#76077

Guidance for Developing Ecological Soil Screening Levels

OSWER Directive 92857-55

RECEIVED
SEP 10 2003
By

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460

August 2003

14426

EXECUTIVE SUMMARY

This document describes the process used to derive a set of risk-based ecological soil screening levels (Eco-SSLs) for many of the soil contaminants that are frequently of ecological concern for plants and animals at hazardous waste sites and provides guidance for their use. The Eco-SSL derivation process represents the group effort of a multi-stakeholder workgroup consisting of federal, state, consulting, industry, and academic participants led by the U.S. Environmental Protection Agency Office of Superfund Remediation and Technology Innovation (OSRTI). The Eco-SSLs are concentrations of contaminants in soil that are protective of ecological receptors that commonly come into contact with soil or ingest biota that live in or on soil. These values can be used to identify those contaminants of potential concern in soils requiring further evaluation in a baseline ecological risk assessment. The Eco-SSLs should be used during Step 2 of the Superfund Ecological Risk Assessment process, the screening-level risk calculation. The Eco-SSLs are not designed to be used as cleanup levels and EPA emphasizes that it is inappropriate to adopt or modify these Eco-SSLs as cleanup standards.

EPA derived the Eco-SSLs in order to conserve resources by limiting the need for EPA and other risk assessors to perform repetitious toxicity data literature searches and data evaluations for the same contaminants at every site. This effort should also allow risk assessors to focus their resources on key site-specific studies needed for critical decision-making. EPA also expects that the Eco-SSLs will increase consistency among screening risk analyses and decrease the possibility that potential risks from soil contamination to ecological receptors will be overlooked.

EPA prepared a list of twenty-four (24) contaminants to be addressed initially by the Eco-SSL guidance. This list was based on a review of the contaminants of concern reported in recent Record of Decisions at Superfund National Priority List sites. The Eco-SSL contaminant list also included contaminants nominated by the EPA regional Biological Technical Assistance Group Coordinators. The list of 24 Eco-SSL contaminants contained 17 metals including aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, silver, vanadium, and zinc. The organic contaminants on the list were dieldrin, Hexahydro -1,3,5-trinitro-1,3,5-triazine (RDX), trinitrotoluene (TNT), 1,1,1-Trichloro-2,2-bis (p-chlorophenyl)ethane (DDT) and metabolites (DDE and DDD), pentachlorophenol, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs).

The omission of other contaminants, such as phthalates, cyanides, dioxins and mercury, does not imply that these contaminants can be excluded from the ERA screening process for soil contamination. The processes and procedures established here for developing the Eco-SSLs were intended to be sufficiently transparent to allow others to derive values for additional contaminants, as needed. PCBs were included by the workgroup in the original Eco-SSL contaminant list. However, it became apparent early in the process, that development of a PCB soil screening value was not warranted. Because of the known high persistence and toxicity of PCBs, and the conservative nature of the Eco-SSLs, it was acknowledged that soil screening

levels derived for PCBs would normally be lower than the soil analyses detection limits. EPA believes that if PCBs are detected in soil above background levels, the PCBs are probably site-related and therefore should be included as a contaminant of potential concern in the baseline risk assessment.

The approach developed for deriving the Eco-SSLs for plants and soil invertebrates was similar to the approach taken for deriving the wildlife Eco-SSLs (specifically the toxicity reference values). The general approach included four steps: (1) conduct literature searches, (2) screen identified literature with exclusion and acceptability criteria, (3) extract, evaluate, and score test results for applicability in deriving an Eco-SSL, and (4) derive the value. These procedures were finalized as standard operating procedures prior to initiating any work to derive the actual values.

Chapter 3 provides a description of the procedures used for deriving plant and soil invertebrate Eco-SSL values. The values were derived directly after an evaluation of all available plant and soil invertebrate chronic toxicity test data (measured toxicity related to soil contaminant concentrations). Chapter 4 provides a description of the procedures for deriving the wildlife Eco-SSLs. The wildlife Eco-SSLs were the result of back-calculations from a hazard quotient of 1.0. The hazard quotient is equal to the estimated exposure dose divided by the toxicity reference value (TRV). An HQ of 1.0 is the condition where the exposure and the dose associated with no adverse chronic effects are equal, indicating adverse effects at or below this soil concentration are unlikely. A generic food-chain model was used to estimate the relationship between the concentration of the contaminant in soil and the dose for the receptor (mg per kg body weight per day). The TRV represents a receptor-class specific estimate of a no-observed adverse effect level (dose) for the respective contaminant for chronic exposure.

The Eco-SSLs apply to sites where terrestrial receptors may be exposed directly or indirectly to contaminated soil. Seven groups of ecological receptors were initially considered in the development of the Eco-SSLs. These included mammals, birds, reptiles, amphibians, soil invertebrates, plants, and soil microbes and their processes. After investigation, the toxicity data for amphibians and reptiles were deemed insufficient to derive Eco-SSLs. EPA recognizes that the Eco-SSL may not be protective of these receptor groups. Eco-SSLs protective of microbes and soil microbial processes were also not derived. Like amphibians and reptiles, EPA recognizes their importance within terrestrial systems, but concurs with the workgroup that data are insufficient and the interpretation of test results too uncertain for establishing risk-based thresholds.

Eco-SSLs are appropriate to all sites where key soil parameters fall within a certain range of chemical and physical parameters. The Eco-SSLs for plants and soil invertebrates were derived to apply to soils where the pH is greater than or equal to 4.0 and less than or equal to 8.5, and the organic matter content is less than or equal to 10%. Based on these stated parameters, it is expected that there are certain soils and situations to which Eco-SSLs do not apply. These situations include (but may not be limited to) wetland soils that are regularly flooded (i.e., sediments), sewage sludge amended soils where the organic matter content is > 10%, and waste types where the pH is < 4.0.

Because of the diversity of the workgroup scientists, the process developed to derive the Eco-SSLs underwent constant peer review. There were also two external peer reviews performed during the development process. The first was a consultation requested by EPA's Office of Solid Waste and Emergency Response of EPA's Science Advisory Board (SAB). This consultation was held on April 6, 1999. At this meeting, the SAB provided verbal comments to the presenters which were subsequently addressed, as appropriate, by the workgroup as they prepared the guidance. A peer review of the draft guidance document was also performed. The peer review workshop was held on July 26 and 27, 2000 and was open to the public. Each of the comments received was carefully considered by the workgroup Steering Committee and appropriate changes were made to both the procedures for establishing Eco-SSLs and to the guidance document.

After developing the procedures and completing the peer review process, the workgroup focused primarily on deriving Eco-SSL values for the list of contaminants. The results of the application of the derivation procedures reported in this document are provided as separate contaminant-specific documents. In cases where data were limited or not available and Eco-SSL values could not be derived for specific contaminants and receptor groups, EPA may at some point in the future revise the contaminant-specific documents or add contaminants as appropriate.

ACKNOWLEDGMENTS

The development of this guidance was a team effort led by the U.S. Environmental Protection Agency Office of Superfund Remediation and Technology Innovation (OSRTI). A Steering Committee coordinated the activities of four task groups. A team of scientists from Syracuse Research Corporation (SRC) managed by Janet Burris provided technical and administrative support in the development of this guidance. Listed below are the members of the Steering Committee and each task group.

Steering Committee
Steve Ells, U.S. EPA OSRTI, Co-Chair
Ralph Stahl, DuPont, Co-chair
Randy Wentsel, U.S. EPA ORD, Co-chair

Bill Adams	Rio Tinto
Doris Anders	U.S. Air Force Center for Environmental Excellence (AFCEE)
John Bascietto	U.S. Department of Energy (DOE)
David Charters	U.S. EPA OSRTI
Ron Checkai	U.S. Army Edgewood Chemical Biological Center (ECBC)
Stiven Foster	U.S. EPA, Office of Research and Development (ORD)
Dale Hoff	U.S. EPA, Region 8
Charlie Menzie	Menzie-Cura & Associates
Chris Russom	U.S. EPA, ORD
Brad Sample	CH2MHill
Jason Speicher	North Division of the Naval Facilities Engineering Command
Mike Swindoll	Exxon Mobile Biomedical Sciences, Inc.

Task Group on Soil Chemistry
Randy Wentsel, U.S. EPA, Co-Chair
Charlie Menzie, Menzie-Cura & Associates, Co-Chair

Bill Berti	DuPont
Ron Checkai	U.S. Army Edgewood Chemical Biological Center (ECBC)
Mary Goldade	U.S. EPA, Region 8
Roman Lanno	Oklahoma State University
Charles R. Lee	U.S. Army Corps of Engineers, Waterways Experiment Station
Linda Lee	Purdue University
Mike Ruby	Exponent
John Samuelian	OGDEN Environmental and Energy Services

Task Group on Eco-SSLs for Soil Invertebrates and Plants
Ron Checkai, U.S. Army ECBC, Co-Chair
Mike Swindoll, Exxon Mobile Biomedical Sciences, Inc., Co-Chair

David Barclift	North Division of the Naval Facilities Engineering Command
Ron Checkai	U.S. Army ECBC
William Desmond	Tetra Tech EM, Inc.
Steve Ells	U.S. EPA, OSRTI
Charlene Falco	Illinois EPA
Stiven Foster	U.S. EPA, ORD.
Dave Gannon	Zeneca Corp.
Andrew Green	International Lead Zinc Research Org. (ILZRO)
Larry Kapustka	ecological, planning & toxicology, Inc.
Roman Kuperman	U.S. Army ECBC
Les Morrow	Illinois EPA
Daniel Mazur	U.S. EPA, Region 5
Chris Russom	U.S. EPA, ORD
Jason Speicher	North Division of the Naval Facilities Engineering Command
Gladys Stephenson	ESG International, Ltd. / University of Guelph

Task Group on Wildlife Toxicity Reference Values
Dale Hoff, U.S. EPA, Co-Chair
Doris Anders, U.S. Air Force, Co-Chair

Nelson Beyer	U.S. Geological Survey
David Charters	U.S. EPA OSRTI
David Cozzie	U.S. EPA Office of Solid Waste
Dave Cragin	Elf-Atochem North America
Steve Dole	Exponent
Anne Fairbrother	U.S. EPA, ORD, Corvallis, Oregon
Bob Fares	Environmental Standards, Inc.
Gary Friday	Westinghouse Savannah River Co.
Kinzie Gordon	Parsons Engineering Science, Inc.
Gerry Henningsen	U.S. EPA, Region 8 (retired)
Mark Johnson	U.S. Army Center for Health Promotion and Preventative Medicine
Paul Kuhlmeier	Dames & Moore
Jackie Little	TN & Assoc.
Patricia Newell	Environmental Health Associates, Inc.
Drew Rak	U.S. Army Corps of Engineers, Baltimore District
Linda Schmeising	Exponent

Task Group on Exposure Models for Wildlife Species
John Bascietto, U.S. Department of Energy (DOE), Co-Chair
Brad Sample, CH2M Hill, Co-Chair

Amber Brenzikofer	Parsons Engineering Science
Bridgette Deshields	Harding Lawson Associates
Will Gala	Chevron
Tracy Hammon	Colorado Department of Health and Environmental Protection
Rob Pastorok	Exponent
Phillip Rury	Arthur D. Little, Inc.
Randy Ryti	Neptune and Co.
William Schew	Environmental Standards, Inc.
Ralph Stahl	DuPont
Jeff Yurk	U.S. EPA, Region 6

TABLE OF CONTENTS

EXECUTIVE SUMMARY

LIST OF FIGURES
LIST OF TABLES
LIST OF ATTACHMENTS
LIST OF ACRONYMS AND ABBREVIATIONS

1.0 INTRODUCTION 1-1
- 1.1 Scope of the Eco-SSLs 1-4
- 1.2 The General Process for Establishing Eco-SSLs 1-7
- 1.3 Peer Review Process 1-11
- 1.4 Quality, Objectivity, Utility, and Integrity of Information 1-12
- 1.5 Using Eco-SSLs to Screen Contaminated Soils 1-12

2.0 SOIL PROPERTIES 2-1
- 2.1 Introduction 2-1
- 2.2 Soil Properties Influencing Contaminant Bioavailability 2-1
- 2.3 Using Soil Properties to Guide Eco-SSL Derivation 2-8

3.0 DERIVATION OF PLANT AND SOIL INVERTEBRATE ECO-SSLs 3-1
- 3.1 Literature Search, Acquisition, and Screening 3-2
- 3.2 Identification of Potentially-Acceptable Literature 3-3
- 3.3 Extraction of Data and Scoring Studies 3-3
- 3.4 Derivation of Eco-SSLs 3-6
- 3.5 Soil Toxicity Test Methods 3-8

4.0 DERIVATION OF WILDLIFE ECO-SSLs 4-1
- 4.1 The Wildlife Risk Model for Eco-SSLs 4-1
- 4.2 Selection of Surrogate Wildlife Species 4-2
- 4.3 The Exposure Dose 4-4
- 4.4 Derivation of Toxicity Reference Values (TRVs) 4-11
- 4.5 Calculation of Wildlife Eco-SSLs 4-18

5.0 ECO-SSL DOCUMENTS 5-1

6.0 REFERENCES 6-1

LIST OF FIGURES

	Title	Page
Figure 1.1	Eight Step Process Recommended in Ecological Risk Assessment Guidance for Superfund (ERAGS)	1-2
Figure 1.2	Eco-SSL Contaminants	1-4
Figure 1.3	Comparison of Eco-SSL Derivation Procedures for Wildlife and Plant and Soil Invertebrates	1-9
Figure 3.1	The Four-Step Process for Deriving Eco-SSLs for Plants and Soil Invertebrates	3-1
Figure 3.2	Literature Exclusion Criteria	3-2
Figure 3.3	Eleven Study Acceptance Criteria	3-3
Figure 4.1	The Wildlife Risk Model for Eco-SSLs (Equation 4-1)	4-2
Figure 4.2	Summary of Method Used for Estimation of Contaminant Concentrations in Biota Types (B_i)	4-7
Figure 4.3	Comparison of Soil-to-Foilage and Soil-to-Seed Bioaccumulation for Cadmium, Copper, Lead and Zinc	4-8
Figure 4.4	Comparison of Mean Concentrations in Multiple Species near a Smelter	4-10
Figure 4.5	Steps of the Wildlife TRV Derivation Process	4-11
Figure 4.6	Ten Attributes Scored as Part of the Wildlife Toxicological Data Evaluation	4-12
Figure 4.7	Example of a Toxicological Plot for the TRV Derivation Process (Cobalt)	4-15
Figure 4.8	Procedure for Deriving the Wildlife Toxicity Reference Value (TRV)	4-16
Figure 4.9	Example of Wildlife TRV Derivation (Cobalt)	4-17

LIST OF TABLES

	Title	Page
Table 1.1	Comparison of Eco-SSL Derivation Procedures	1-10
Table 2.1	General Contaminant Classification	2-3
Table 2.2	Log K_{ow} Values for Organic Contaminants	2-5
Table 2.3	Mean Reported Soil Metal Background Concentrations (ppm dry weight) by State	2-9
Table 2.4a	Qualitative Bioavailability of Metal Cations in Natural Soils to Plants	2-10
Table 2.4b	Qualitative Bioavailability of Metal Cations in Natural Soils to Soil Invertebrates	2-10
Table 2.5	Qualitative Bioavailability of Non-Ionizing Organic Contaminants in Natural Soils	2-11
Table 2.6	Qualitative Bioavailability of Metal Anions in Natural Soils	2-11
Table 3.1	Ecologically Relevant Endpoints (EREs) for Soil Invertebrate Eco-SSLs	3-4
Table 3.2	Ecologically Relevant Endpoints (EREs) for Plant Eco-SSLs	3-5
Table 3.3	Summary of Nine Study Evaluation Criteria for Plant and Soil Invertebrate Eco-SSLs	3-7
Table 3.4	Standard Methods Appropriate for use in Generating Data for the Derivation of Plant or Soil Invertebrate Eco-SSLs	3-9
Table 4.1	Parameterization of the Eco-SSL Wildlife Exposure Model	4-5
Table 4.2	Cases where the Median of the BAF Distribution for Metals is Greater or Less than One	4-10
Table 4.3	Example of Extracted and Scored Toxicity Data for Wildlife TRV (Cobalt)	4-14
Table 4.4	Summary of Conservatism Associated with the Wildlife Eco-SSL Risk Model Parameters.	4-20

LIST OF ATTACHMENTS

Attachment 1-1	Review of Existing Soil Screening Guidelines
Attachment 1-2	Discussion Concerning Soil Microbial Processes
Attachment 1-3	Review of Dermal and Inhalation Exposure Pathway for Wildlife
Attachment 1-4	Review of Background Concentrations for Metals
Attachment 3-1	Eco-SSL Standard Operating Procedure #1: Plant and Soil Invertebrate Literature Search and Acquisition
Attachment 3-2	Eco-SSL Standard Operating Procedure #2: Plant and Soil Invertebrate Literature Evaluation and Data Extraction, Eco-SSL Derivation, Quality Assurance Review, and Technical Write-up
Attachment 4-1	Exposure Factors and Bioaccumulation Models for Derivation of Wildlife Eco-SSLs
Attachment 4-2	Eco-SSL Standard Operating Procedure # 3: Wildlife TRV: Literature Search and Retrieval
Attachment 4-3	Eco-SSL Standard Operating Procedure # 4: Wildlife TRV Literature Review, Data Extraction and Coding
Attachment 4-4	Eco-SSL Standard Operating Procedure # 5: Wildlife TRV Data Evaluation
Attachment 4-5	Eco-SSL Standard Operating Procedure #6: Wildlife TRV Derivation

Due to the length of many of these Attachments, they are only available on the EPA Superfund web site at www.epa.gov/oswer/riskassessment/ecorisk/ecossl.htm.

LIST OF ACRONYMS AND ABBREVIATIONS

AEC	Anion exchange capacity
ASTM	American Society of Testing and Materials
AUF	Area use factor
AF_{ij}	Absorbed fraction of contaminant (j) from biota type (i)
AF_{sj}	Absorbed fraction of contaminant (j) from soil (s)
B_i	Contaminant concentration in biota type (i)
$B0_{ij}$	Intercept from log-linear bioaccumulation model for contaminant (j) for biota type (i)
$B1_{ij}$	Slope from log-linear bioaccumulation model for contaminant (j) for biota type (i)
BAF	Bioaccumulation factor
BEH	Behavior
BIO	Biochemical
BTAG	Biological Technical Assistance Group
BW	Body weight
C_{soil}	Concentration of contaminant in soil
CCME	Canadian Council of Ministers of the Environment
CEC	Cation exchange capacity
CI	Confidence interval
COC	Contaminant of concern
COPC	Contaminant of potential concern
DDT	1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane
DQO	Data quality objective
dw	Dry weight
EC_{xx}	Effect concentration for the xx% of the test population
Eco-SSL	Ecological soil screening level
EPA	U.S. Environmental Protection Agency
ERA	Ecological risk assessment
ERAGS	Ecological Risk Assessment Guidance for Superfund
ERE	Ecologically relevant endpoint
f_{oc}	fraction organic carbon content
FBRC	Federal Biology Research Cooperative
FIR	Food ingestion rate
g	Grams
GRO	Growth
HQ	Hazard quotient
HQ_j	Hazard quotient for contaminant (j)
HSDB	Hazardous Substance Data Bank
ISO	International Standards Organization
kg	Kilogram
K_{oc}	Organic carbon-normalized partition coefficient
K_{ow}	Octanol water partition coefficient
LC_{50}	Concentration lethal to 50 percent of test population
LOAEC	Lowest-observed adverse effect concentration
LOAEL	Lowest-observed adverse effect level

LIST OF ACRONYMS AND ABBREVIATIONS
(Continued)

MATC	Maximum acceptable toxicant concentration
mg	Milligram
mmol	Millimole
MOR	Mortality
MPA	Maximum permissible addition
MPC	Maximum permissible concentration
NC	Negligible concentration
NOAEL	No-observed adverse effect level
NOAEC	No-observed adverse effect concentration
NOC	Non ionic organic compounds
OC	Organic carbon
OECD	Organization for Economic Cooperation and Development
OM	Organic matter
ORNL	Oak Ridge National Laboratory
OSRTI	Office of Superfund Remediation and Technology Innovation
P_i	Proportion of biota type (i) in diet
P_s	Soil ingestion as proportion of diet
pKa	Acid dissociation constant
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PCP	Pentachlorophenol
PHY	Physiology
PTH	Pathology
QA	Quality assurance
QSAR	Quantitative Structure Activity Relationship
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
REP	Reproduction
RIVM	Dutch National Institute of Public Health and the Environment
ROD	Record of decision
SAB	Science Advisory Board
SMDP	Scientific Management Decision Point
$Soil_j$	the Eco-SSL for contaminant j for wildlife
SOP	Standard operating procedure
SQG	Soil quality guideline
T_{ij}	Soil-to-biota bioaccumulation factor for contaminant (j) for biota type (i)
T_{ver}	diet-to-biota BAF
TNT	Trinitrotoluene
TRV	Toxicity reference value
TRV_j	Toxicity reference value for contaminant (j)
UCL	Upper confidence limit
U.S.	United States
µm	micrometer

LIST OF ACRONYMS AND ABBREVIATIONS
(Continued)

