multiple generations	reduced adult survival, pregnancy frequency, time and fetal survival	NA	NA	0.03 (EPA 1993)	NA	Shabad et al. (1973)

[a] A chronic NOAEL was extrapolated from the chronic LOAEL using a UF of 5.

BW – body weight
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
LOAEL – lowest-observed-adverse-effect level
NA – not applicable
NOAEL – no-observed-adverse-effect level
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)
ww – wet weight

Bold identifies the NOAEL and LOAEL selected as dietary TRVs.

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