VOC	Volatile organic compound
ww	Wet weight

1.0 INTRODUCTION

This guidance describes the process used to derive a set of risk-based ecological soil screening levels (Eco-SSLs) for many of the soil contaminants that are frequently of ecological concern for plants and animals at hazardous waste sites and further provides guidance on using Eco-SSLs. The specific Eco-SSL values and the data upon which they were derived are described in separate contaminant specific Eco-SSL documents. The Eco-SSL derivation process represents the group effort of a multi-stakeholder workgroup consisting of federal, state, consulting, industry, and academic participants led by the U.S. Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI). The workgroup developed the following mission statement at the initiation of the Eco-SSL project:

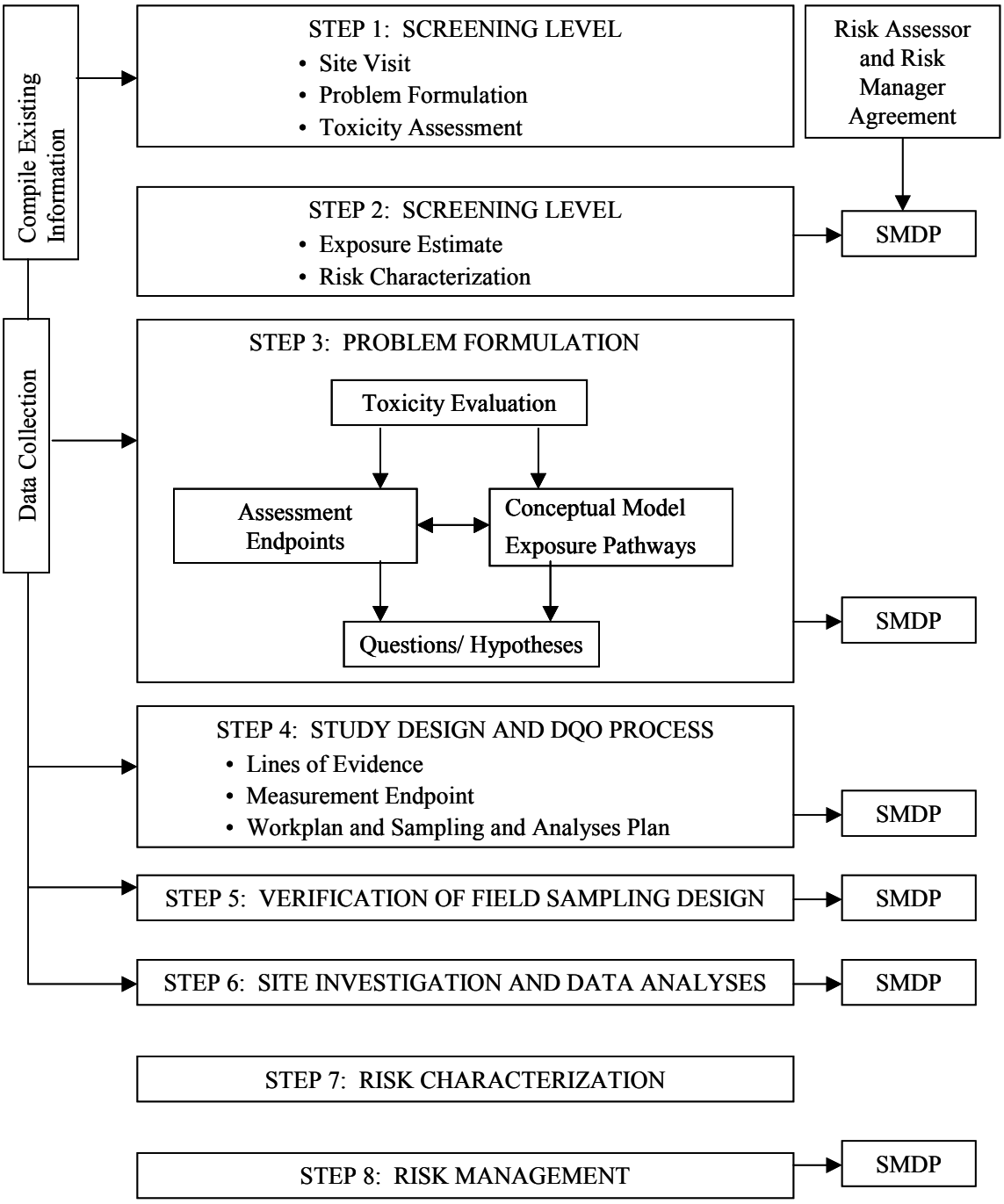
> *Develop a set of generic, scientifically sound, ecologically based, soil screening levels that are protective of the terrestrial environment for up to 24 contaminants of concern; and methodologies and models that use site-specific exposure data to modify these screening levels. The screening levels and methodologies should be sufficiently specific and transparent to allow for consistent implementation by EPA and other Federal Agencies, States, and private parties at all Superfund sites.*

The Eco-SSLs are screening values that can be used routinely to identify those contaminants of potential concern (COPCs) in soils requiring further evaluation in a baseline ecological risk assessment (ERA). Although these screening levels were developed specifically to be used during Step 2 of the Superfund ecological risk assessment process, EPA envisions that any federal, state, or private environment assessment or cleanup program could use these values to screen soil contaminants and sites in order to determine if additional ecological site study was warranted. **The Eco-SSLs were not designed to be used as cleanup levels and EPA emphasizes that it would be inappropriate to adopt or modify these Eco-SSLs as cleanup standards.**

This document provides guidance and is designed to communicate national policy on identifying contaminants in soil that may present an unacceptable ecological risk to terrestrial receptors. The document does not, however, substitute for EPA's statutes or regulations, nor is it a regulation itself. Thus, it does not impose legally-binding requirements on EPA, states, or the regulated community, and may not apply to a particular situation based upon the circumstances of the site. EPA and state personnel may use and accept other technically sound approaches, either on their own initiative, or at the suggestion of potentially responsible parties, or other interested parties. Therefore, interested parties are free to raise questions and objections about the substance of this guidance and the appropriateness of the application of this document to a particular situation. EPA welcomes public comments on this guidance at any time and may consider such comments in future revisions of this guidance.

What are Eco-SSLs?

Eco-SSLs are concentrations of contaminants in soil that are protective of ecological receptors that commonly come into contact with soil or ingest biota that live in or on soil. Eco-SSLs are derived separately for four groups of ecological receptors: plants, soil invertebrates, birds, and mammals.



SMDP = Sample Management Decision Point

DQO = Data Quality Objective

Figure 1.1 Eight Step Process Recommended in Ecological Risk Assessment Guidance for Superfund (ERAGs) (U.S. EPA, 1997)

Protection of Rare, Endangered and Threatened Species

Eco-SSLs should be protective of rare, endangered, and threatened species. However, the final decision should be made on a site-specific basis in consultation with the United States Fish and Wildlife Service and other natural resource trustees.

As such, these values are presumed to provide adequate protection of terrestrial ecosystems. Eco-SSLs for wildlife are derived to be protective of the representative of the conservative end of the distribution in order to make estimates for local populations. The Eco-SSLs are conservative and are intended to be applied at the screening stage of the assessment. These screening levels should be used in the ERA process to identify the COPCs that require further evaluation in the site-specific baseline risk assessment. This Eco-SSL guidance was written with the assumption that the reader is familiar with Superfund's guidance on performing ERAs (Ecological Risk Assessment Guidance for Superfund (ERAGS)), U.S. EPA, 1997, Figure 1.1), with Superfund's ecological risk assessment and risk management principles (U.S. EPA, 1999) and with EPA's risk assessment guidelines (U.S. EPA, 1998).

The Eco-SSLs should be used during Step 2 of the Superfund ERA process, the screening-level risk calculation. This step normally is completed at a time when limited soil concentration data are available, and other site-specific data (e.g., contaminant bioavailability information, area use factors) are not available. It is expected that the Eco-SSLs will be used to screen the site soil data to identify those contaminants that are not of potential ecological concern and do not need to be considered in the subsequent baseline ERA. The Eco-SSLs are intentionally conservative in order to provide confidence that contaminants which could present an unacceptable risk are not screened out early in the ERA process. EPA believes that the Eco-SSLs generally provide an appropriate balance of protectiveness and reasonableness.

Why are Eco-SSLs Needed?

EPA derived the Eco-SSLs with the intent to conserve resources by limiting the need for EPA, state, contractor, and other federal risk assessors to perform repetitious toxicity data literature searches and toxicity data evaluations for the same contaminants at every site. These Eco-SSLs are also intended to increase consistency among screening risk analyses, decrease the possibility that potential risks from soil contamination to ecological receptors will be overlooked, and allow risk assessors to focus their resources on identifying key site studies needed for critical decision-making.

In the process of deriving the Eco-SSLs, the workgroup examined currently available soil screening guidelines (see text box) for their potential use within the Superfund process.

Some Other Available Soil Screening Guidelines

Canadian Council of Ministers of the Environment (CCME) Canadian Soil Quality Guidelines (SQGs). The CCME guidelines are numerical limits for contaminants intended to maintain, improve, or protect environmental quality and human health. They are intended for use in the assessment and remediation of contaminants at sites in Canada (CCME, 1997).

The Dutch National Institute of Public Health and the Environment (RIVM). Maximum permissible concentrations (MPCs), maximum permissible additions (MPAs), and negligible concentrations (NCs) were developed in a series of reports for soils, sediments, and water for metals and pesticides (RIVM, 1997a and 1997b).

Oak Ridge National Laboratory (ORNL). A series of reports have been issued from ORNL that provide screening levels for plants (Efroymson et al., 1997a), soil invertebrates and microbial processes (Efroymson et al., 1997b), wildlife (Sample et al., 1996), and sediments (Jones et al., 1997).

Because these existing guidelines were developed in response to country-specific legislation and/or included policies not totally consistent with current EPA policies, EPA believes use of these guidelines may not be appropriate. A summary and evaluation of the available guidelines was completed and provided as Attachment 1-1.

How Are the Eco-SSLs Derived?

Eco-SSLs were derived using standardized procedures for literature review, toxicity data selection, and data evaluation. Where acceptable data were judged to be adequate, four Eco-SSLs were derived for each contaminant: one each for plants, soil invertebrates, birds, and mammals.

Plant and soil invertebrate Eco-SSL values were derived directly from an evaluation of available plant and soil invertebrate toxicity test data (measured toxicity related to soil contaminant concentrations), as described in Chapter 3. The process for deriving mammalian and avian Eco-SSLs is described in Chapter 4. The wildlife Eco-SSLs were the result of back-calculations from a Hazard Quotient (HQ) of 1.0. The HQ is equal to the estimated exposure dose divided by a toxicity reference value (TRV). An HQ of 1.0 is the condition where the exposure and the dose associated with no adverse effects are equal, indicating adverse effects at or below this soil concentration are unlikely. A generic food-chain model was used to estimate the relationship between the concentration of the contaminant in soil and the dose for the receptor (milligrams per kilogram body weight per day (mg/kg bw/d)). The TRV represents a receptor-class specific estimate of a no-observed adverse effect level (NOAEL) (dose) for the respective contaminant.

1.1 Scope of the Eco-SSLs

Contaminants Considered

EPA prepared a list of twenty-four (24) contaminants to be addressed initially by the Eco-SSL guidance. This list was based on a review of the contaminants of concern reported to be the subject of soil remediation in recent Record of Decisions (ROD) at Superfund National Priority List sites. The Eco-SSL contaminant list also included contaminants nominated by the EPA regional Biological Technical Assistance Group (BTAG) Coordinators. The list of 24 Eco-SSL contaminants contained seven organics and17 metals (see Figure 1.2).

Figure 1.2 Eco-SSL Contaminants

Organics

- Dieldrin
- Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)
- Trinitrotoluene (TNT)
- 1,1,1-Trichloro-2,2-bis (p-chlorophenyl)ethane (DDT) and metabolites DDE and DDD.
- Pentachlorophenol (PCP)
- Polycyclic Aromatic Hydrocarbons (PAHs)
- Polychlorinated biphenyls (PCBs)

Metals

- Aluminum
- Antimony
- Arsenic
- Barium
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Copper
- Iron
- Lead
- Manganese
- Nickel
- Selenium
- Silver
- Vanadium
- Zinc

The omission of other contaminants, such as phthalates, cyanides, dioxin, and mercury, does not imply that these contaminants can be excluded from the ERA screening process for soil contamination, only that these 24 contaminants have historically been of greatest ecological concern in soil. The process and procedures

established here for developing the Eco-SSLs are intended to be sufficiently transparent to allow others to derive values for additional contaminants, as needed. Polychlorinated biphenyls (PCBs) were included by the workgroup in the original 24 identified Eco-SSL contaminants. However, it became apparent early in the process that development of a screening value would not be appropriate. Because of the known persistence and toxicity of PCBs, and the conservative nature of the Eco-SSLs, any soil screening level derived for PCBs would often be lower than the detection limits used in a screen. EPA recommends that if PCBs are detected in soil above background levels, then they should be considered site-related and therefore should be included as a COPC in a baseline ERA.

Ecological Receptors of Concern

The Eco-SSLs generally apply to sites where terrestrial receptors may be exposed directly or indirectly to contaminated soil. Seven groups of ecological receptors were initially considered in the development of the Eco-SSLs. These initial groups included mammals, birds, reptiles, amphibians, soil invertebrates, plants, and soil microbes and their processes. After further investigation, the toxicity data for amphibians and reptiles were deemed insufficient to derive Eco-SSLs. EPA recognizes that the Eco-SSL values do not address possible risks for reptiles and amphibians and may not be protective of these receptor groups. The user should consider including these receptors in the site-conceptual model for the site-specific risk assessment.

Eco-SSLs protective of microbes and soil microbial processes were also not derived. Like amphibians and reptiles, EPA recognized their importance within terrestrial systems, but believes that data are insufficient and the interpretation of test results too uncertain for establishing risk-based thresholds for risk screening purposes. While Eco-SSLs for microbes and soil microbial processes were not established at this time, they may be considered in the future as the science develops and appropriate studies are completed. A summary of the task group discussion concerning establishing Eco-SSLs for soil microbes and their processes was documented as Attachment 1-2.

Eco-SSLs were derived for four general groups of ecological receptors: mammals, birds, plants, and soil invertebrates. By deriving conservative soil screening values considered protective of these groups, it is assumed that these receptor groups are protected from possible adverse effects associated with soil contamination. This assumption is consistent with the use of "generic assessment endpoints" as discussed in Section 1.2.5 of ERAGS.

Exposure Pathways for Ecological Receptors

A complete exposure pathway is defined in ERAGS as "one in which the contaminant can be traced or expected to travel from the source to a receptor that can be affected by the contaminant." Exposure pathways can be classified as incomplete, complete, or potentially complete. An exposure pathway is not considered complete if natural habitat for ecological receptors is not present and is not expected to be present in the future.

The Eco-SSLs for plants considered direct contact of contaminants in soils. The Eco-SSLs for soil invertebrates considered ingestion of soil and direct contact exposures with a preference for conditions of high bioavailability (refer to Chapters 2 and 3).

The Eco-SSLs for birds and mammals considered two potentially complete exposure pathways: 1) incidental ingestion of soils during feeding, grooming and preening; and 2) ingestion of food contaminated as a result of the uptake of soil contaminants. Two potentially complete exposure pathways (dermal contact and inhalation) were not considered in the derivation of wildlife Eco-SSLs. The rationale for this decision included the following:

What is a Complete Ecological Exposure Pathway for Contaminants in Soil?

For an exposure pathway to be complete, a contaminant must be able to travel from the source to ecological receptors and be taken up by the receptors via one or more exposure routes (U.S. EPA, 1997).

Exposure pathways may not be complete for ecological receptors if:

✓ Soil contamination exists only below the root zone, and deep burrowing mammalian species are not identified as potential receptors in the site conceptual model.

✓ The site is within urban and/or industrialized areas where natural habitat and receptors are absent.*

*Urban settings may in some cases be used by protected species. The appropriate trustees should be consulted.

- Burrowing animals could be exposed to relatively high concentrations of volatile organic compounds (VOCs) in their burrows via inhalation. However, with the exception of some of the polynuclear aromatic hydrocarbons (PAHs), none of the Eco-SSL contaminants were VOCs. At sites with high VOC and/or certain PAH concentrations in soils with burrowing mammals present, the inhalation exposure pathway should be considered in the baseline ERA. In this case, the contaminants would not be excluded in the screening step.

Exposure Pathways Considered in Eco-SSLs

Birds and Mammals

- Ingestion of soils during grooming, feeding, and preening
- Ingestion of food contaminated as a result of uptake of soil contaminant

Plants

- Direct contact

Soil Invertebrates

- Direct contact
- Soil ingestion

- Soil particles containing non-VOC contaminants (by either adsorption or absorption) could also be inhaled by wildlife. Respirable particles (greater than five µm) are, however, most likely ingested as a result of mucocilliary clearance rather than being inhaled (Witschi and Last, 1996). At equal exposure concentrations, inhalation of contaminants associated with dust particles is expected to contribute less than 0.1 % of total risk compared to oral exposures (Attachment 1-3).

- Birds and mammals may also be exposed to contaminants in soils via dermal contact. Studies investigating dermal exposures to birds from the application of pesticides by spray to tree branches have shown this exposure route to be significant relative to oral exposures for some substances; e.g. organophosphate pesticides, (Abou-Donia and Graham 1978, Driver et al. 1991, and Henderson et al. 1994). However, current information is

insufficient to evaluate dermal exposure for the 24 selected Eco-SSL contaminants in various soil matrices, or to predict possible rates of absorption for many species. For most contaminants, the dermal exposure is expected to contribute less than one percent to 11 % of the total risk (Attachment 1-3) compared to oral exposures.

This approach is consistent with Section 9.2.4 of ERAGS (U.S. EPA, 1997), which states that the ingestion route is most important for terrestrial animals and that "although other exposure routes can be important, more assumptions are needed to estimate exposure levels for these routes, and the results are less certain". Exclusion of dermal and inhalation exposure routes for the Eco-SSLs does not preclude their inclusion in the site-specific baseline ERA. If it is expected that receptors may be more exposed to contaminant(s) via dermal and/or inhalation exposures relative to oral exposures due to site-specific conditions, these exposure routes should be evaluated as part of the baseline ERA.

Soils for Which Eco-SSLs are Applicable

It is recommended that Eco-SSLs be considered at sites where key soil parameters fall within a certain range of chemical and physical parameters. The Eco-SSLs for plants and soil invertebrates are usually appropriate for application to soils where: the pH is greater than or equal to 4.0 and less than or equal to 8.5 and the organic matter content is less than or equal to 10 %.

The Eco-SSLs are intended for use in upland soils. However, they may also be useful for screening wetland soils. The wildlife Eco-SSLs are derived for several general receptor groups that are likely to be representative of wildlife found in wetlands. A major caveat, however, is the omission of the amphibians and reptiles from derivation of the wildlife Eco-SSLs. These groups could be especially important in wetlands. The Eco-SSLs for plants and soil invertebrates are expected to be broadly applicable (i.e., conservative enough for most soils) as preference was given to studies with high bioavailability of the contaminants in soils. For this reason, the Eco-SSLs for plants and soil invertebrates may be useful for screening for contaminants in wetland soils. In general, wetland soils are expected to exhibit a lower bioavailability (compared to those used to derive Eco-SSLs) as a result of the high organic content.

Based on these stated parameters, it is expected that there are certain soils and situations to which Eco-SSLs may not be appropriate. These situations include (but may not be limited to):

- Wetland soils that are regularly flooded (i.e., sediments).
- Sewage sludge amended soils where the organic matter (OM) content is > 10 %.
- Waste types where the pH is < 4.0.

1.2 The General Process for Establishing Eco-SSLs

Four separate task groups were formed to develop the procedures for establishing Eco-SSLs and to accomplish the work necessary to derive the Eco-SSL values for the 24 listed contaminants. The task groups were composed of a cross-section of the stakeholders represented in the larger work

Eco-SSL Task Groups

Soil Chemistry. This task group provided information on the factors that influence bioavailability of contaminants from soils. The task group developed the soils matrix used to select studies for establishing plant and soil invertebrate Eco-SSLs, the background soils database, and Chapter 2 of this guidance document.

Plant and Soil Invertebrate Eco-SSLs. This task group developed the procedures for establishing plant and soil invertebrate Eco-SSLs (Chapter 3). The task group derived the plant and soil invertebrate Eco-SSL values according to these procedures.

Wildlife Eco-SSLs. The wildlife Eco-SSLs were developed by the combined efforts of two separate task groups:

> **Wildlife Toxicity Reference Values (TRVs).** This task group developed the procedures for establishing the wildlife toxicity reference values as presented in Chapter 4.
>
> **Wildlife Exposure Model.** This task group developed the equations, assumptions, and factors for establishing the exposure model for wildlife. The model is presented in Chapter 4. The model estimates the soil contaminant concentration associated with no adverse effects to representative wildlife species.

group with efforts directed by a steering committee. One task group focused on information related to the factors that influence the bioavailiblity of contaminants from soils. A second task group focused on deriving the Eco-SSLs protective of plants and soil invertebrates. The third and fourth task groups focused on deriving Eco-SSLs protective of wildlife. One group developed the procedures for deriving wildlife TRVs (mammalian and avian receptors) while the other group developed the models necessary for estimating contaminant transfer from soils to the terrestrial food chain and for deriving exposures for wildlife.

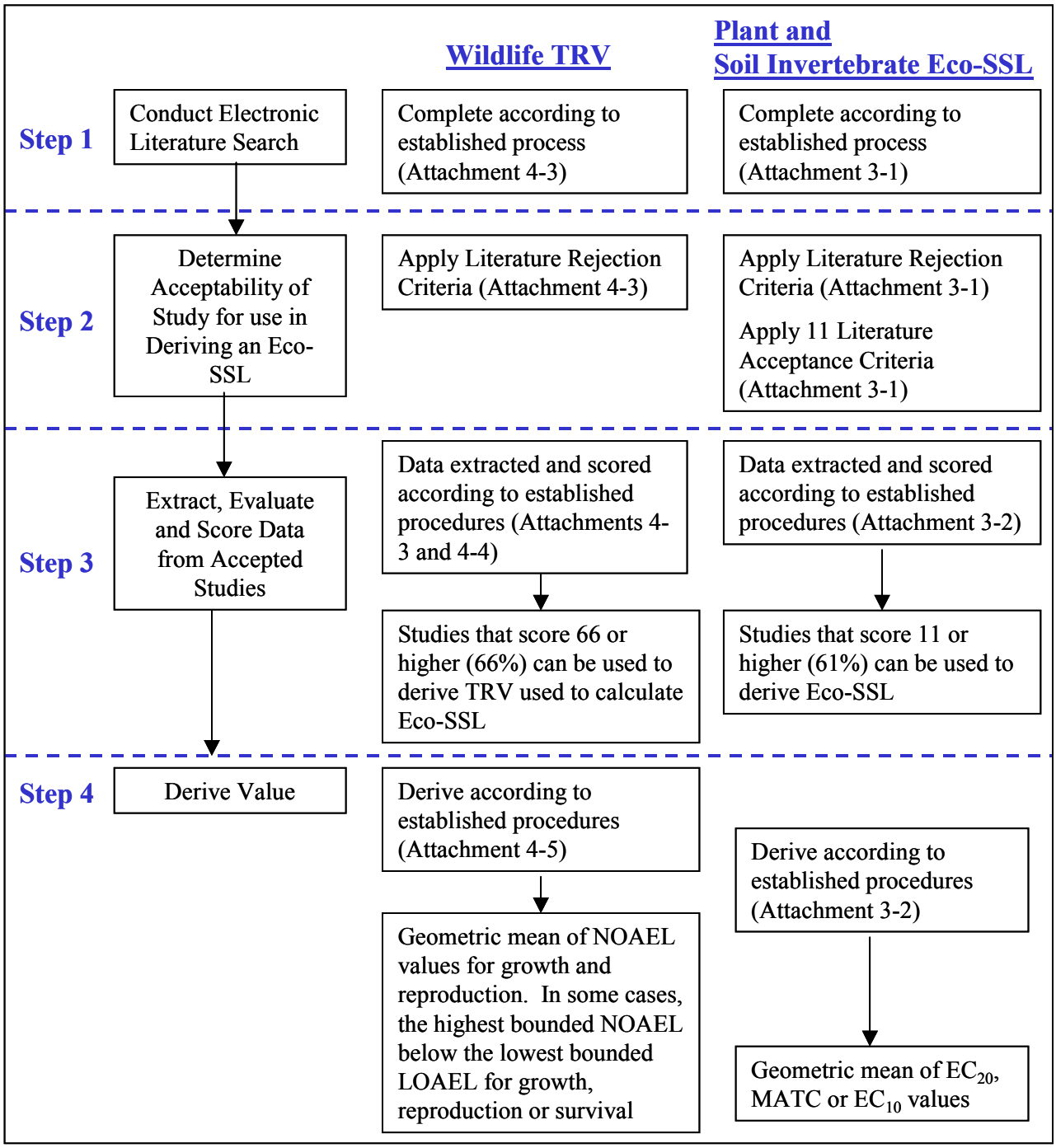
Although the task groups worked independently, the approach taken for deriving the Eco-SSLs for plants and soil invertebrates was similar (see Figure 1.3) to the approach taken for deriving the wildlife Eco-SSLs (specifically the TRVs). The general approach included four steps (1) conduct literature searches, (2) screen identified literature with exclusion and acceptability criteria, (3) extract, evaluate, and score test results for applicability in deriving an Eco-SSL, and (4) derive the value.

Step 1: Literature Search

For all receptors, potentially relevant publications were identified through literature searches of computerized abstracting databases combined with the examination of citations associated with published literature review articles. The literature searches for avian and mammalian species included all publication years, while those for plants and soil invertebrates included only publications after 1987 (Table 1.1). The task group theorized that most of the pre-1988 publications would be identified through the review bibliographies, and this was confirmed in subsequent analysis of the literature search results with approximately 40 % of potentially applicable papers identified through non-computerized search techniques. In cases where contaminant/receptor pairings had less than 20 potentially applicable articles, searches were completed for all publication years.

Step 2: Determine Acceptability of Study for Use in Deriving Eco-SSL

Both task groups used similar exclusion criteria to assess the potential applicability of publications identified through the literature searches. Publications were excluded for similar reasons as



NOAEL = No-Observed Adverse Effect Level
LOAEL = Lowest-Observed Adverse Effect Level
EC_{20} = Effect Concentration 20%
EC_{10} = Effect Concentration 10%
MATC = Maximum Acceptable Toxicant Concentration

Figure 1.3 Comparison of Eco-SSL Derivation Procedures for Wildlife and Plant and Soil Invertebrates

Table 1.1. Comparison of Eco-SSL Derivation Procedures			
Step in Eco-SSL Process	**Common to Both Approaches**	**Unique to Wildlife Approach**	**Unique to Plant and Soil Invertebrate Approach**
Step 1: Conduct electronic literature search	Searches were conducted with appropriate abstracting databases finding the intersection of contaminant, species and toxicological terms. The final electronic search result was reviewed to determine potentially applicable studies. Bibliographies of review articles were skimmed to identify additional publications.	All publication years were searched.	Searches were limited to 1988 to present. For limited data sets, searches included literature published prior to 1988. Holdings of U. S. EPA MED-Duluth library were searched.
Step 2: Determine acceptability of study for use in deriving an Eco-SSL	• Must be the primary source of the data • Exposure to single contaminant • Control must be included • Duration of exposure must be reported • Effects must be reported for relevant endpoints • Dose or concentration must be reported • Laboratory or field studies accepted • Beneficial effects not considered • Species must be reported • Percent metal or purity used to calculate nominal concentrations	• Oral route of exposure • At least two exposures: 1 control and 1 contaminant • Endpoints are behavioral, biochemical, growth, mortality, pathology, population, physiology, and reproduction • Chronic studies only (> 3 days exposure duration)	• Application rates not used • Natural or artificial soils • At least three exposures: 1 control and 2 contaminant • Test media must have: % organic matter (OM) content ≤ 10 %; pH ≥ 4 and ≤ 8.5 • Endpoints are growth , physiology (plants only), population, and reproduction • Priority given to chronic studies, but acute studies with sublethal effects or plant emergence as an endpoint were used
Step 3: Extract, evaluate and score data from accepted studies	Papers were reviewed and the results were extracted according to established guidelines.	Separate results were used if any of the following varied: test organism (species or strains), contaminant form, test location, control type, doses, application frequency, or route of exposure.	Separate results were used if any of the following parameters varied: test species (not strain), contaminant (not form), soil (natural vs. artificial), pH, or % OM content.
	Each result was scored according to established guidelines.	All endpoints were scored in order of preference based on: source of data; chemical form, measurement or no measurement in substrate; ability to calculate a dose; bounded vs unbounded NOAEL/LOAEL, route of exposure, endpoint type, duration of exposure, statistical power, and adherence to test guidelines. Studies that scoreed > 65 % were used to derive a TRV.	Within a study with multiple endpoints only one was used in the following order of preference: reproduction > population > growth > physiology. Score was based on soil bioavailability score; experimental design (i.e.,adherence to ideal test guidelines); reporting of chemical concentration; use of appropriate controls; duration of exposure; NOAEC and LOAEC or EC_{10},EC_{20} reported (or can be estimated); statistical analysis; and origin of test organism. Studies that scored ≥ 11 out of 18 (≥ 61 %) were used to derive an Eco-SSL.
Step 4: Calculation of value	Results that scored above a cutoff were used in and established approach to determine value.	The TRV was equal to the geometric mean of NOAEL values for growth and reproduction or the highest bounded NOAEL below the lowest bounded LOAEL for growth, reproduction or survival. The process considered NOAEL and LOAEL endpoints and included unbounded NOAEL values, but not unbounded LOAEL values.	The Eco-SSL was equal to geometric mean of EC_{20}, MATC or EC_{10} values. Only EC_{20}, MATC and EC_{10} values were considered. NOAEC and LOAEC values were used to calculate the MATC. Unbounded NOAECs and LOAECs were not used. When a study reported multiple endpoints, the selection followed the following order of preference: EC_{20} > MATC > EC_{10}

specified later in Chapters 3 and 4 and summarized in Table 1.1. Acceptable plant and soil invertebrate studies were further restricted to those that followed state-of-the-art soil testing requirements (e.g., $4.0 \leq pH \leq 8.5$, organic matter content $\leq$ 10 %, use of natural or artificial soil). Both task groups agreed that three or more treatment levels (including the control) were preferred, but a substantial portion of the avian and mammalian studies would have been excluded if this requirement was applied. Therefore only two treatment levels were required for mammalian and avian receptors and five were required for plants and soil invertebrates. Only chronic toxicity studies (greater than a three-day exposure) were accepted for mammalian and avian studies. Although acute studies were not excluded for plants and soil invertebrates, the exposure duration was considered later in the process for selecting the most appropriate test results for deriving the Eco-SSL.

Step 3: Extract, Evaluate and Score Data

The extraction of toxicity data from the acceptable literature, evaluation of test methods and results, and scoring of each test result also followed similar processes. When the methods diverged, it was due mainly to inherent differences in study designs (e.g., direct exposures to soils versus exposures in the diet or drinking water). Both task groups determined a cutoff for acceptable results for use in deriving the wildlife TRV or plant or soil invertebrate Eco-SSL by plotting data for various data sets and identifying logical breaks. For mammalian and avian species this break occurred at an evaluation score of 66 out of a possible 100 (i.e., studies with a score greater than or equal to 66 % were used to derive the TRV), while the break for plants and soil invertebrates occurred with a score of 11 out of 18.

Step 4: Select Value

For both task groups, only the results from studies scoring above the respective cutoffs were used to determine the value. For mammals and birds the TRV was equal to the geometric mean of NOAEL values for growth and reproduction, or the highest bounded NOAEL (NOAEL with paired LOAEL) below the lowest bounded lowest-observed adverse effect level (LOAEL) for growth, reproduction or survival (whichever was lower). For contaminants with no growth, reproduction, or survival data, the TRV was derived from biochemical, behavioral, pathology and physiology results. The methodology considered both NOAEL and LOAEL endpoints including unbounded NOAEL values but not unbounded LOAEL values.

For plants and soil invertebrates, the Eco-SSL was equal to the geometric mean of values for the maximum acceptable toxicant concentration (MATC), the effective concentration that affects 20 % of the test population (EC_{20}), or the effective concentration that affects 10 % of the test population (EC_{10}). When a study reported multiple endpoints, the selection of endpoints for use in deriving the Eco-SSL followed an order of preference of the EC_{20}, then the MATC, then the EC_{10}. The MATC was either reported in the study or was calculated from the geometric mean of the no-observed adverse effect concentration (NOAEC) and the lowest-observed adverse effect concentration (LOAEC).

1.3 Peer Review Process

The Eco-SSL procedures received both internal and external peer review. Because of the diversity of the workgroup scientists, the process developed to derive the Eco-SSLs underwent constant peer review. There were also two external peer reviews performed during the development of the Eco-SSLs. The first was a consultation requested by EPA's Office of Solid Waste and Emergency Response of EPA's Science Advisory Board (SAB). This consultation was held April 6, 1999. At this meeting the SAB provided verbal comments to presenters at the SAB review, which were passed on to the workgroup and incorporated into the guidance as appropriate. A formal external peer review of the draft guidance document was also performed. The peer review workshop was held on July 26 and 27, 2000 and was open to the public. The results of this peer review are provided in separate documentation on the Eco-SSL website. Each of the comments received was carefully considered by the Steering Committee and the individual work groups and appropriate changes were made to both the procedures for establishing Eco-SSLs and the associated guidance document.

1.4 Quality, Objectivity, Utility, and Integrity of Information

The EPA is committed to a policy of ensuring that the information it provides to the public, and uses to make its decisions, maintain a basic standard of quality, which includes objectivity, utility, and integrity. The Eco-SSLs are primarily derived from information the EPA obtained from external sources that may not have used the same standards, guidelines, and controls that EPA imposes on itself, and those who gather data on behalf of the agency. The agency has recently proposed five assessment factors for evaluating the quality of information it obtains from external sources (67 FR 57225, September 9, 2002):

- Soundness The extent to which the procedures, measures, methods, or models employed to generate the information are reasonable for, and consistent with, the intended application and are scientifically/technically appropriate.

- Applicability and Utility The extent to which the information is applicable and appropriate for the Agency's intended use.

- Clarity and Completeness The degree of clarity and completeness with which the data, assumptions, methods, quality controls, and analyses employed to generate the information are documented.

- Uncertainty and Variability The extent to which the variability and uncertainty in the information or in the procedures, measures, methods, or models are evaluated or characterized.

- Evaluation and Review The extent of independent application, replication, evaluation, validation, and peer review of the information or of the procedures, measures, methods, or models.

Because these five assessment factors were developed after this guidance document was prepared, they are not addressed by name. However, all five of these principles were embedded in the standardized procedures for literature review, toxicity data selection, and data evaluation that were used to derive the Eco-SSLs.

1.5 Using Eco-SSLs to Screen Contaminated Soils

The Eco-SSLs are intended for use in identifying soil contaminants (i.e., COPCs) and/or areas of soil contamination that warrant further consideration in a baseline ERA. Screening is typically completed during Step 2 of the 8-step Superfund ERA process, as depicted in Figure 1.1. Prior to using the Eco-SSLs, it is assumed that the risk assessor has completed Step 1, including the site visit and initial problem formulation. With the information gathered in Step 1, it is recommended that the risk assessor completes a screening of soils data using the Eco-SSLs in the risk calculation performed during Step 2.

Comparing the Site Conceptual Model to the General Eco-SSL Model

The user should compare the preliminary site conceptual model developed for their site during Step 1, with the assumptions and limitations inherent in the Eco-SSLs to determine if additional or more detailed assessments are needed for any exposure pathways or contaminants. Early identification of areas, conditions, or receptors where Eco-SSLs are not appropriate is important for adequate planning and sampling strategies for the ERA.

Are There Soil Exposure Pathways for Ecological Receptors?

The Eco-SSLs are designed for use at sites where terrestrial receptors may be exposed directly or indirectly to contaminated soil. Therefore, generally the first step in determining whether use of the Eco-SSLs is appropriate is to identify all complete and potentially complete soil pathways present at the site. The following are the receptor group-specific pathways of exposure to soil contaminants considered in deriving the Eco-SSLs:

Mammals and Birds

- Incidental ingestion of soil
- Ingestion of food (soil invertebrates and plants)

Soil Invertebrates and Plants

- Direct contact
- Ingestion of soil (by soil invertebrates)
- Uptake (by plants)

For surface soils (i.e., those soils within the root zone at the specific site), all the above pathways were considered. Ecological risks from potential exposure to contaminated subsurface soils were generally not considered. In some site-specific cases, however, there may be risks to animals that

burrow beneath the root zone. It should also be noted that, for some plants, the root zone can extend several feet.

As part of Step 1 of the ERAGS process, the site manager and risk assessor generally need to know enough about the site to answer at least the following questions:

- What contaminants are known or suspected to exist at the site?
- What complete exposure pathways might exist at the site?
- What habitat types located on or near the site are potentially contaminated?

If it is determined that there are no complete soil exposure pathways (e.g., the current and future land-use is industrial and there are no terrestrial habitats, or the only soil contamination is well below both the root zone and the burrow zone at the site), then additional screening for soil effects on ecological receptors is generally not needed.

Are There Exposure Pathways at the Site Not Addressed by the Eco-SSLs?

In some cases, the site-specific conceptual model may identify complete or potentially complete ecological soil exposure pathways that are not considered in the derivation of the Eco-SSLs. In these instances, the additional pathways should be considered in a separate screening analysis or as part of the baseline ERA. Examples of such instances include:

- The contaminated soil is near a surface water body or wetland where there is potential for contamination of surface water and/or sediments by transport during rain events.

- There are other likely ecological exposure routes not considered in the derivation of the Eco-SSLs. For example, inhalation of VOCs may be of concern for burrowing animals.

- Some site conditions may be a source of contamination to groundwater. For example, contaminants from soils may leach to groundwater, which could result in exposures for ecological receptors upon discharge to surface waters.

Comparing Site Soil Concentrations to the Eco-SSLs

Comparisons of site soil concentrations to the Eco-SSLs during Step 2 of the ERAGS process may be used to answer the following questions:

- Are there any potential ecological risks associated with soil contamination, and is it necessary to proceed with a baseline ERA (Steps 3 to 8 of ERAGS)?

- Which contaminants in soil can be dropped from further consideration and which ones should be the focus of the baseline ERA?

- Which geographic areas of soil contamination may result in ecological risks?

- Which receptors/functional groups (e.g., birds or soil invertebrates) appear to be at most risk and should be the focus of the baseline ERA?

Are the Existing Site Soil Contaminant Data Adequate?

At this point of the process, the user should make a decision concerning the adequacy of the available contaminant concentration data for soils for use in completing a screening level analysis. This decision, typically made by the site manager and risk assessor, usually considers the following:

- Are all expected areas of soil contamination sampled, or are there other areas of potential exposure for ecological receptors for which soil data are not available?

- Are the parameters of the soil analyses sufficient to identify the possible contaminants deposited as part of known waste disposal processes and practices? For example, if DDT is suspected as part of the deposited waste, are soil analyses available for DDT? Or are data only available for metals?

- Are the quantification limits adequate to measure the contaminants at the Eco-SSL levels?

How do you Calculate the Concentration Term for Comparison to the Eco-SSLs?

The appropriate soil contaminant concentration for comparison to the Eco-SSL is dependent on a number of factors, including the size of the site, the nature and extent of the contamination, and the level of confidence in the site sampling data. In most cases, there are limited soil data available at Step 2 of the ERAGS process; therefore, it is recommended that the maximum soil contaminant concentrations be compared to the Eco-SSLs. However, if the data set is large, the 95 % upper confidence limit (UCL) of the arithmetic mean may be the appropriate value to use. Decisions concerning concentration terms used for comparisons should be made in consultation with the site manager, site risk assessor, and the regional BTAG (as applied in Superfund).

Which Eco-SSL Should be Used?

Assuming there is a complete exposure pathway, the lowest of the four reported Eco-SSLs should generally be used to compare to the site soil concentrations. The ERA process assumes that complete exposure pathways exist for each of the four receptor groups; i.e., every terrestrial habitat at or near a hazardous waste site is, or should be, suitable for mammals, birds, plants, and soil invertebrates.

What if Soil Contaminant Concentrations Exceed Eco-SSLs?

If the appropriate site soil contaminant concentration exceeds an Eco-SSL, then the user should retain that contaminant as a COPC for further consideration in the baseline ERA. If soil concentrations exceed some receptor-specific Eco-SSLs and not others, then it is recommended that the contaminant be retained as a COPC only for those receptor groups where Eco-SSLs are exceeded.

What if Soil Contaminant Concentrations Do Not Exceed Eco-SSLs?

Contaminants in soils with concentrations lower than Eco-SSLs can be excluded as COPCs in the subsequent ERA. However, the user should recognize that new information may become available during the baseline ERA which may show that initial assumptions are no longer valid (e.g., site contaminant levels are higher than reported earlier). In this case, contaminants may be placed back on the list of COPCs. If there are no soil contaminant concentrations that exceed the Eco-SSLs, a baseline ERA for soils is generally not needed for that site.

What if There is No Eco-SSL?

At this time, Eco-SSLs are not available for all four receptor groups and for all 24 soil contaminants. For some of the Eco-SSL contaminants, there was an insufficient number of acceptable toxicity studies to establish an Eco-SSL. For some contaminants, EPA had not completed the review of toxicity data for derivation of Eco-SSLs. The current Eco-SSLs are available on the EPA website http://www.epa.gov/oswer/riskassessment/ecorisk/ecossl.htm. The user should consult this source for the current values.

For those contaminants with an insufficient number of acceptable toxicity studies to establish an Eco-SSL, a summary of the toxicity studies evaluated in the Eco-SSL process was made available in the contaminant specific Eco-SSL documents. The information from these studies can be used according to the process described in Section 1.3.1 of ERAGS to derive screening values. As more toxicity information becomes available, EPA may use these processes to revise existing Eco-SSLs or to develop new ones.

Can I Use Site-specific Data to Modify an Eco-SSL or Should I Proceed to a Baseline Risk Assessment?

If one or more Eco-SSL values are exceeded it is recommended that the user proceed to a baseline ERA. The Eco-SSLs are intended to be conservative values used to identify those contaminants that should be the focus of a baseline ERA and as such they should not be modified as part of the screening step. During the baseline ERA, it will be possible for the user to collect and use site-specific data as part of development of the site-specific exposure and toxicity assessments in the baseline ERA.

Consideration of Background Soil Concentrations

Due to conservative modeling assumptions (e.g., metal exists in most toxic form or highly bioavailable form, high food ingestion rate, high soil ingestion rate) which are common to screening processes, several Eco-SSLs are derived below the average background soil concentration for a particular contaminant as presented in Attachment 1-4. Since Eco-SSLs are not designed to be used as clean-up levels, EPA is not promoting clean-up to below background concentrations. It is EPA's policy to not screen against background levels. Background concentrations, the speciation of metals, and the effects of conservative modeling assumptions are generally taken into account in the initial steps of the baseline risk assessment. Specific procedures for comparing risk information to site specific background levels is addressed in the Office of Solid Waste and Emergency Response document *Role of Background in the CERCLA Cleanup Program* (OSWER 9285.6-07P) (U.S. EPA, 2002). However, if a specific exposure parameter or toxicity endpoint is found to consistently produce an Eco-SSL that is below background concentrations (taking into account natural species of metals), EPA may reevaluate specific Eco-SSL values as they are updated.

Information on background concentrations of contaminants in soils was collected and reviewed during the Eco-SSL derivation process to examine how the Eco-SSL values compare to natural soil conditions. These comparisons were used to guide the process and are presented as Attachment 1-4. The review indicated that there are regions of the country where natural background levels for some metals exceed Eco-SSLs. For these regions and for specific local areas, the acquisition of adequate data on background soil concentrations is an important step toward evaluating, on a site-specific basis, if observed concentrations are related to releases or are naturally occurring. Background concentrations are further discussed in each of the contaminant-specific Eco-SSL documents.

Definitions

Contaminants of concern (COCs) are the contaminants that, at the completion of the risk assessment, are found to pose unacceptable human or ecological risks. The COCs drive the need for a remedial action.

Contaminants of potential concern (COPCs) generally comprise the contaminants that are investigated during the baseline risk assessment that may or may not pose unacceptable risks.

Screening is a common approach used by risk assessors to refine the list of COPCs to those hazardous substances, pollutants and contaminants that may pose substantial risks to health and the environment.

Background refers to constituents or locations that are not influenced by the releases from a site, and is usually described as naturally occurring or anthropogenic (US EPA, 2002)

- **Anthropogenic** -natural and human-made substances present in the environment as a result of human activities (not specifically related to the release in question); and,
- **Naturally occurring** - substances present in the environment in forms that have not been influenced by human activity.

2.0 SOIL PROPERTIES

2.1 Introduction

Soil properties influence the toxicity of contaminants to invertebrates, plants, and wildlife. Therefore, they are generally important to consider in the development of Eco-SSLs and provide a basis for guiding site-specific evaluations that may follow application of Eco-SSLs. This chapter discusses the primary soil parameters that influence bioavailability of contaminants from soils. This soil property information provides the rationale for defining a set of soil parameters used in the selection of the most appropriate studies for deriving Eco-SSLs for plants and soil invertebrates and specific recommendations for screening soils for aluminum and iron.

This chapter focuses primarily on the relationship between soil chemistry factors that influence the toxicity to and accumulation of contaminants in soils to plants and soil invertebrates. The absorption of contaminants bound to incidentally ingested soil particles in the animal gut is influenced by other parameters including gut residence time as well as toxicokinetic and physiological factors that may affect the uptake of contaminants in wildlife. Because wildlife species vary in the anatomy and physiology of their digestive systems (e.g., herbivores vs. carnivores), generalizations can not and should not be made concerning bioavailability of contaminants on soil incidentally ingested by wildlife at the screening level.

2.2 Soil Properties Influencing Contaminant Bioavailability

Bioavailability is a measure of the potential for entry of the contaminant into ecological or human receptors and is specific to the receptor, the route of entry, time of exposure, and the soil matrix containing the contaminant (Anderson et al., 1999). In order to ensure that Eco-SSLs are adequately conservative for a broad range of soils, an effort is made in the procedures developed to select studies that favor the bioavailability of the selected contaminants. To accomplish this, it is first necessary to develop a basic understanding of how various soil properties may influence bioavailability. Several authors stress the importance of physical and chemical properties of contaminants that influence the bioavailability in soils and thus exposure and toxicity (Alexander, 1995; Allen et al., 1999; Linz and Nakles, 1997; and Loehr and Webster, 1996). The behavior and bioavailability of contaminants are greatly influenced by their interactions with soil parameters, such that not all contaminants are equally available to biota. However, estimating the availability of metals and organic contaminants in soil to soil biota and plant toxicity is not a straightforward process.

The bioavailability of contaminants depends on their chemical properties and the specific physical and geochemical binding mechanisms that vary among contaminants and soil types. Contaminants interact with soil through interactions with the surface of particulate material in soils (adsorption), by penetration through the particulate surfaces where the contaminant becomes associated with the internal material (absorption or partitioning), and through specific contaminant reactions sometimes referred to as chemisorption. Also some contaminants, in particular metals, can associate with inorganic ligands and precipitate. The affinity of a

contaminant to be removed from solution and become associated with soil particulates irrespective of mechanism, is generally referred to as "sorption". The exception are precipitation reactions, which are often discussed independently from sorption processes. Contaminants are generally considered to be bioavailable when they are released from interactions with the soil and soil constituents and released into the soil pore-water. The exception to this rule is the direct ingestion of soil by terrestrial wildlife.

Identifying and quantifying soil properties that control the distribution of a contaminant in soil/water systems at equilibrium are useful for exposure situations where time is sufficient for equilibrium conditions to develop. For exposure situations that are dominated by discrete events often of short duration (e.g., incidental ingestion of soil), the kinetics of contaminant release from soils into another medium (i.e., the amount released per unit time) and residence time (i.e., time allowed for transfer to occur) controls the fraction of a contaminant that would be labile to target biota. Both adsorption and absorption partitioning processes are considered reversible, although mass transfer from the particle to the pore-water can be constrained. In the case of interactions within a particle, a contaminant can become sequestered or trapped through various physical and contaminant alterations that occur over time, such that contaminant release is completely constrained. The decline of the availability of many organic contaminants in soil over months or years has been well-documented (Alexander, 1995; Loehr and Webster, 1996). For chemisorption, the binding mechanism is considered irreversible under most environmental conditions. For precipitation reactions, release to pore-water is controlled by the factors affecting the stability or solubility of the contaminant precipitate. Overall, bioavailability of a contaminant in soil strongly depends on its physical and chemical properties, the characteristics of the soil, the interactions between the contaminant and the medium, including time of exposure, and the physiological and biochemical conditions of the receptor.

Contaminant Characteristics Impacting Lability

The soil parameters important in affecting sorption and precipitation reactions and the extent of their influence and thus contaminant bioavailability, are dependent on the intrinsic properties of the contaminants. The 24 contaminants considered in this guidance include both metals and organic contaminants. Metals can exist as either cations or anions in the soil environment, which significantly affects their sorption, mobility, and solubility in soils. For example, soil is primarily negatively charged, thus, metal cations have a higher propensity to be sorbed by soil particles relative to metal anions. For organics, lipophilicity and persistence alter their availability, as well as ionic potential in the case of organic contaminants with ionizable functional groups. Collectively, the 24 contaminants are classified into the four groups (Table 2.1).

Metals. Metals occur naturally in soils primarily as amorphous oxides and hydroxides, and to a lesser extent as carbonates, phosphates, sulfates, and sulfides, which are relatively insoluble. The same is generally true for metal-contaminated soils, because metals quickly undergo precipitation and coprecipitation reactions forming relatively insoluble solid phases, and/or are strongly complexed by soil minerals or organic matter (Lindsay, 1979). Toxicity testing on the

other hand usually employs very soluble metals not commonly found in any appreciable amounts in soils relative to total metal concentrations.

Table 2.1 General Contaminant Classification	
Contaminant Class	**Eco-SSL Contaminant**
Metal Cations	aluminum, antimony, barium, beryllium, cadmium, cobalt, copper, iron, lead, manganese, nickel, silver, and zinc
Metal Anions	arsenic, chromium, selenium, and vanadium
Nonionic Organics	PCBs, DDT and metabolites, dieldrin, PAHs, TNT, and RDX
Ionizable Organics	PCP

As identified in Table 2.1, most of the 24 contaminants considered for Eco-SSLs are metals that typically exist as cationic species. These metals can complex with inorganic soil constituents, e.g., carbonates, sulfates, hydroxides, sulfides, to form either precipitates or positively charged complexes. Both complexation and precipitation reactions are pH dependant. Therefore, although these metals can form complexes with a net negative charge, under most environmentally relevant scenarios (pH = 4 to 8.5), these metals either precipitate or exist as cations.

Arsenic, chromium, selenium, and vanadium complex with oxygen and typically exist as anionic species under most environmentally relevant scenarios (Bohn et al., 1985; Lindsay, 1979). The most common forms of arsenic are arsenate (arsenic V) and arsenite (arsenic III), which are present in soil solution in the form of AsO_4^{3-} and AsO^{2-}, respectively. The chemistry of arsenic resembles that of phosphate (Barber, 1995; Bohn et al., 1985). Chromium can exist as chromate (chromium VI or CrO_4^{2-}), which is usually considered more soluble, mobile and bioavailable than the sparingly soluble chromite (chromium (III)), which is normally present in soil as the precipitate $Cr(OH)_3$ (Barnhart, 1997; James et al., 1997). Similarly, selenium can be present as selenates (SeO_4^{2-}) and selenites (SeO_3^{2-}). For vanadium, vanadate (VO_4^{3-}) is the most common form.

Metals in their various forms can exist in the pore-water as charged species, as soluble complexes, or precipitate out of solution. Retention by soil is usually electrostatic with cationic species and anionic species being associated with negatively and positively charged sites on the soil, respectively. For most soils in the United States, negatively charged sites are more plentiful with less than 5% of the total available charge on the soil surface being positively charged. Therefore, metals existing as cationic species have a greater propensity to associate with the soil and are less bioavailable, whereas, distribution of anionic metals is generally more towards the pore-water for most soil/water systems. The soil pH and availability of charged sites on soil surfaces are the primary soil factors controlling their release to the pore-water, and subsequently, bioavailability.

Organic Contaminants. Of the seven organic contaminants identified in Table 2.1, DDT and metabolites, dieldrin and PCBs are very hydrophobic, highly lipophilic, and persistent nonionic organic contaminants. These contaminants are highly sorbed to soil surfaces and organic matter and tend to bioaccumulate and biomagnify in the food chain. The structure and degree of chlorination of PCBs and associated congeners directly impacts their behavior, persistence, and bioavailability (e.g., see citations in Hansen et al., 1999). As solubility decreases, sorption increases, and bioavailability generally decreases with increasing chlorination. However, uptake, degradability, and toxicity are also impacted by placement of the chlorines in the biphenyl structure. The remaining nonionic organic contaminants, PAHs and explosives (TNT and RDX) are generally considered less persistent and more bioavailable than pesticides or PCBs under identical soil conditions. PAHs are compounds with two or more aromatic rings in their structure and consist of only carbon and hydrogen. PAHs can be highly retained by soil in a similar manner as pesticides or PCBs, but are considered less persistent due to their higher affinity to be degraded microbially. TNT and RDX, a trinitro aromatic and trinitro nitrogen-heterocyclic respectively, are explosive materials and are more polar than PCBs or PAHs. The only ionizable organic contaminant being considered at this time in the development of Eco-SSLs, is the organic acid pentachlorophenol (PCP). Organic acids can exist as either a nonionic species or as an organic anion, which is dependent on the acid dissociation constant (pKa) and pH. In the pH range relevant to most environmental scenarios, PCP can exist as both a neutral species and as an anionic species; however, the majority will exist as the organic anion (Lee et al., 1990).

For all nonionic organic compounds (NOC) and the neutral form of PCP, sorption by soil is primarily related to their hydrophobicity and the amount of organic matter present in the soil (Lagrega, 1994; Lee et al., 1990), with the exception of the more polar, nitro-substituted organic contaminants (i.e., the explosives). Differences in the distribution of several NOCs in diverse soil-water and sediment-water systems have been minimized by normalization to organic matter or more specifically organic carbon (OC) with OC-normalized distribution coefficients, referred to as K_{oc} values (e.g., Gertsl, 1990; Lyman et al., 1990;). The greater the affinity of a contaminant for organic matter, the larger the organic carbon-normalized partition coefficient (K_{oc}), and a soil with higher amounts of organic matter has a higher propensity to sorb NOCs. The hydrophobicity and K_{oc}, of organic compounds increases with the size of the compound and with increasing chlorine content, as in the case of chlorinated organics. Therefore, sorption of PAHs by soils increases with the number of aromatic rings. For compounds like PCBs, sorption increases with increasing chlorination. Increasing compound hydrophobicity also reflects increasing lipophilicity, which will result in a greater propensity to bioaccumulate in the lipid fraction of biota. For PCP, an ionic contaminant, the anionic species has a greater tendency relative to the neutral PCP to remain in the pore-water similar to metal anions. Therefore, pH-dependent speciation drastically modifies the solubility, sorption, transport, and bioavailability of PCP. Although organic matter is the primary sorption domain in soils, all contaminants have some affinity to be associated with any surface through weak physical forces (Schwarzenbach et al., 1993). In addition, the nitro-substituted NOCs are known to have specific interactions with clay surfaces that are impacted by the inorganic cations present and

clay charge density, and less so by the amount of organic matter present (Weissmahr et al., 1998; 1999).

A common contaminant index representing the degree of hydrophobicity and lipophilicity of an organic contaminant is the octanol-water partition coefficient (K_{ow}), which is the contaminant distribution between octanol and water phases. K_{ow} values are positively correlated to both K_{oc} values and bioconcentration factors (Lyman et al., 1990). For reference, log K_{ow} values for selected organic contaminants are summarized in Table 2.2.

Table 2.2. Log K_{ow} Values for Organic Contaminants

Analyte	CAS no.	log K_{ow}	Source
RDX	121824	0.87	Syracuse Research Corporation (SRC)
TNT	118967	1.6	SRC
DDT	50293	6.53	U.S. EPA (1996)
DDD	72548	6.1	U.S. EPA (1996)
DDE	72559	6.76	U.S. EPA (1996)
Dieldrin	60571	5.37	U.S. EPA (1996)
Pentachlorophenol (PCP)	87865	5.09	U.S. EPA (1996)
PCBs		4.5 (1 chlorine) >8 (10 chlorines)	Verschueren (1996) Schwarzenbach et al. (1993)
PAHs			
Naphthalene (2 rings)	91203	3.36	U.S. EPA (1996)
Acenaphthene (3 rings)	83329	3.92	U.S. EPA (1996)
Phenanthrene (3 rings)	85018	4.55	U.S. EPA (1995)
Anthracene (3 rings)	120127	4.55	U.S. EPA (1996)
Chrysene (4 rings)	218019	5.7	U.S. EPA (1996)
Benzo(a)anthracene (4 rings)	56553	5.7	U.S. EPA (1996)
Benzo(a)pyrene (5 rings)	50328	6.11	U.S. EPA (1996)
Dibenzo(ah)anthracene (5 rings)	53703	6.69	U.S. EPA (1996)
Benzo(b)fluoranthene (5 rings)	92240	6.2	U.S. EPA (1996)
Benzo(k)fluoranthene (5 rings)	207089	6.2	U.S. EPA (1996)
Benzo(ghi)perylene (6 rings)	191242	6.7	U.S. EPA (1995)

Key Soil Parameters Affecting Contaminant Bioavailability in Soils

From the preceding overview of how contaminants interact with soil constituents, it is clear that soil plays a very significant role in reducing the potential bioavailability of contaminants in the environment. Given the types of contaminant-soil interactions presented, the primary soil factors controlling the potential bioavailability of all contaminants are identified as soil pH, available charged sites on soil surfaces, clay content, and soil organic matter. Below is a discussion

briefly detailing the key soil parameters affecting the various contaminants' availability to the pore-water, thus bioavailability.

Soil pH. Soil pH is often termed the master soil variable because it controls virtually all aspects of contaminant and biological processes in soil. These processes include solubility, precipitation, speciation, and sorption processes as well as microbial activity. Soil pH controls the speciation of both ionizable organic contaminants such as PCP, and metals. For metals, the net charge of the metal complexes and their precipitation/dissolution reactions are directly impacted by soil pH. For organic acids such as PCP, the fraction of contaminant existing as an anion increases with increasing pH. The anion has a lower affinity for the soil relative to the neutral species. Increasing soil pH also results in an increase in the number of negatively charged soil sites with a concomitant decrease in the positively charged sites. Therefore, increasing the soil pH directly impacts the sorption and removal from the pore-water of metal or organic ions (Bohn et al., 1985). The impact of pH on the behavior and bioavailability of nonionic organic contaminants is less marked and is generally achieved through its influence on organic matter and on microbial activity.

Cation and Anion Exchange Capacities. The available charges on soil surfaces are quantified in the soil parameters known as cation exchange capacity (CEC) and anion exchange capacity (AEC). CEC is a measure of the soil's ability to adsorb and release cations, which is directly proportional to the number of available, negatively charged sites. Likewise, AEC is a measure of the soil's ability to adsorb and release anions. As a result, the AEC is a measure of available positively-charged surface sites. CEC is directly related to the clay mineral content and type, organic matter and soil pH. CEC is greater for 2:1 clays such as montmorillonite (600 to 1,000 millimole (mmol)/kg) compared to 1:1 clays such as kaolinite (20 to 160 mmol/kg). CEC in organic matter ranges from 2,000 to 4,000 mmol/kg; however, the organic matter fraction of a soil is usually much less than the clay fraction. CEC arising from pH-dependent charge, which includes organic matter contributions to CEC, increases with increasing pH. CEC in soil ranges from values as low as 10 millimole (mmol) per kg for extremely coarse-textured soil to as much as 600 mmol/kg for fine textured soil, containing large amounts of 2:1 clays and organic matter (Bohn et al., 1985). AEC, which is primarily associated with amorphous oxides, decreases with increasing soil pH. As previously mentioned, the number of positively charged sites (i.e., AEC) on the majority of soil types is very small, and in environmentally-relevant pH ranges, is usually negligible. Therefore, AEC is not generally considered an important parameter in assessing contaminant availability at most sites in the United States.

Clay Minerals. Clays, by definition, are soil particles less than 2 microns in size (Miller and Gardiner, 1998); therefore, high clay soils have higher surface areas relative to sandy soils (sand particle size ranges from: 20 microns to 2 millimeters (mm)). For nonionic organic contaminants, the primary sorption domain is organic matter; however, soils with high surface area will result in enhanced sorption of organic contaminants through weak physical interactions, as well. Much of the CEC of a soil comes from the negatively charges sites on clay surfaces. Therefore, high clay soils will have a higher affinity to sorb cationic species whether organic or

inorganic due to CEC, and to sorb nonionic organic contaminants due to high surface areas, thus making contaminants less bioavailable relative to sandy soils. In addition to charged sites available in clays, siloxane oxygens present in clays can interact specifically with contaminants such as the nitro-substituted explosives. Metals can form precipitates with inorganic soil constituents, such as carbonate and phosphate minerals under certain soil conditions. Carbonate- and phosphate-metal complexes have varying degrees of solubility and reactivity depending on the metal, its oxidation state, the ligand to which it is bound, and pH. Precipitation removes a contaminant from the pore-water, thus decreasing bioavailability.

Organic Matter (Organic Carbon) Content. Organic matter includes plant and animal remains in various stages of decomposition (e.g., cells and tissues, of soil organisms and substances from plant roots and soil microbes) (Sumner, 2000). Organic matter is primarily composed of carbon, oxygen, and nitrogen. Organic matter is often reported or analytically determined on a carbon basis. On average, approximately 58% of organic matter is organic carbon. Soils encompass a range in organic matter from <1% for a sandy soil to almost 100% for a peat soil, with most soils having organic matter contents <10% (Bohn et al., 1985). Also, organic matter content is usually higher in surface soils or in the root zone and decreases with depth in the soil profile.

Organic matter has a high affinity to bind organic compounds as well as some metals in soils thereby, reducing their availability. Organic contaminants preferentially partition to organic matter relative to the polar aqueous phase, while the organic acid functional groups typically present in organic matter have a high affinity to attract metal cations. For nonpolar or neutral organic contaminants at equilibrium, sorption is positively correlated to the amount of organic matter, usually reported as the fraction of organic carbon (f_{oc}), and inversely proportional to aqueous solubility. Sorption of organic contaminants increases with increasing amounts of soil organic matter. The greater the hydrophobicity or lipophilicity of an organic contaminant, the greater potential it has to be sorbed onto organic matter. The latter has led to the use of K_{oc} for estimating contaminant sorption with the soil-specific distribution coefficient estimated by K_{oc} multiplied by f_{oc}. Another indirect effect of soil organic matter is its role on limiting contaminant mass-transfer. The rate of mass-transfer of an organic contaminant from soil particles to the surrounding pore-water is inversely proportional to the contaminant's soil-water distribution coefficient (Pignatello, 2000). Therefore, with increasing organic matter content, retention of an organic contaminant increases and rates of release decrease, thereby, decreasing overall contaminant bioavailability.

Other Factors

Background. Background refers to constituents or locations that are not influenced by the releases from a site, and is usually described as naturally occurring or anthropogenic background (US EPA, 2002). Background contaminant concentrations can vary due to soil type, depth, and region of the country. Due to this variation, background metal levels in soils are addressed on a

site-specific basis in the baseline ERA. As part of the development of Eco-SSLs, background metal concentrations from the literature were compiled to provide a general comparison of the screening levels with current available information. Background metal concentrations were reviewed and compiled in Attachment 1-4. For reference, background levels by state are provided in Table 2.3. In the contaminant specific Eco-SSL documents, the Eco-SSL values are compared to a summary box-and-whisker chart depicting background concentrations in eastern and western United States soils. A discussion on the quality of available toxicity data and the reasonableness of the Eco-SSL values when compared to background concentrations is presented. Background data is site-specific and should be derived for each site investigated**.**

Aging. The issue of adsorption, complexation, lability of contaminants in soils, and the corresponding reduction in toxicity over time is an important issue in understanding the fate of contaminants in soils. In the evaluation of the available toxicological literature for plants and soil biota, few studies incorporated a step to age or weather spiked contaminants in soils. The use of contaminated soils from the field in laboratory tests is a viable option; however, due to the common presence of mixtures and the specific soil chemistry parameters, the use of field contaminated soils is primarily useful only for site-specific studies. While no standard setting organization has established methods for aging contaminants in soils, an aging step has been added by some investigators in plant and soil invertebrate test methods that involves several cycles of wetting and drying of a freshly spiked soil (Kuperman et al., 2002 and Phillips et al., 2002).

2.3 Using Soil Properties to Guide Eco-SSL Derivation

In identifying a set of soil parameters for use in selecting studies for deriving Eco-SSLs for plants and soil invertebrates, four soil parameters were selected: soil pH, CEC, clay content, and organic matter. However, when the plant and soil invertebrate task group evaluated the current literature, they observed that CEC and clay content were not routinely reported. Thus, these parameters were not used and the matrices were constructed using only pH and organic matter content as the primary soil parameters affecting bio-availability and toxicity. For these soil parameters, ranges were within that typically found in soils. Tests that used soils with characteristics that fell outside the selected ranges were not considered. Although other soil factors can be significant, combinations of these two soil parameters are sufficient for use in this screening process as a qualitative guide to address how most soils across the United States may influence bioavailability of contaminants. Qualitative rankings of high, medium, and low bioavailability were used to categorize each combination of the soil parameters and their ranges. Information on bioavailability was used to help select and score studies to include in the derivation of the Eco-SSL values. Greater weight was given to those studies that had higher bioavailability. Using the selected soil parameters and defining ranges that correspond qualitatively to the soil's affinity for the contaminant and thus for bioavailability, Tables 2.4a and 2.4b, 2.5, and 2.6 are provided for metal cations, nonionic organics, and anionic species, respectively. For each of the soil parameters, the values typically found in soils were divided into three ranges. For example, most environmentally relevant scenarios fall between pH values

Table 2.3. Mean Reported Soil Metal Background Concentrations (mg/kg dry weight) by State*																	
	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Iron	Manganese	Nickel	Lead	Selenium	Silver	Vanadium	Zinc
Alabama	23100	3.6	4.7	200	0.6		30.6	4.4	9.6	11950	420	11	9.3	0.3		38	26
Arkansas	33429	1.2	9.7	336	0.9		53.1	12	17	19857	731	18	21	0.7		52	39
Arizona	32933	1.4	9.6	364	1.0	0.4	37.3	9.9	23	20787	447	23	16	0.4	0.5	42	51
California	75633	0.8	5.1	598	1.1	0.4	119.9	14	39	36867	640	48	26	0.2	0.8	118	113
Colorado	61557	1.1	6.7	662	1.4		41.7	6.8	21	23048	343	13	31	0.4		74	87
Connecticut	85000		4.1	400	0.5		40.0	7.5	15	17500	450	13	5.0	0.8		60	40
Delaware	22500	1.0	1.4	400	0.5		30.0	3.3	5.0	7500	85	6.0	15	0.3		20	23
Florida	9944	0.9	3.0	48	0.6	0.1	15.4	1.6	5.6	3705	86	8.5	12	0.3	0.5	11	12
Georgia	38250	1.0	5.0	232	0.6		32.4	6.9	21	16976	252	17	19	0.4		43	47
Iowa	64667	1.0	7.3	617	1.3		64.7	11	31	23278	603	26	19	0.4		97	57
Idaho	58500	1.0	6.4	757	1.1		52.1	12	28	32000	580	22	22	0.3		90	83
Illinois	48714	1.1	7.1	551	0.7		48.4	9.8	24	19159	646	19	39	0.5		62	67
Indiana	50000	1.0	7.5	500	0.7		46.8	10	27	21364	518	18	18	0.4		74	56
Kansas	61818	1.1	6.8	694	1.0		49.0	8.9	25	18788	452	17	32	0.4		77	67
Kentucky	54123	1.0	7.8	349	1.1		79.8	11	17	30432	483	23	16	0.5		66	35
Louisiana	42188	1.0	7.6	441	0.6		60.8	8.6	33	19688	470	33	16	0.7		76	55
Massachusetts	34083	1.0	8.6	203	1.3	0.2	39.5	7.8	16	19000	439	13	13	1.9		87	54
Maryland	39167	1.2	3.8	393	1.3		47.9	7.5	20	28571	291	13	22	0.2		63	39
Maine	65385	1.0	9.4	319	1.6		71.2	10	28	45385	581	30	19	0.7		98	80
Michigan	10964	1.3	4.2	127	0.7	0.9	13.8	4.6	12	10520	230	12	9.2	0.3	0.5	44	33
Minnesota	49457	1.0	5.5	571	0.7	0.3	25.4	7.2	20	19581	583	14	9.9	0.3		72	38
Missouri	42094	1.0	10	499	1.0		50.0	12	19	24733	940	20	23	0.5		72	53
Mississippi	45368	1.0	8.8	390	0.9		53.2	12	20	19684	471	21	18	0.5		68	45
Montana	70938	1.1	8.8	739	1.1		63.3	7.5	29	27766	366	20	14	0.4		101	69
Nebraska	59474	1.0	5.5	711	1.1		32.5	5.9	15	16000	306	15	16	0.4		62	54
North Carolina	60105	1.0	4.8	356	0.6		64.8	15	34	37053	563	24	17	0.4		107	56
North Dakota	62857	1.0	7.0	682	0.9		53.2	6.9	23	25357	530	20	13	0.4		83	64
New Hampshire	66667		4.4	500	2.3	0.6	18.4	5.3	12	33333	633	10	28	0.3		57	23
New Jersey	10075	1.4	7.0	54	0.3	0.3	13.9	1.7	14	11632	221	3.8	35	0.9		30	22
New Mexico	54423	1.0	5.9	727	1.0		55.5	8.8	21	20898	367	28	18	0.3		72	44
Nevada	66078	1.0	9.0	822	1.3		36.8	8.4	25	22725	481	15	25	0.3		78	69
New York	58800	1.0	6.4	666	1.4	0.2	66.9	9.1	36	38900	418	21	20	0.3		132	82
Ohio	54615		12	469	1.0		55.0	13	28	27308	550	25	23	0.6		88	69
Oklahoma	39200	1.0	7.0	430	1.1		46.0	7.1	16	19320	465	15	18	0.3		50	50
Oregon	94412	1.2	5.1	682	0.9		121.6	16	53	50147	725	23	15	0.3		168	70
Pennsylvania	63438	1.0	13	366	1.4		52.8	15	37	36063	609	24	23	0.5		80	81
Rhode Island	100000		3.5	500	0.5		50.0	10	15	30000	500	15	15	0.9		70	30
South Carolina	39143		3.9	151	1.4		21.4	3.5	16	12500	87.1	7.8	5.0	0.3		45	25
South Dakota	74333	1.3	8.5	1043	1.4		58.7	7.7	29	25667	1013	28	16	0.5		108	75
Tennessee	31894	0.7	16	193	0.8	0.2	40.3	14	17	28479	1112	18	23	0.6	1.2	49	57
Texas	41958	1.1	6.4	404	0.9		39.6	5.3	15	16328	303	12	14	0.3		52	39
Utah	45638	1.1	8.0	493	0.9		45.6	6.6	26	18830	371	13	35	0.3		70	96
Virginia	60438	1.2	5.1	436	0.9		54.3	9.7	33	27750	441	17	36	0.4		77	233
Vermont	56667		3.6	333	1.7		66.7	12	18	30000	800	25	20	0.4		70	43
Washington	66834	1.0	4.5	606	0.9	0.8	49.9	18	31	42635	760	23	14	0.3	0.7	160	78
Wisconsin	48000	1.0	4.4	543	2.0		40.3	7.7	12	15667	365	14	12	0.3		48	44
West Virginia	67000	1.3	8.6	360	1.0		46.0	14	22	28500	770	23	17	0.5		65	60
Wyoming	56125	1.1	6.5	756	0.7		47.9	8.3	21	25250	416	16	17	0.5		84	57

* Summary of background soil concentration data provided as Attachment 1-4.

of 4.0 and 8.5. This pH range was divided into the following sub-ranges: 4.0 to 5.5, 5.5 to 7.0, and 7.0 to 8.5. Qualitative bioavailability indices of very high, high, medium, low, and very low were assigned for each combination of soil parameters within each class of the contaminants (Tables 2.4a, 2.4b, 2.5, and 2.6). For example, a soil with a pH between 5.5 to 7.0, and organic matter content between 2 and 6%, would bind metal cations to a moderate extent. Therefore, a bioavailability index of 'medium' for metal cations was assigned (see Table 2.4a and 2.4b).

These tables simplified and facilitated the use of soil chemistry information in the derivation of Eco-SSLs for plants and soil invertebrates. The ranges given in these tables were used in selecting the most appropriate plant and soil invertebrates toxicity data for deriving Eco-SSLs (Chapter 3).

Table 2.4a.
Qualitative Bioavailability of Metal Cations in Natural Soils to Plants

Soil Type	Soil pH		
	Low Organic Matter (< 2%)	**Medium Organic Matter (2 to < 6%)**	**High Organic Matter (6 to 10%)**
4 ≤ Soil pH ≤ 5.5	Very High	High	Medium
5.5 < Soil pH < 7	High	Medium	Low
7 ≤ Soil pH ≤ 8.5	Medium	Low	Very Low

Table 2.4b.
Qualitative Bioavailability of Metal Cations in Natural Soils to Soil Invertebrates

Soil Type	Soil pH		
	Low Organic Matter (< 2%)	**Medium Organic Matter (2 to <6%)**	**High Organic Matter (6 to 10%)**
4 ≤ Soil pH ≤5.5	Very High	High	Medium
5.5 < Soil pH < 7	High	Medium	Low
7 ≤ Soil pH ≤ 8.5	Medium	Medium	Very Low

Table 2.5 Qualitative Bioavailability of Non-Ionizing Organic Contaminants in Natural Soils				
Soil Type	**Log K_{ow}**	**Organic Matter (%)**		
		< 2	**2 to <6**	**6 to 10**
4 ≤ Soil pH ≤5.5	Log K_{ow} > 3.5	High	Medium	Low
	Log K_{ow} < 3.5	Very High	High	Medium
5.5 < Soil pH < 7	Log K_{ow} > 3.5	Medium	Low	Low
	Log K_{ow} < 3.5	High	Medium	Low
7 ≤ Soil pH ≤ 8 .5	Log K_{ow} > 3.5	Low	Low	Low
	Log K_{ow} < 3.5	Medium	Low	Low

Table 2.6 Qualitative Bioavailability of Metal Anions in Natural Soils			
Soil Type	**Soil pH**		
	Low Organic Matter (< 2%)	**Medium Organic Matter (2 to <6%)**	**High Organic Matter (6 to 10%)**
4 ≤ Soil pH ≤5.5	Medium	Low	Very Low
5.5 < Soil pH < 7	High	Medium	Low
7 ≤ Soil pH ≤ 8.5	Very High	High	Medium

3.0 DERIVATION OF PLANT AND SOIL INVERTEBRATE ECO-SSLs

Eco-SSLs for plants and soil invertebrates were derived using a four-step process. These procedures built upon previous efforts (CCME, 1997; Efroymson *et al*., 1997 a,b), and established a process for evaluating published studies and selecting relevant data from the literature. The process (Figure 3.1) was guided by a set of standard operating procedures (SOPs) that specified the steps for identifying and evaluating data for appropriateness in deriving an Eco-SSL as well as the actual calculation of the screening values (Attachments 3-1 and 3-2). The process was intended to ensure that the Eco-SSLs for plants and soil invertebrates were based on sound science. The process required data from ecotoxicity studies that met prescribed requisites including but not limited to a thorough experimental design, appropriate quality control, and specific soil boundary conditions.

When appropriate and sufficient data were available for a specific contaminant, Eco-SSLs for plants and soil invertebrates generally could be derived using the prescribed process. Alternatively, if sufficient data does not exist, then toxicity testing could be completed under the preferred Eco-SSL experimental conditions (refer to Section 3.5) to generate the data needed to derive an Eco-SSL for the contaminant of interest.

Eco-SSLs for plants and soil invertebrates were derived using data from tests performed within soil boundary conditions favoring relatively high bioavailability for upland aerobic soils (refer to Tables 2.4 - 2.6 of Chapter 2). The soil chemistry conditions of relatively high bioavailability were defined by low soil pH and organic matter. These parameters were frequently found to be the predominant factors affecting contaminant bioavailability to plants and soil invertebrates in aerobic soils. Extreme pH values (< 4 and > 8.5) will substantially affect the solubility, precipitation, speciation, and sorption processes of contaminants, and therefore were not appropriate for use in Eco-SSL derivation. Similarly, organic matter, composed primarily of carbon, oxygen, and nitrogen, at elevated levels in the soils (i e. >10%) has a high affinity to bind organic compounds as well as some metals, thereby reducing their bioavailability.

Figure 3.1 The Four-Step Process for Deriving Eco-SSLs for Plants and Soil Invertebrates

Step 1. Literature search, acquisition, and screening (Attachment 3-1). Apply 22 Literature Exclusion Criteria.

Step 2. Identify acceptable literature by applying eleven Study Acceptance Criteria to retrieved papers (Attachment 3-1).

Step 3. Extract and score data from acceptable literature according to nine Study Evaluation Criteria (Attachment 3-2).

Step 4. Derive soil invertebrate and plant Eco-SSLs according to specified procedures (Attachment 3-2).

- Sort study data by bioavailability score
- Complete QA review
- Calculate value

3.1 Literature Search, Acquisition, and Screening

The first step in the process of developing Eco-SSLs for plants and soil invertebrates was to identify, retrieve, and screen published papers that reported data for soil toxicity to terrestrial plants or soil invertebrates. The procedures used to complete the literature search, retrieval and review are provided as Attachment 3-1.

The literature search included both paper-based searches and searches of computerized abstracting databases. The paper-based literature search process consisted primarily of the manual review of bibliographies, guidance documents, and review articles. This manual search was not limited by publication year. Searches of computerized abstracting databases included the use of DIALOG, SilverPlatter and Ovid commercial database vendors. Within DIALOG, the targeted databases included AGRICOLA, BIOSIS and ChemAbstracts. The searches were supplemented with other electronic databases including Toxline, PolTox1, Toxnet, and Current Contents. Searches of computerized abstracting databases were limited to papers published after 1988, except in cases when fewer than 20 publications were identified for a contaminant- receptor pairing (e.g., cadmium- plants). In these cases, the electronic search was expanded to include all publication years in the databases. It was assumed that relevant studies prior to 1988 would be identified in the bibliographies of review articles. A list of 22 Literature Exclusion Criteria (see Figure 3.2) was then used to screen out those studies not appropriate for use in deriving Eco-SSLs. These Literature Exclusion Criteria were applied to retrieved abstracts, or to the entire publication if the needed information was not available in the abstract.

Figure 3.2 Literature Exclusion Criteria

Biological Product	Biological toxins (venoms, etc.)
Chemical Methods	Methods for measuring contaminants
Drug	Testing for drug effects
Effluent	Effluent, sewage, polluted run-off
Contaminant Fate	Fate and transport of substance in the environment (only)
Human Health	Human or primate subjects
In Vitro	In vitro studies, including cell cultures and excised tissues
Methods	Methods reported but no usable specific toxicity test results
Mixture	Combinations of chemicals in laboratory testing
Modeling	Only modeling results reported
No Conc	No dose or concentration reported, or not able to calculate from information given
No Duration	No exposure duration reported
No Effect	No effect reported for a biological test species
No Species	No viable plant or animal present or tested
No Toxicant	No toxicant used
No Tox Data	Toxicant used, but no results reported that had a negative impact
Nutrient	Nutrition studies reporting no concentration-related negative impact
Oil	Oil and petroleum products
Publ As	Author states information is published in another source
QSAR	Data developed only from quantitative-structure activity relationships
Review	Data reported are not primary data
Survey	Assessment of toxicity in the field over a period of time

QSAR = Quantitative Structure Activity Relationship

For the 24 contaminants listed in the Chapter 1, EPA completed the literature searches according to the SOP (Attachment 3-1). The searches identified more than 7,600 papers. These publication abstracts and titles were screened to determine if they were likely to meet the Eco-SSL requirements using the 22 Literature Exclusion Criteria. This process resulted in the acquisition of more than 5,200 papers.

Figure 3.3 Eleven Study Acceptance Criteria

1. The document is the primary source of the test result.
2. Adverse effects are caused by an identified chemical stressor (i.e., no mixture testing in laboratory studies).
3. The chemical form (e.g., metal salt used) and concentration are reported by the author(s).
4. The test medium used in the study is a natural or artificial soil.
5. The study reports the organic matter content and it is ≤10 % of the composition of the soil; or equivalent concentration reported on the basis of organic carbon.
6. Except for studies on non-ionizing substances (e.g., PCP), the study reports the pH of the soil, and the soil pH is within the range 4.0 ≤ soil pH ≤ 8.5.
7. The study includes at least one control treatment.
8. The duration of the exposure is reported, or a standard study method with a defined duration is used.
9. For studies conducted in a laboratory setting, at least three treatment levels are used (i.e., control plus two chemical exposures).
10. Biological effects are reported for ecologically relevant endpoints (ERE).
11. Either the test species' scientific name, common name, variety, or strain is reported.

3.2 Identification of Potentially-Acceptable Literature

The second step of the process identified which publications acquired through Step 1 included at least the minimum information necessary for deriving an Eco-SSL. Eleven Study Acceptance Criteria (see Figure 3.3) were applied to each of the acquired publications. Publications that meet all 11 Study Acceptance Criteria were further evaluated in Step 3. Detailed descriptions of the Study Acceptance Criteria are presented in Attachment 3.1. Approximately seven percent of the plant and soil invertebrate publications reviewed by EPA (identified during Step 1) met all 11 Study Acceptance Criteria.

3.3 Extraction of Data and Scoring Studies

In Step 3, each of the publications that met all 11 Study Acceptance Criteria were reviewed and study data extracted and scored. If a publication contained more than one study, each study was evaluated and scored separately. For each study reviewed, a set of critical notes were recorded in a spreadsheet. A separate "study" was defined if any of the following parameters varied: test species (not strain), contaminant (not form), soil (natural vs. artificial), pH or percent organic matter (% OM) content. The specific procedures used to extract and record study data are provided as Attachment 3-2.

Ecologically Relevant Endpoints

For each of the studies reviewed, the measures of toxic effects to either plants or soil invertebrates were grouped into one of four ecologically relevant endpoints (EREs) (see Table 3.1). If a study reported toxic effects for multiple EREs, only the preferred ERE and corresponding contaminant concentration were recorded in the critical notes. For soil invertebrates, the preferred ERE followed the order: reproduction > population > growth. For soil invertebrates, reproduction was the preferred ERE because it is necessary for sustaining populations, and reproductive endpoints are good indicators of longer term (i.e., chronic) exposure. Although population endpoints were considered less robust than reproductive endpoints, they were next in preference because screening ecological risk assessments focus on protection at the population level. Growth measurements on individuals were the traditional measurement endpoints, and are frequently extrapolated to represent impact at the population level.

For plants, the preferred ERE was biomass production as it is normally the most sensitive measurement. If no measurement of biomass production was reported, some physiological endpoints were accepted as there were established linkages between certain measures of photosynthesis and productivity (refer to Table 3.1).

Table 3.1 Ecologically Relevant Endpoints (EREs) for Soil Invertebrate Eco-SSLs

Ecologically Relevant Endpoint	Definition
Reproduction	Measures of the effect of toxicants on offspring production. Examples of EREs associated with reproduction included changes in fecundity, number of progeny produced (eggs, cocoons, etc.), rate of reproduction (hatching rates, etc.), rate of maturation, sexual development, change in sex expression, and sterility number or proportion of abnormal progeny.
Population	Measurements and endpoints regarding a group of soil invertebrates of the same species occupying the same area at a given time. Measurement included population dynamics. Examples of EREs associated with population included changes in size and age class structures, changes in sex ratio, intrinsic population growth rate, survivability of subsequent generations, diversity, evenness, index to population size (count, number, abundance), life table data, population density (number/area).
Growth	Broad category which encompassed measures of weight/mass and length. EREs associated with growth and development included responses such as a change in body weight.

Table 3.2 Ecologically Relevant Endpoints (EREs) for Plant Eco-SSLs	
Ecologically Relevant Endpoint	**Definition**
Growth (Biomass)	Measurement of plant products including standing crop biomass, seedling emergence, shoot length/growth, root elongation/growth, fresh or dry mass, yield or production (e.g., seed production).
Physiology	For the purposes of developing Eco-SSLs, plant studies reporting EREs associated with physiological responses were used. Physiological endpoints for plants included net photosynthesis (CO_2 uptake, oxygen release), decrease in chlorophyll content or chlorophyll fluorescence, increased deformation, membrane damage, desiccation/decrease in water content, detrimental changes in dormancy measures, decreased flowering, and increased senescence.

Toxicity Parameters

For each study, a toxicity parameter was recorded. The toxicity parameter was the concentration-response measurement associating the adverse effect with the contaminant exposure. Toxicity parameters considered acceptable for deriving Eco-SSLs were the EC_{20} (effective concentration that affects 20% of the test population), the MATC and the EC_{10} (effective concentration that affects 10% of the test population). The MATC was equal to the geometric mean of the NOAEC and the LOAEC. Some toxicity data were not used to derive Eco-SSLs including acute toxicity data such as the concentration lethal to 50% of the test population (LC_{50}) or the effective concentrations affecting more than 50% of the test population (EC_{50}). Effect concentrations affecting less than 5% of the test population (EC_x <5) were also not considered acceptable for deriving Eco-SSLs. The LC_{50} and EC_{50} values were not considered sufficiently protective of ecological resources, while EC_5 values have low levels of confidence due to natural variability.

When NOAEC and LOAEC values were reported, these data were used to calculate an MATC. A bounded value was a study result with both a NOAEC and LOAEC reported (other than control). Unbounded NOAEC or LOAEC values do not describe a dose-response curve and thus were not used due to the high uncertainty over where the real threshold of toxicity lies. If a study reported multiple toxicity parameters, a single preferred toxicity parameter was selected. Selection of the preferred toxicity parameter followed the order:

$$\mathbf{EC_{20} > MATC > EC_{10}}$$

If a study reported more than one adverse effect concentration with the "preferred" ERE and toxicity parameter, the lowest effect concentration was then selected. If a publication did not report an EC_{20}, MATC or EC_{10}, but sufficient data were provided, the reviewer calculated and recorded the toxicity value under the appropriate toxicity parameter. Toxicity data were reported as mg/kg of the chemical on the critical notes form (Attachment 3-2). Data not reported in these units were converted to mg/kg or converted from formulation to active ingredient. When metal

concentrations were reported, these were converted to an elemental basis. The only data extracted were for results where an adverse effect was significantly different from the control.

Scoring Each Study

Each study was scored according to nine specific Study Evaluation Criteria (Table 3.3) and the results documented in the critical notes. If a single publication contained data for multiple studies (e.g., reports toxicity data for more than one species or soil type, etc.), each study within the publication was scored separately. The information recorded for each study included test species, soil characteristics (e.g., pH, %OM), relative bioavailability score, the ERE, toxicity parameter, and toxicity value (Attachment 3.2). The specific procedures used to score studies and document the results are provided as Attachment 3-2.

Scoring for each Study Evaluation Criterion used a three-point scale (i.e., 0, 1, or 2). The maximum score for a study was 18. Studies were deemed inappropriate for deriving Eco-SSLs for plants and soil invertebrates if they did not score above ten. Studies with an evaluation score of 10 or less were presumed to lack sufficient detail about the study to enable reviewers to assess the quality of the data. These studies results were not included in the pool of data considered for deriving the Eco-SSL values.

3.4 Derivation of Eco-SSLs

Sorting Data by Bioavailability Score

The first step in deriving an Eco-SSL was to sort the studies accepted at Step 3 (receiving a Study Evaluation Score greater than ten out of 18 possible points) by their bioavailability score. The bioavailability score was determined as part of the scoring process in Step 3 (Table 3.3). This score was based on the soil matrix tables presented in Chapter 2 (Tables 2.4 to 2.6), the type of soil (natural versus artificial), pH and OM content. A score of two was applied to natural soils with relatively high or very high bioavailability, a score of one was applied to natural soil with medium bioavailability and to standard artificial soil, and a score of zero was applied for natural soil with low or very low relative bioavailability.

Quality Control Review

A quality assurance review of the sorted data was preformed by a panel of experts. The reviewers verified that all studies used to derive the Eco-SSLs were correctly evaluated and scored. All studies were reviewed by at least two individuals (other than the original reviewer). The quality control review provided a forum for confirming that the appropriate data were identified and documented, resolving any comments or concerns, and ensuring consensus on data selection. For example, in cases where a study reported data for multiple test species and for several endpoints, the quality control review provided a forum to reach a consensus that the most

Table 3.3 Summary of Nine Study Evaluation Criteria for Plant and Soil Invertebrate Eco-SSLs		
Criteria Title	**Rationale**	**Scoring**
#1: Testing was Done Under Conditions of High Bioavailability	Bioavailability of metals and polar organic compounds is influenced by pH and soil organic matter, cationic exchange capacity, and clay content. The scoring is intended to favor relatively high bioavailability.	Scores were based on the bioavailability matrix (see Chapter 2). Scored 2 if bioavailability of natural soil was high or very high. Scored 1 for natural soil with medium bioavailability or standard artificial soil. Scored 0 for natural soil with low and very low bioavailability.
#2A (laboratory) and **#2B** (field): Experimental Designs for Studies are Documented and Appropriate	Experimental design can significantly influence the quality of a study. Higher quality studies will use an experimental design sufficiently robust to allow analysis of the test variables and discriminate non-treatment effects.	Scored based on experimental design and methods used for statistical analyses. Scored 2, 1 or 0. Specific criteria used provided in Attachment 3-2.
#3: Concentration of Test Substance in Soil is Reported	The concentration of the contaminant tested must be reported unambiguously.	Scored 2 if measured concentrations were reported. Scored 1 for nominal concentrations and scored 0 in all other cases.
#4: Control Responses are Acceptable	Negative controls are critical to distinguish treatment effects from non-treatment effects.	Scored 2 if a standardized procedure were used and control values were within procedural guidelines or acceptable range (if non-standard procedure used). Scored 1 if results of control were not reported or were ambiguous. Score d0 if control results were not within an acceptable range.
#5: Chronic or Life Cycle Test was Used	Chronic toxicity tests assessing long-term adverse sub-lethal impacts on the life-cycle phases of an organism are considered superior to acute toxicity tests.	Scored 2 if chronic exposures were used. Scored 1 if acute tests were used. Scored 0 if very short term exposures were used.
#6: Contaminant Dosing Procedure is Reported and Appropriate for Contaminant and Test	Contaminant dosing procedure may affect the outcome of a test. Dosing procedure should include: (A) the form of the contaminant; (B) the carrier or vehicle (e.g., solvent, water, etc.); (C) how the carrier was dealt with following dosing (i.e., allowed to volatilize, controls, etc.); (D) procedure for mixing of soil with contaminant (homogeneity).	Score applied based on how well the study reports the four contaminant dosing procedures (A to D). Scored 2 if study reported all. Scored 1 if information for items A and B, but not C or D; Scored 0 if details were not provided and could not be inferred.
#7: A Dose-Response Relationship is Reported or can be Established from Reported Data	Two methodologies can be used to identify this benchmark concentration. The first method generates a no observed adverse effect concentration (NOAEC) and a lowest observed adverse effect concentration (LOAEC). The second method uses a statistical model to calculate a dose response curve and estimate an effect concentration for some percentage of the population (EC_x), usually between an EC_5 and an EC_{50}.	Scored 2 if an EC_{10}- EC_{20}; or a NOEC and LOEC were within a factor of 3. Scored 1 if the difference between the NOEC and LOEC was > 3x but < 10x. Scored 0 if an EC_x was not reported or the difference between the NOEC and LOEC was > 10, or only a NOEC or LOEC was reported.
#8: The Statistical Tests used to Calculate the Benchmark and the Level of Significance were Described	Statistical tests and results reported in the study should be sufficient to determine the significance of the results.	Scored 2 if ANOVA or statistical method were based on a P = 0.05; or the 95% CI of the EC_x. Scored 1 if an ANOVA was completed but P level not provided or > 0.05; or if EC data did not include the 95% CI or used a 90% CI. Scored 0 if a NOEC, LOEC, or EC/LC_x were not reported, or were reported without a description of the method used to calculate the values.
#9: The Origin of the Test Organisms is Described	The results of a toxicity test can be influenced by the condition of the test organisms. Culture conditions should be maintained such that the organisms are healthy and have had no exposure above background to contamination prior to testing (inverts) or detailed information is provided about the seed stock (plants).	Scored 2 if the source and condition of the test organisms were known and described. Scored 1 for a non-commercial source not adequately described, or if insufficient information was provided about a commercial source. Scored 0 if organisms were from a known contaminated site, or insufficient information was provided on the a commercial source.

appropriate data were used to derive the Eco-SSL. The quality assurance review consisted of verifying the following information:

- Adherence to all eleven Study Acceptance Criteria
- Accuracy of study evaluation scores
- Accuracy of soil pH, OM, and relative bioavailability score for each study
- Selection of preferred EREs, toxicity parameter(s), and toxicity results
- Units of the toxicity result (wet weight/dry weight, contaminant form)

Calculation of the Eco-SSL Values

The Eco-SSL was calculated as the geometric mean of all the toxicity values at the highest relative bioavailability score for which sufficient data existed (i.e., ≥ three data points). If less than three data values were available at the highest relative bioavailability level, data from the next highest bioavailability level were included in that Eco-SSL data set. This process proceeded until a combined data set of three or more data values were identified for calculating the Eco-SSL. For example, if there were only two toxicity values from studies using soils with relatively high bioavailability (i.e., score = two), but there were data from four medium bioavailability studies (i.e., score = one), then an Eco-SSL was calculated using the combined six data values. If there were less than three acceptable studies (score > ten) an Eco-SSL was not calculated.

3.5 Soil Toxicity Test Methods

If sufficient data for deriving an Eco-SSL were not available from the published literature, additional plant or soil invertebrate data could be generated through completion of appropriately designed soil toxicity studies. The Agency recommends that such studies be designed with consideration of the nine Study Evaluation Criteria (Table 3.3) to generate the highest quality data to derive an Eco-SSL. For example, the ideal studies would be conducted using natural soils within the specified soil chemistry conditions, have the highest relative bioavailability (i.e., score = two), and satisfy the other evaluation criteria.

Several standardized soil test procedures are available that can be used to generate the data for deriving Eco-SSLs. Alternative test methods or designs could also be used if they use the appropriate EREs. Whether standardized or other methods are used, experimental design options should be selected that best fit the Study Evaluation Criteria outlined in Table 3.3. To obtain data that best represent natural conditions, investigators are encouraged to incorporate aging/weathering of contaminated soil into their study design. Examples of standard procedures that may be used are described in the following subsections and are listed in Table 3.4.

Soil Invertebrate Toxicity Testing

Several internationally standardized soil invertebrate toxicity tests may be used to generate data for Eco-SSLs. Specifically, three soil toxicity tests are identified as generally appropriate: 1) a 21-day chronic earthworm reproduction (cocoon production) toxicity test (ISO/11268-2:1998),

2) the enchytraeid reproduction test (ISO/16387:2001), and 3) the collembolan reproduction test (ISO/11267:1998) (Table 3.4). These specific tests are recommended as they measure contaminant toxicity during chronic assays, and include at least one reproductive component among the measurement endpoints. Guidelines for these methods have been approved by the International Standards Organization (ISO), and similar efforts are in the final stages of review or approval by one of several national and international organizations (e.g., the Organization for Economic Cooperation and Development (OECD), the American Society for Testing and Materials (ASTM), the European Community, and the Federal Biology Research Cooperative (FBRC)).

Plant Toxicity Testing

There are relatively few standardized plant toxicity test procedures that EPA expects would generate data acceptable for deriving Eco-SSLs (Table 3.4). The EPA guidelines for the early seedling growth and vigor plant test may be used, as well as similar ASTM methods (e.g., ASTM E 1963-98). The use of these procedures may require a modified design to best meet the nine Study Evaluation Criteria.

Table 3.4 Standard Methods Appropriate for use in Generating Data for the Derivation of Plant or Soil Invertebrate Eco-SSLs

Species	Citation
Eisenia fetida	ISO (International Standardization Organization). 1998. Soil Quality – Effects of Pollutants on Earthworms (*Eisenia fetida*) – Part 2: Determination of Effects on Reproduction. ISO 11268-2:1998
Enchytraeus sp.	ISO (International Standardization Organization) (2001). Soil Quality – Effects of Pollutants on Enchytraeidae (*Enchytraeus sp.*) – Determinations of effects on reproduction and survival. ISO/CD 16387.
Folsomia candida	ISO (International Standardization Organization) (1999). Soil Quality – Inhibition of Reproduction of Collembola (*Folsomia candida*) by Soil. ISO 11267:1999.
Terrestrial Plants	ASTM (American Society for Testing and Materials). 2002. Standard Guide for Conducting Terrestrial Plant Toxicity Tests. Designation: E 1963-98 Annual Book of Standards. American Society for Testing and Materials. West Conshohocken, PA.
Terrestrial plants	U.S. EPA (U.S. Environmental Protection Agency). 1996. Ecological effects test guidelines. OPPTS 850.4230: Early seedling growth toxicity test. Report Number EPA 712–C–96–347. Office of Prevention, Pesticides and Toxic Substances, Washington, DC.
Terrestrial plants	U.S. EPA (U.S. Environmental Protection Agency). 1996. *Ecological effects test guidelines. OPPTS 850.4250. Vegetative vigor, Tier II.* Report Number EPA 712–C–96–364. Office of Prevention, Pesticides and Toxic Substances, Washington, DC.
Terrestrial plants	U.S. EPA (U.S. Environmental Protection Agency). 1996. *Ecological effects test guidelines. OPPTS 850.4150. Terrestrial Plant Toxicity, Tier 1: Vegetative vigor*. Report Number EPA 712–C–96–163. Office of Prevention, Pesticides and Toxic Substances, Washington, DC.

4.0 DERIVATION OF WILDLIFE ECO-SSLs

Eco-SSLs for wildlife were derived using a five-part process that included: selecting a wildlife risk model, selecting surrogate species, estimating an exposure dose, deriving the TRVs, and calculating the Eco-SSL. Wildlife Eco-SSLs were derived for two groups of receptors: mammals and birds. Eco-SSLs were not derived for amphibians or reptiles at this time, as described in Chapter 1.

4.1 The Wildlife Risk Model for Eco-SSLs

The basic equation that was used for estimating potential risks to wildlife was:

$$\text{Hazard Quotient (HQ)} = \frac{\text{Exposure Dose (mg / kg bw / day)}}{\text{Toxicity Reference Value (mg / kg bw / day)}}$$

Contaminant exposure for terrestrial wildlife was expressed as an Exposure Dose in mg/kg bw/day, and the Toxicity Reference Value (TRV) was expressed in the same units.

Steps for Establishing a Wildlife Eco-SSL

1. **Identify the Wildlife Risk Model -** Equation relates the contaminant soil concentration to an acceptable threshold based on a food-chain exposure model.
2. **Select Surrogate Wildlife Species** - Specific indicator species were identified for parameterization of the exposure model.
3. **Estimate Exposure Dose** - Parameterization of the exposure dose model for the estimation of exposure doses for each contaminant.
4. **Derive the Effects Dose or TRV**- Identification of an acceptable dose.
5. **Calculate the Eco-SSL** - Calculation of the Eco-SSLs by solving equation for an HQ=1.

The Eco-SSL is the soil concentration that results in an HQ=1, that is, when the TRV and the Exposure Dose are equal. The Exposure Dose for wildlife was equal to the amount of contaminant in the diet that is taken up or transferred from the soil. Therefore, it was necessary to model the contaminant specific soil concentration that would result in a dietary concentration equal to the Exposure Dose that was equal to the TRV. Estimation of the Exposure Dose is described in Section 4.3. Derivation of the TRV is described in Section 4.4. Calculation of the Eco-SSLs to solve for an HQ = 1 is described in Section 4.5. The full HQ equation is provided in Figure 4.1. In this model, incidental oral soil exposure was added to the total dietary (food-based) exposure, making the total oral exposure greater than 100%. This equation also included terms for the absorbed fraction (AF) of the contaminant from soil and the diet as well as an area use factor (AUF) (representing the fraction of time an animal would be exposed). For the purposes of establishing Eco-SSLs, which are conservative screening values, these terms (AF and AUF) were set equal to one.

Figure 4.1. The Wildlife Risk Model for Eco-SSLs (Equation 4-1)

$$HQ_j = \frac{\left([Soil_j * P_s * FIR * AF_{js}] + [\sum_{i=1}^{N} B_{ij} * P_i * FIR * AF_{ij}] \right) * AUF}{TRV_j}$$

where:

HQ_j	=	Hazard quotient for contaminant (j) (unitless),
$Soil_j$	=	Concentration of contaminant (j) in soil (mg/kg dry weight),
N	=	Number of different biota types in diet,
B_{ij}	=	Concentration of contaminant (j) in biota type (i) (mg/kg dry weight),
P_i	=	Proportion of biota type (i) in diet,
FIR	=	Food ingestion rate (kg food [dry weight]/ kg BW [wet weight] /day),
AF_{ij}	=	Absorbed fraction of contaminant (j) from biota type (i) (for screening purposes set equal to 1),
AF_{sj}	=	Absorbed fraction of contaminant (j) from soil (s) (for screening purposes set equal to 1),
TRV_j	=	Toxicity reference value (mg/kg BW/day) (Section 4.4),
P_s	=	Soil ingestion as proportion of diet,
AUF	=	Area use factor (for screening purposes set equal to 1).

4.2 Selection of Surrogate Wildlife Species

It was neither feasible nor necessary to derive an Eco-SSL for each and every wildlife species potentially present at a hazardous waste site; therefore, surrogate species were used to derive wildlife Eco-SSLs. In this approach, specific species were selected as "representatives" for other species within the same class (mammalian or avian) with similar diets. The advantages of focusing Eco-SSLs on representatives within generic trophic groups included, but were not limited to, the following:

- This approach provided generic screening values that could be applied to any site, regardless of the presence or absence of a particular species. The trophic groups selected were expected to be present or potentially present at all sites across the nation.

- This approach provided results that could be used to examine comparative risks associated with different exposure routes (e.g., ingestion of food versus ingestion of soil) representing different contaminant transport pathways (e.g., soil to herbivore, soil to ground insectivore, soil to soil invertebrate, and soil to plant) versus direct soil ingestion.

- This approach was consistent with ERAGS which states: "for the screening-level ERA, assessment endpoints are any adverse effects on ecological receptors, where receptors are plant and animal populations and communities, habitats, and sensitive environments." (p. 1-7; U.S. EPA, 1997)

Criteria for Selection of Surrogate Taxa

Three general trophic groups (e.g., herbivore, ground insectivore, and carnivore) for both mammals and birds were used for the Eco-SSL wildlife exposure model. Within each of these trophic groups, a specific species was identified as a "surrogate" species. Surrogate species were selected to provide a conservative representation of their respective trophic groups. Selected species were generally small in size relative to other species within their respective trophic groups (e.g., weasels and voles vs. foxes and coyotes or rabbits and deer). Because small size was considered to be associated with higher metabolic rates (Nagy et al., 1999) and smaller home ranges (McNab, 1963), exposure for small receptors was assumed to be high. Eco-SSLs based on these species were therefore likely to be protective of other, larger species in their trophic group.

Selection of specific surrogate species was necessary for parameterizing the Eco-SSL wildlife model, which required estimates of body weights, food ingestion rates, and soil ingestion rates. The following criteria were used to guide the selection of surrogate species for each trophic group:

1) **Exposure pathway link to soil.** Each surrogate species had to have a clear direct or indirect exposure pathway link to soil. Direct exposure pathways to soil included ingestion of soil dwelling biota (e.g., plants or soil invertebrates) and incidental ingestion of soil as a result of foraging at the soil surface (as opposed to from plants). Species with direct exposure pathways to soil were assumed to be the most highly exposed to soil contamination with the exception of contaminants that biomagnify. Indirect exposure included ingestion by carnivores of prey that have direct contact with soil.

2) **Diet Composition.** The selected, surrogate species must forage in terrestrial, upland habitats. This criteria ensured that only potential exposures related to soil contamination were considered and consumption of aquatic prey items (exposures to the aquatic environment) were not considered.

3) **Diet composition can be simplistically classified.** The dietary composition of each surrogate species had to be easily classified into one of the three selected trophic groups (herbivore, ground insectivore, carnivore). Clear classification of diet served to

What Wildlife Groups are not Considered Appropriate for Eco-SSLs?

Some specific wildlife groups were not considered suitable for deriving wildlife Eco-SSLs. These groups include:

- **Generalist species (e.g., raccoons, jays)** were excluded due to difficulty in defining diet and, therefore, exposure. These species forage opportunistically and are likely to consume different foods in different parts of their range.
- **Piscivores (e.g., herons, otter)** were excluded due to the lack of a direct exposure pathway to soil.
- **Aerial Insectivores (e.g., swallows) and Arboreal Insectivores (e.g., warblers)** were excluded as they do not forage primarily from terrestrial environments.

simplify the exposure assumptions related to dietary composition into three classes: plants, invertebrates and animals. Further, the dietary composition for the surrogate species needed to be realistically assumed to consist of a single food type. This assumption allowed for the evaluation of the potential maximum exposure and risk from that dietary pathway. Evaluation of the maximum risk that may be presented by a given pathway (i.e., plants, invertebrates, or vertebrates) produced results that are protective of species with more varied diets. Omnivorous species were assumed to be more likely to consume foods with differing contaminant concentrations. As a result, their total exposure would be less than that for species whose diets that consisted of the single most contaminated food type. By selecting surrogate species that foraged exclusively on a specific food type (plants, invertebrates, or vertebrates), maximum risks were expressed for any given contaminant. This helped to ensure protectiveness of all other species.

4) **Mammalian and avian species identified.** Because toxic responses for the same contaminant could differ among wildlife taxa, surrogate species were selected for both mammals and birds. Based upon the above factors, three mammalian and three avian species (listed in Table 4.1) were selected to represent some of the most highly exposed species. It was assumed that the use of these six species also protected other herbivores, ground insectivores, and carnivores.

4.3 The Exposure Dose

Estimation of the exposure dose associated with contaminant concentrations in soil required parameterization of the general model provided as Equation 4-1 (see Figure 4.1).

Reduced Wildlife Risk Model for Screening

The Eco-SSLs are intended to be conservative screening values that can be used to eliminate contaminants clearly not associated with unacceptable risks. Therefore, several simplifying, conservative assumptions were made in the parameterization of the general wildlife risk model (Equation 4-1). These assumptions included:

- Surrogate species were assumed to reside and forage exclusively on and within the contaminated site. Therefore, the area use factor (AUF) was set equal to 1.

- Bioavailability of the contaminant in both soil and food was assumed to be comparable to the bioavailability of the contaminant in the laboratory studies used to establish the TRVs. Therefore, the absorbed fraction from soil (AF_{sj}) and absorbed fraction from biota type 'i' (AF_{ij}) were both equal to 1.

- The surrogate species' diet consisted of just one food type. Therefore, the proportion of biota type 'i' in the diet (P_i) was equal to 1 and the number of biota types (N) in the diet was equal to 1.

Parameterizing the Model for Estimating the Exposure Dose

Parameterization of the model included using exposure factors related to the surrogate species (see Table 4.1) and estimating the contaminant concentrations in biota items (B_{ij}) consumed in the diet. The exposure factors identified and derived for surrogate species-specific exposure factors are described in Attachment 4-1. The food and soil ingestion rates used in the exposure model were represented by high-end values. For the food ingestion rate a high end point estimate was selected based on measured data. For soil ingestion, the 90th percentile from the distribution was selected. Use of exposure parameter values from the upper tails of the distributions ensures the protectiveness of the Eco-SSLs for other wildlife species.

Table 4.1. Parameterization of the Eco-SSL Wildlife Exposure Model

Receptor Group (Surrogate Species)	Food Ingestion Rate (kg dw/kg bw day) [1]	Soil Ingestion (P_s) [2]	Assumed Diet
Mammalian Herbivore (Meadow Vole)	0.0875	0.032	100% foliage
Mammalian Ground Insectivore (Short-tailed shrew)	0.209	0.030	100% earthworms
Mammalian Carnivore (Long-tailed weasel)	0.130	0.043	100% small mammals
Avian Grainivore (Mourning dove)	0.190	0.139	100% seeds
Avian Ground Insectivore (American woodcock)	0.214	0.164	100% earthworms
Avian Carnivore (Red-tailed hawk)	0.0353	0.057	100% small mammals that consume 100% earthworms

Parameterization details provided in Attachment 4-1.
[1] High end point estimate based on measured data. Derivation presented in Attachment 4-1.
[2] Soil ingestion as proportion of diet. 90th percentile. Derivation presented in Attachment 4-1.
dw = dry weight

Estimating Contaminant Concentrations in Biota (Dietary Items)

The contaminant concentrations in biota types (B_{ij}) composing the wildlife diets (plants, earthworms, or small mammals) were estimated by assuming that the concentration of the contaminant 'j' in the food type 'i' could be predicted from the concentration of the contaminant in the soil ($Soil_j$).

The concentration of contaminant (j) in biota or food type type (i) (B_{ij}) is related to the concentration in soil ($Soil_j$) by an uptake model which has one of the following forms:

Case 1) $B_{ij} = BAF_{ij} * Soil_j$ (constant)
Case 2) $\ln(B_{ij}) = I_{ij} + S_{ij} * \ln(Soil_j)$ (log-linear)
Case 3) $B_{ij} = I_{ij} + S_{ij} * Soil_j$ (linear)

where:

B_{ij}	=	Concentration of contaminant (j) in food type (i) (where i = plant, earthworm, or small mammal)
BAF_{ij}	=	Soil-to-biota bioaccumulation factor (BAF) for contaminant (j) for biota type (i)
I_{ij}	=	Intercept from bioaccumulation model for contaminant (j) for food type (i)
S_{ij}	=	Slope from bioaccumulation model for contaminant (j) for food type (i)
$Soil_j$	=	Concentration of contaminant (j) in soil

For the predatory surrogate species that are assumed to consume 100% small mammals, BAFs or regression equations were not available for all contaminants relating soil concentration to concentration in small mammal tissue. In these instances, it was necessary to estimate small mammal tissue concentrations (B_{ij}) from dietary-based BAFs or regressions:

Case 4) $B_{ij} = C_{diet} * BAF_{dm}$
Case 5) $\ln(B_{ij}) = I_{ij} + S_{ij} * \ln(C_{diet})$
Case 6) $B_{ij} = I_{ij} + S_{ij} * C_{diet}$

where:

B_{ij}	=	Concentration of contaminant (j) in food type (i) (where i = small mammal)
C_{diet}	=	Concentration of contaminant (j) in diet where diet is 100% earthworms estimated as in Case 1, 2 or 3, above
BAF_{dm}	=	Diet-to-biota BAF for contaminant (j) in mammal or bird tissue

A hierarchy was established for decision-making concerning the use of available data to estimate contaminant concentrations in biota types (B_{ij}). The following values were used in order of preference:

1) **Existing Regression (R).** If regression equations were available from the literature and the r-square values were > 0.2, then these were preferentially used. The primary sources of existing regression equations were: Sample et al. (1999) for earthworms; Sample et al. (1998a) for small mammals; and Bechtel-Jacobs (1998) for plants.

2) **New Regression (R).** If regressions were not available from the literature, then paired data (contaminant concentration in soil versus concentration in plant foliage; concentration in soil versus soil invertebrate; or concentration in diet versus mammal or

bird tissue) were identified from the literature. If the paired data were sufficient to establish a regression and the regression was significant with r-square values > 0.2, then the regression was used to estimate uptake.

3) **Ratio (BAF).** If regressions were not significant then BAFs (or ratios of the contaminant in soil to the contaminant in the food item) were used to estimate uptake. BAFs were identified either from the literature or from the paired data compiled in the attempt to establish a regression in Step 2. The median BAF value was selected to estimate uptake.

4) **Modeled BAFs or B_{ij} (M for modeled).** If BAFs were not available in the literature or the paired data were not available to derive the BAF, then B_{ij} was estimated using relationships established between physical or chemical parameters of the contaminant 'j' and B_{ij}. Existing models from the literature were used where possible. In some cases, new models were derived. The models are provided in Attachment 4-1.

5) **Assumptions (A)**. In instances where data were not available to complete any of the previously listed options in the hierarchy (1 to 4), then it was necessary to make assumptions concerning the bioaccumulation of contaminants for soil into biota types. These assumptions are discussed in following subsections.

Figure 4.2 Summary of Method Used for Estimation of Contaminant Concentrations in Biota Types (B_i)

COC	Soil to Plant	Soil to Earthworm	Diet to Mammal	Soil to Mammal
Antimony	R	A	BAF	NA
Arsenic	BAF	R	NA	R
Barium	BAF	BAF	BAF	NA
Beryllium	R	BAF	BAF	NA
Cadmium	R	R	NA	R
Chromium	BAF	BAF	NA	R
Cobalt	BAF	BAF	NA	R
Copper	R	BAF	NA	R
Lead	R	R	NA	R
Manganese	BAF	R	NA	R
Nickel	R	BAF	NA	R
Selenium	R	R	NA	R
Silver	BAF	BAF	NA	BAF
Vanadium	BAF	BAF	NA	BAF
Zinc	R	R	NA	R
Dieldrin	BAF	R	R	NA
DDT	R	R	R	NA
DDD	R	R	R	NA
DDE	R	R	R	NA
PCP	R	R	R	NA
PAHs	R or BAF	M	A	A
TNT	BAF	TBD	A	A
RDX	BAF	TBD	A	A

A = Assumption .
BAF = Bioaccumulation Factor.
M = Estimated based on equation relating physical-chemical factor to bioaccumulation (model).
NA = Not applicable. Only one method is needed for estimating tissue concentrations in mammals based on either diet or soil concentrations.
R = Either existing or new regression equation (Attachment 4-1)
TBD = To be determined in the chemical specific Eco-SSL document.

Figure 4.2 summarizes the method (based on the hierarchy) used for estimating contaminant concentrations in biota types (dietary items) for each of the Eco-SSL contaminants. The following subsections describe how contaminant concentrations were estimated in each of the dietary items including plants, soil invertebrates and small mammals.

How Contaminant Concentrations Are Estimated for Plants and Soil Invertebrates as Dietary Items

The specific information concerning how contaminant concentrations were estimated for the plant, earthworm and small mammal biota types (B_{ij}) of the diets of the surrogate species is provided as Attachment 4-1. Regressions (R), BAFs, models (M) and assumptions (A) were all used (Figure 4.2).

The existing models for plants produce estimated contaminant concentrations in foliage. Although these data are suitable for receptors that consume foliage (e.g., meadow vole), their suitability for receptors whose diets consist of seeds (e.g., mourning dove) is unknown. To address this issue, a literature search was performed to locate studies in which contaminant concentrations in seeds and in soil were evaluated. The few data located (limited to metals) were plotted over reported soil-to-plant foliage bioaccumulation data (Figure 4.3).

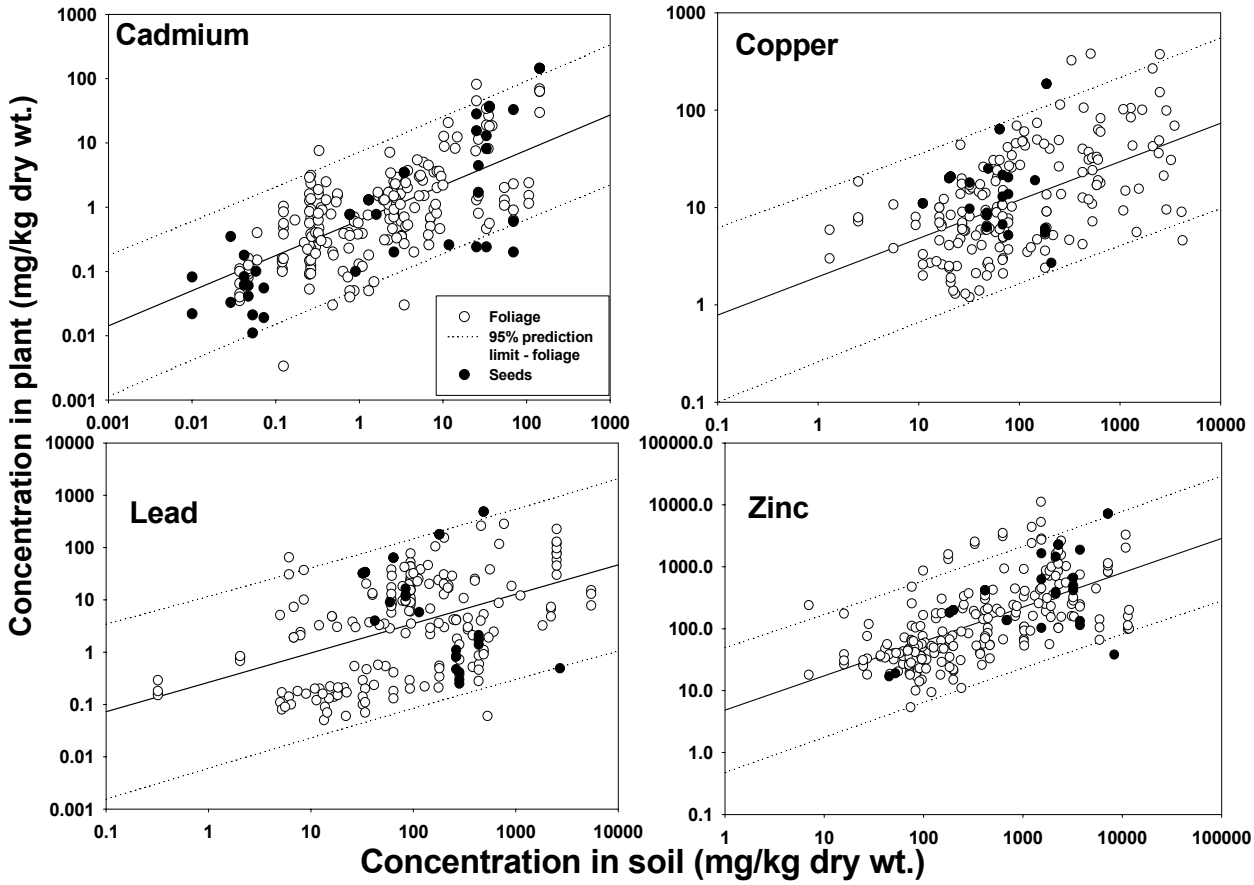


Figure 4.3 Comparison of Soil-to-Foilage and Soil-to-Seed Bioaccumulation for Cadmium, Copper, Lead and Zinc

For cadmium, copper, lead, and zinc soil-to-seed bioaccumulation mirrors the pattern observed for soil-to-foliage bioaccumulation. The degree of spread in the seed bioaccumulation data was comparable to that for foliage data. Based on these data, the models estimating contaminant concentrations in foliage were assumed to be suitable surrogates (at least for metals) for estimating contaminant concentrations in seeds.

How Contaminant Concentrations Are Estimated for Mammals as Dietary Items

Empirical soil-to-whole body log-linear regression models and BAFs were available from Sample et al. (1998a) for 11 of the 24 contaminants. For the remaining contaminants for which empirical regression models or BAFs were not available, bioaccumulation was estimated using the methods presented in Attachment 4-1.

Although many species of predatory wildlife consume both birds and mammals as prey, few data were available to estimate bioaccumulation of contaminants into birds. As a consequence, the bioaccumulation models for mammals were assumed to produce estimates that adequately represent concentrations in birds. The validity of this assumption was supported by data presented in Beyer et al. (1985). Birds (representing multiple species), white-footed mice, and short-tailed shrews were collected from two locations in the vicinity of a zinc smelter in Pennsylvania. Analyses were available for carcasses (tissue remaining after removal of the gastrointestinal tract, skin, feet, and beaks) for lead, zinc, cadmium, and copper. Mean analyte concentrations (and 95% confidence limits) in birds and mammals from both locations are presented in Figure 4.4. Based on these data, concentrations in birds appear to be approximately equivalent to or less than those found in omnivorous or insectivorous small mammals.

What if Data are not Available to Estimate Concentrations in Dietary Items?

For some contaminants and biota types (i.e., earthworms for antimony), data were not available to derive BAFs (as described in Attachment 4-1). For these contaminants, an assumption or default BAF of 1 was used. This assumption was supported by analyses of BAFs for plants, earthworms, and small mammals from Bechtel Jacobs (1998), Sample et al. (1998b), and Sample et al. (1998a), respectively (refer to Table 4.2). Approximately 90% of plant BAFs, 68% of earthworm BAFs and 83% of small mammal BAFs were less than one. Assuming BAFs for inorganic contaminants when data are absent generally over-estimate uptake and are, therefore, suitable for screening purposes only. A default BAF of 1 was also used for organic compounds.

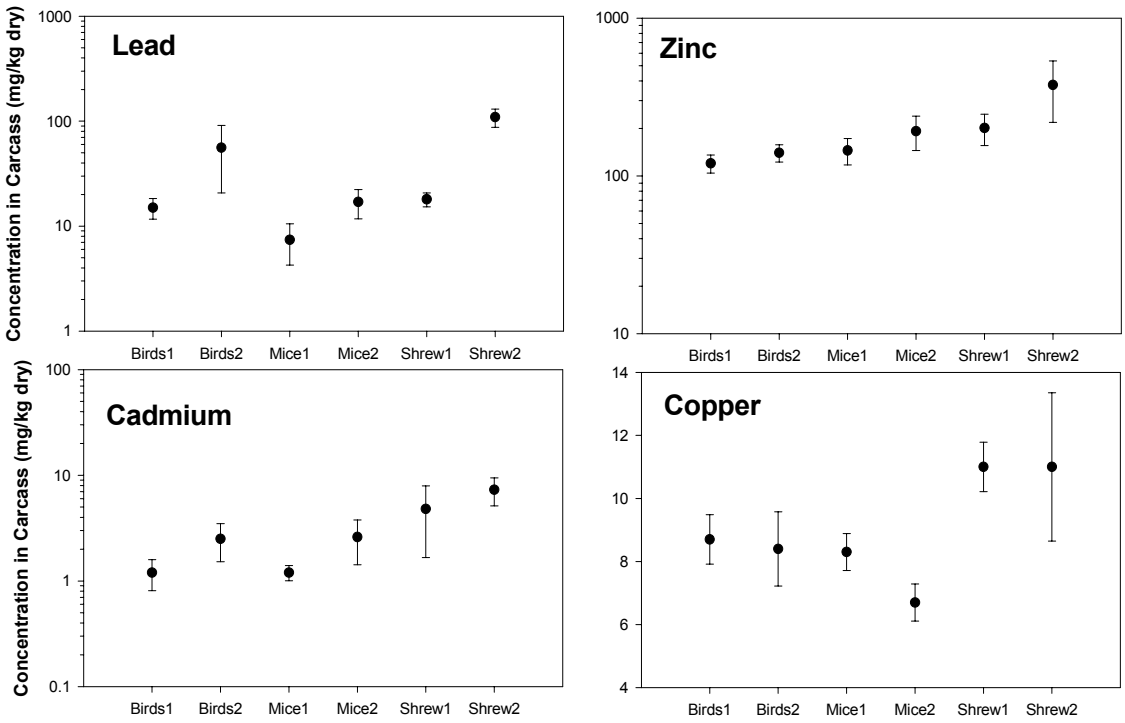


Figure 4.4 Comparison of Mean Concentrations in Multiple Species near a Smelter

Table 4.2 Cases where the Median of the BAF Distribution for Metals is Greater or Less than One			
Biota Type	**Total Number of Contaminants**	**BAFs < 1**	**BAFs > 1**
Plants	21	19	2
Earthworms	31	21	10
Small Mammals	24	20	4

4.4 Derivation of Toxicity Reference Values (TRVs)

The wildlife TRV is defined as:

> *Dose above which ecologically relevant effects might occur to wildlife species following chronic dietary exposure and below which it is reasonably expected that such effects will not occur.*

As presented in Figure 4.5, a four-step process was used to select TRVs appropriate for calculating wildlife Eco-SSLs. The four steps included: 1) conduct a literature search, 2) complete a review of the literature and extract data, 3) complete an evaluation of the extracted data and score data, and 4) derive a TRV.

Figure 4.5. Steps of the Wildlife TRV Derivation Process

The wildlife TRV derivation process is composed of four general steps that are documented as separate standard operating procedures (SOPs):

- **Literature Search and Retrieval**
  Wildlife TRV Literature Search and Retrieval (Attachment 4-2). A literature search identifies dose-response literature for retrieval.
- **Literature Review and Data Extraction**
  Wildlife TRV Literature Review, Data Extraction and Coding (Attachment 4-3). The retrieved literature studies are reviewed and data are extracted according to an established coding system. Data are entered into an electronic data base.
- **Data Evaluation**
  Wildlife TRV Data Evaluation (Attachment 4-4). Each of the results identified in the reviewed literature is scored for quality and applicability for TRV derivation.
- **TRV Derivation**
  Wildlife TRV Derivation (Attachment 4-5). This procedure plots the collective dose-response information and establishes the process for estimating the TRV.

Literature Search and Retrieval

The first step in deriving the TRVs was to conduct a literature search to identify toxicological studies for mammals and birds for retrieval and review. The search procedure was described in detail in Attachment 4-2. EPA completed a literature search for 23 of the Eco-SSL contaminants (PCBs were excluded). The search process identified over 44,000 records for review. The literature search process was documented in sufficient detail that others may use it to identify relevant data for additional contaminants not completed by EPA.

Literature Review and Data Extraction

The toxicological literature identified from the literature search was next reviewed for usefulness in establishing wildlife TRVs. Literature exclusion criteria (similar to those discussed in Chapter 3 for plants and soil invertebrates) and listed in detail in Attachment 4-3 were applied to the identified literature. Additional types of studies excluded specifically for wildlife included those that only report genotoxic, mutagenic, or carcinogenic effects, acute or non-oral exposures (inhalation, injection, dermal, etc.), or studies unrelated to the contaminant and receptor groups of interest. Where possible, the literature exclusion criteria were applied to identified titles and abstracts prior to retrieval of the paper. For retrieved studies that passed the literature exclusion criteria, the

relevant toxicological data were extracted and entered into an electronic database according to established extraction and coding procedures detailed as Attachment 4-3. These extraction and coding procedures were consistent with EPA's EcoTox database (USEPA, 2003).

The primary purpose of the data extraction process was to identify two values associated with each study result:

- A no-observed adverse effect level (NOAEL), which is the highest dose that does not cause a statistically significant adverse effect; and
- A lowest-observed adverse effect level (LOAEL), which is the lowest dose that caused a statistically significant adverse effect.

In theory, the threshold for the particular adverse effect lies between the NOAEL and the LOAEL.

Data Evaluation

Each test result extracted during the literature review process was scored for quality and applicability for TRV derivation. The data evaluation process was provided as Attachment 4-4. In instances where more than one "experiment" (i.e., different combinations of test organism (species or strains), contaminant form, test location, control type, doses, application frequency, or route of exposure) were reported in a paper, the individual "experiments" were scored separately. In cases of more than one experiment, the scoring system was applied independently to each experimental result. The scoring system was based on the evaluation of ten attributes of the toxicological study (Figure 4.6) assigning a score for each attribute, ranging from zero (no merit in setting a TRV) to 10 (extremely valuable and relevant to setting a TRV). Note that a low score does not necessarily imply the study itself is poor, only that the study design is not the most appropriate for deriving an oral TRV. The total score was calculated by adding the results of the evaluation of each attribute. The use of total

Figure 4.6 Ten Attributes Scored as Part of the Wildlife Toxicological Data Evaluation

1. **Data Source**
   Primary sources only considered.
2. **Dose Route**
   Dietary studies scored higher than gavage, capsule and liquid. Non oral exposures were excluded.
3. **Test Substance Concentrations**
   Studies with measured exposures scored higher than nominal exposures.
4. **Contaminant Form**
   Contaminant forms similar to soil forms scored higher compared to dissimilar forms.
5. **Dose Quantification**
   Exposures reported as doses scored higher than those reported as concentrations.
6. **Endpoint**
   Reproductive effects scored higher than lethality and growth. Physiology, behavioral, biochemical and pathology changes were scored lower and biomarkers scored lowest.
7. **Dose Range**
   Studies with both NOAEL and LOAEL values scored higher than studies which reported only one value. Narrower ranges between NOAEL and LOAEL scored higher.
8. **Statistical Power**
   The statistical power of a NOAEL was scored.
9. **Exposure Duration**
   Exposure durations encompassing multiple generations and critical life stages scored higher than chronic, subchronic, and acute.
10. **Test Conditions**
    Studies that reported standard exposure conditions scored higher then those that reported fewer or none.

Data Evaluation Score was interpreted as follows:

80 to 100	High confidence
71 to 79	Medium confidence
66 to 70	Low confidence
0 to 65	Not used in Eco-SSL derivation

A web-based data entry system and database was created by EPA as a tool to facilitate efficient, accurate, and consistent data extraction from individual reviewed toxicological studies as well as data evaluation scoring. Extraction of the data directly into an electronic database facilitated necessary sorting, searching, and presentation of the data for the purposes of TRV derivation. The TRV database was focused on extracting the NOAEL and LOAEL doses from each of the toxicological studies.

TRV Derivation

The dose-response information for mammals and birds was plotted separately, and a TRV was derived for each class using an established procedure. The process used was documented in Attachment 4-5. The following general steps were completed to derive the TRVs:

Data Sorted. The toxicity data (effect doses) were downloaded from the database into spreadsheet files for each contaminant using a consistent tabular format. One table was constructed for avian data and a second for mammalian data. The tables provided the essential information concerning each of the toxicity testing results. Table 4.4 provides an example using the results for mammals and cobalt. The results were numbered sequentially and sorted by general effect group, then by effect measure.

Data Plotted. Summary plots were constructed depicting the NOAELs and LOAELs for each contaminant. Separate plots were completed for mammalian and avian data. The data plots (example provided as Figure 4.7) were organized by General Effect Group in order from left to right as: biochemical (BIO), behavior (BEH), physiology (PHY), pathology (PTH), reproduction (REP), growth (GRO), and mortality (MOR). Within each toxicological study there may be several effect measures reported that have the same NOAEL and/or LOAEL values. Inclusion of the NOAEL and LOAEL values for all endpoint measures would result in repetitive values on the plots. To avoid the inclusion of repetitive and duplicative data, the results for only one Effect Measure per Effect Group were recorded on the plots. For example, a study may report more the one adverse reproductive effect such as reduced progeny weight as well as progeny survival and reduced number of litters. In this case, only one effect was coded for the most conservative "worst case" result.

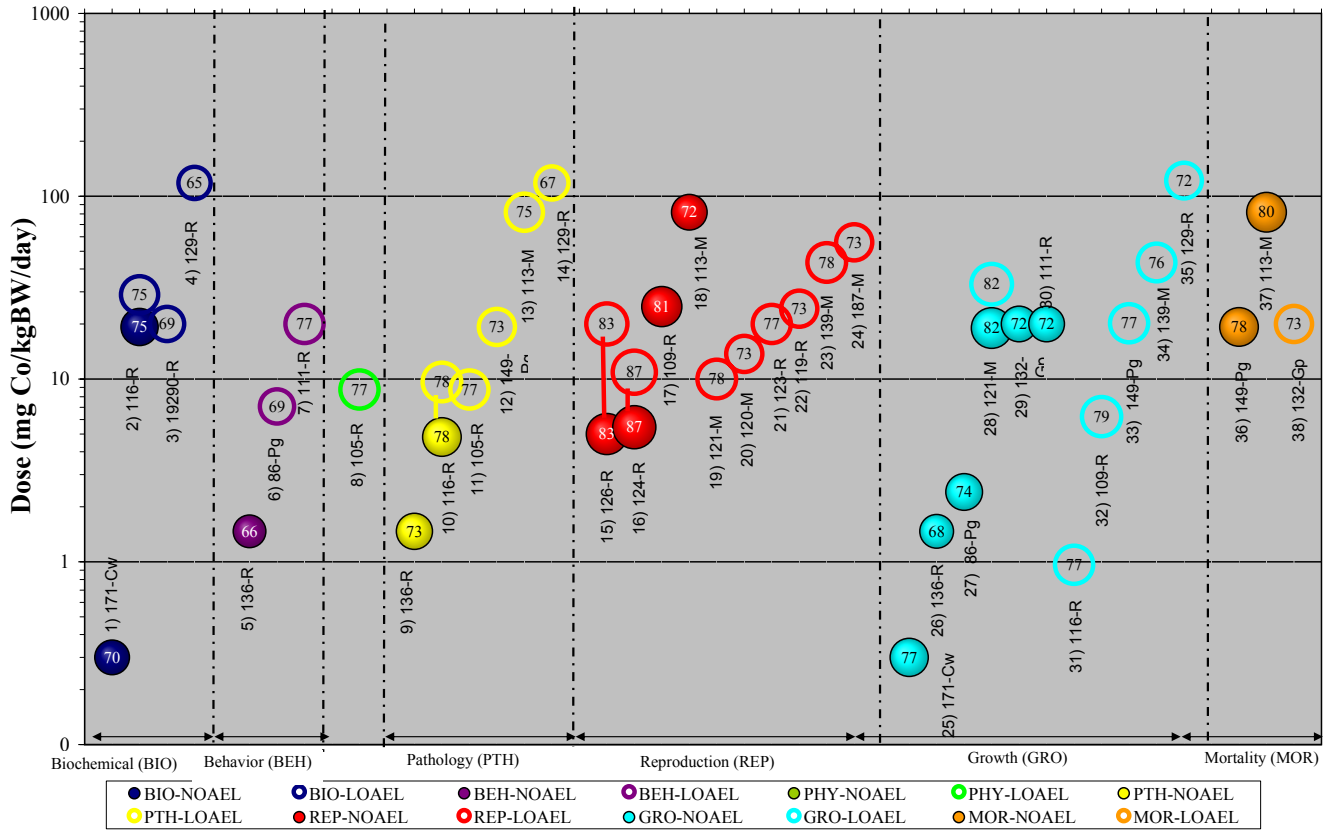
Exclusion of Data with Limited Utility in Establishing an Eco-SSL. Each NOAEL and LOAEL result was evaluated according to the Data Evaluation process (Attachment

Table 4.3. Example of Extracted and Sorted Data for Wildlife TRV Derivation (Cobalt)

Result #	Reference	Ref No.	Test Organism	# of Conc/ Doses	Method of Analyses	Route of Exposure	Exposure Duration	Duration Units	Age	Age Units	Lifestage	Sex	General Effect Group	Effect Measure	Response Site	NOAEL Dose (mg/kg/day)	LOAEL Dose (mg/kg/day)	Data Evaluation Score
Biochemical Effects																		
1	Maro et al., 1980	171	Cow (*Bos taurus*)	2	M	FD	45	d	7	mo	JV	F	BIO	HMGL	BL	0.30		70
2	Chetty et al., 1979	115	Rat (*Rattus norvegicus*)	6	U	FD	4	w	NR	NR	NR	B	BIO	HMGL	BL	19	29	75
3	Kadiiska et al., 1985	19290	Rat (*R. norvegicus*)	2	U	DR	30	d	NR	NR	JV	M	BIO	P450	LI		20	69
4	Derr et al., 1970	129	Rat (*R. norvegicus*)	2	U	DR	35	d	NR	NR	JV	M	BIO	HMCT	BL		118	65
Behavioral Effects																		
5	Gershbein et al., 1983	136	Rat (*R. norvegicus*)	2	U	FD	80	d	44	d	JV	M	BEH	NMVM	WO	1.5		66
6	Huck and Clawson, 1976	86	Pig (*Sus scrofa)*	4	U	FD	28	d	NR	NR	NR	NR	BEH	FCNS	WO		7.1	69
7	Bourg et al., 1985	111	Rat (*R. norvegicus*)	2	M	DR	57	d	80	d	JV	M	BEH	ACTP	WO		20	77
Physiology Effects																		
8	Haga et al., 1996	105	Rat (*R. norvegicus*)	2	U	FD	16	w	NR	NR	NR	M	PHY	Other	HE		8.8	77
Pathology Effects																		
9	Gershbein et al., 1983	136	Rat (*R. norvegicus*)	2	U	FD	80	d	44	d	JV	M	PTH	GHIS	NR	1.5		73
10	Chetty et al., 1979	116	Rat (*R. norvegicus*)	6	U	FD	4	w	NR	NR	NR	B	PTH	SMIX	TS	4.8	9.6	78
11	Haga et al., 1996	105	Rat (*R. norvegicus*)	2	U	FD	16	w	NR	NR	NR	M	PTH	BDWT	WO		8.8	77
12	Van Vleet et al., 1981	149	Pig (*S. scrofa)*	2	U	FD	10	w	NR	NR	JV	M	PTH	GLSN	HE		19	73
13	Seidenberg et al., 1986	113	Mouse (*Mus musculus*)	2	U	GV	5	d	NR	NR	GE	F	PTH	BDWT	WO		82	75
14	Derr et al., 1970	129	Rat (*R. norvegicus*)	2	U	DR	35	d	NR	NR	JV	M	PTH	SMIX	HE		118	67
Reproductive Effects																		
15	Nation et al., 1983	126	Rat (*R. norvegicus*)	3	U	FD	69	d	80	d	MA	M	REP	TEWT	TE	5.0	20	83
16	Domingo et al., 1985	124	Rat (*R. norvegicus*)	4	U	GV	28	d	NR	NR	MA	F	REP	PRWT	WO	5.4	11	87
17	Paternain et al., 1988	109	Rat (*R. norvegicus*)	4	U	GV	9	d	NR	NR	GE	F	REP	PRWT	WO	25		81
18	Seidenberg et al., 1986	113	Mouse (*M. musculus*)	2	U	GV	5	d	NR	NR	GE	F	REP	PROG	WO	82		72
19	Pedigo et al., 1988	121	Mouse (*M. musculus*)	4	U	DR	13	w	10	w	MA	B	REP	RSUC	WO		10	78
20	Anderson et al., 1992	120	Mouse (*M. musculus*)	2	U	DR	9	w	12	w	MA	M	REP	TEWT	TE		14	73
21	Corrier et al., 1985	123	Rat (*R. norvegicus*)	2	U	FD	70	d	100	d	SM	M	REP	TEDG	TE		20	77
22	Mollenhauer et al., 1985	119	Rat (*R. norvegicus*)	2	U	FD	98	d	100	d	MA	M	REP	TEWT	TE		24	73
23	Anderson et al., 1993	139	Mouse (*M. musculus*)	2	U	DR	13	w	12	w	MA	M	REP	TEWT	TE		43	78
24	Pedigo et al., 1993	187	Mouse (*M. musculus*)	2	U	DR	10	w	8 to 10	w	JV	M	REP	PRFM	WO		56	73
Growth Effects																		
25	Maro et al., 1980	171	Cow (*Bos taurus*)	2	M	FD	45	d	7	mo	JV	F	GRO	BDWT	WO	0.30		77
26	Gershbein et al., 1983	136	Rat (*R. norvegicus*)	2	U	FD	80	d	44	d	JV	M	GRO	BDWT	WO	1.5		68
27	Huck and Clawson, 1976	86	Pig (*S. scrofa)*	4	U	FD	16	w	NR	NR	NR	NR	GRO	BDWT	WO	2.4		74
28	Pedigo et al., 1988	121	Mouse (*M. musculus*)	4	U	DR	5	w	6 to 7	w	SM	M	GRO	BDWT	WO	19	33	82
29	Mohiuddin et al., 1970	132	Guinea pig (*Cavia porcellus*)	2	U	OR	5	w	NR	NR	MA	M	GRO	BDWT	WO	20		72
30	Bourg et al., 1985	111	Rat (*R. norvegicus*)	2	M	DR	57	d	80	d	JV	M	GRO	BDWT	WO	20		72
31	Chetty et al., 1979	116	Rat (*R. norvegicus*)	6	U	FD	4	w	NR	NR	NR	B	GRO	BDWT	WO		0.96	77
32	Paternain et al., 1988	109	Rat (*R. norvegicus*)	4	U	GV	9	d	NR	NR	GE	F	GRO	BDWT	WO		6.2	79
33	Van Vleet et al., 1981	149	Pig (*Sus scrofa)*	2	U	FD	5	w	NR	NR	JV	M	GRO	BDWT	WO		20	77
34	Anderson et al., 1993	139	Mouse (*M. musculus*)	2	U	DR	13	w	12	w	MA	M	GRO	BDWT	WO		43	76
35	Derr et al., 1970	129	Rat (*R. norvegicus*)	2	U	DR	24	d	NR	NR	JV	M	GRO	BDWT	WO		122	72
Mortality Data																		
36	Van Vleet et al., 1981	149	Pig (*S. scrofa)*	2	U	FD	10	w	NR	NR	JV	M	MOR	MORT	NR	19		78
37	Seidenberg et al., 1986	113	Mouse (*M. musculus*)	2	U	GV	5	d	NR	NR	GE	F	MOR	MORT	NR	82		80
38	Mohiuddin et al., 1970	132	Guinea pig (*Cavia porcellus*)	2	U	OR	5	w	NR	NR	MA	M	MOR	SURV	WO		20	73

ACTP = activity level; B = both; BIO = biochemical; BL = blood; d = days; BDWT = body weight changes; BEH = behavior; DR = Drinking water; F = female; FCNS = food consumption; FD = food; GE = gestation; GRO = growth; GLSN = gross lesions; GV = gavage; HE = heart; HMCT = hematocrit; HMGL = hemoglobin; JV = juvenile; LI = liver; MA = mature; M = male; M = measured; m = months; MOR = mortality, NMVM = number of movements; NR = Not reported; OR = other oral; PHY = physiology; PTH = pathology; PRFM = sexual performance; REP = reproduction; SM = sexually mature; SMIX = weight relative to body weight; SURV = survival; TE = testes; TEDG = testes degeneration; TEWT = testes weight; U = unmeasured; w = weeks; WO = whole organism

Figure 4.7 Example of a Toxicological Plot for the TRV Derivation Process (Cobalt)



Result number → **1) 10 - C**

Reference Number → 1) ; Test Species → C

Test Species Key

R = rat	Pg = pig
M = mouse	Gp = guinea pig
	Cw = cow

83 ← Lowest Observed Adverse Effect Dose

← Paired values from same study when joined by line

← No Observed Adverse Effect Dose

4-4) and scored within a range of 0 to 100 (worst to best) for usefulness in establishing an oral TRV. Data with limited utility were defined as study endpoints receiving a Total Data Evaluation Score of 65 or less. These data points were excluded from the plots. The purpose of the exclusion was to ensure that the TRV derivation used the most suitable data.

TRV Selected. The general steps and conditional statements of the derivation process are outlined in Figure 4.8. These steps are an a priori framework for selection of the TRV value based on the results of the toxicological plots. The flow chart (Figure 4.8) is used with the toxicity data plots to derive the TRV according to the described steps. The TRV is equal to the geometric mean of the NOAEL values for growth (GRO) and reproductive (REP) effects. In cases where the geometric mean NOAEL is higher than the lowest bounded LOAEL (bounded refers to a LOAEL that has a paired NOAEL) for either, GRO, REP or mortality (MOR), the TRV is equal to the highest bounded NOAEL below the lowest bounded LOAEL. An example is provided using the mammalian cobalt plot depicted as Figure 4.9.

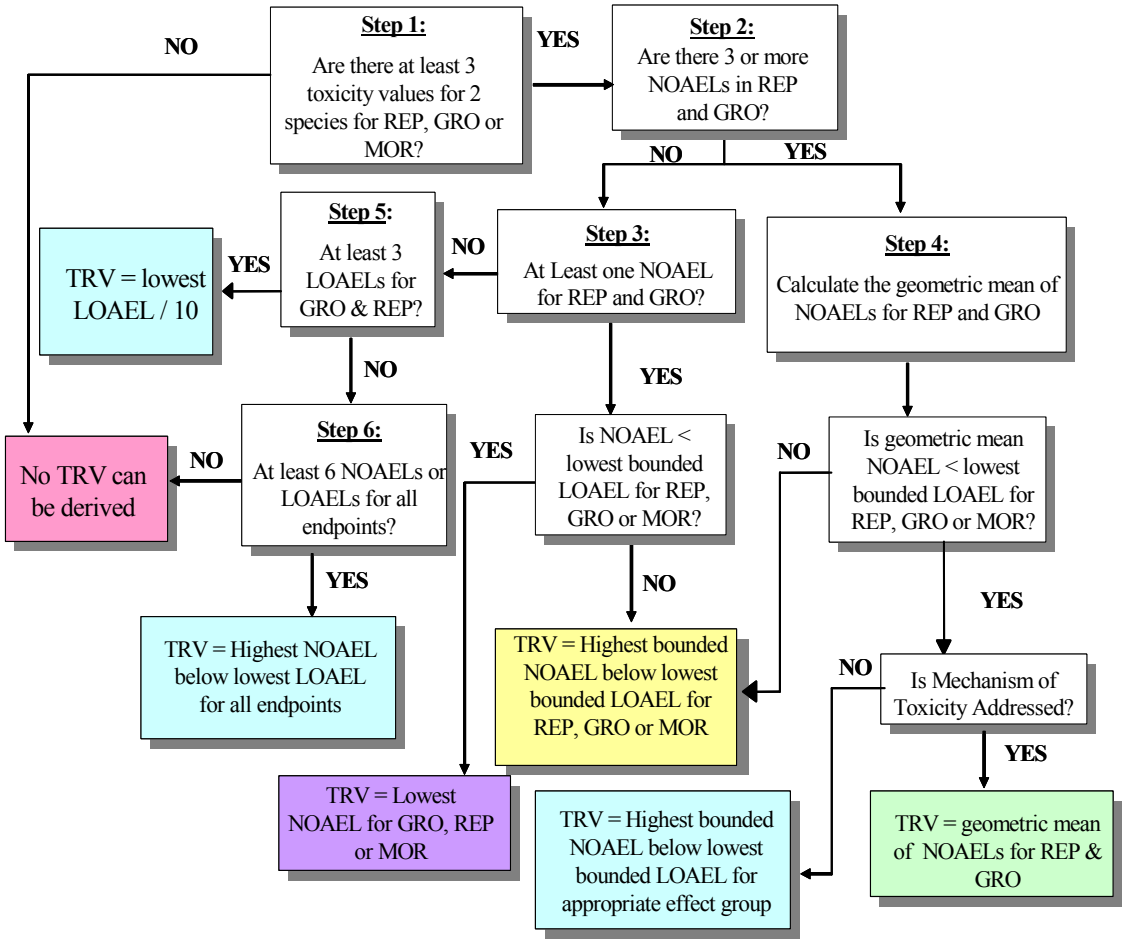
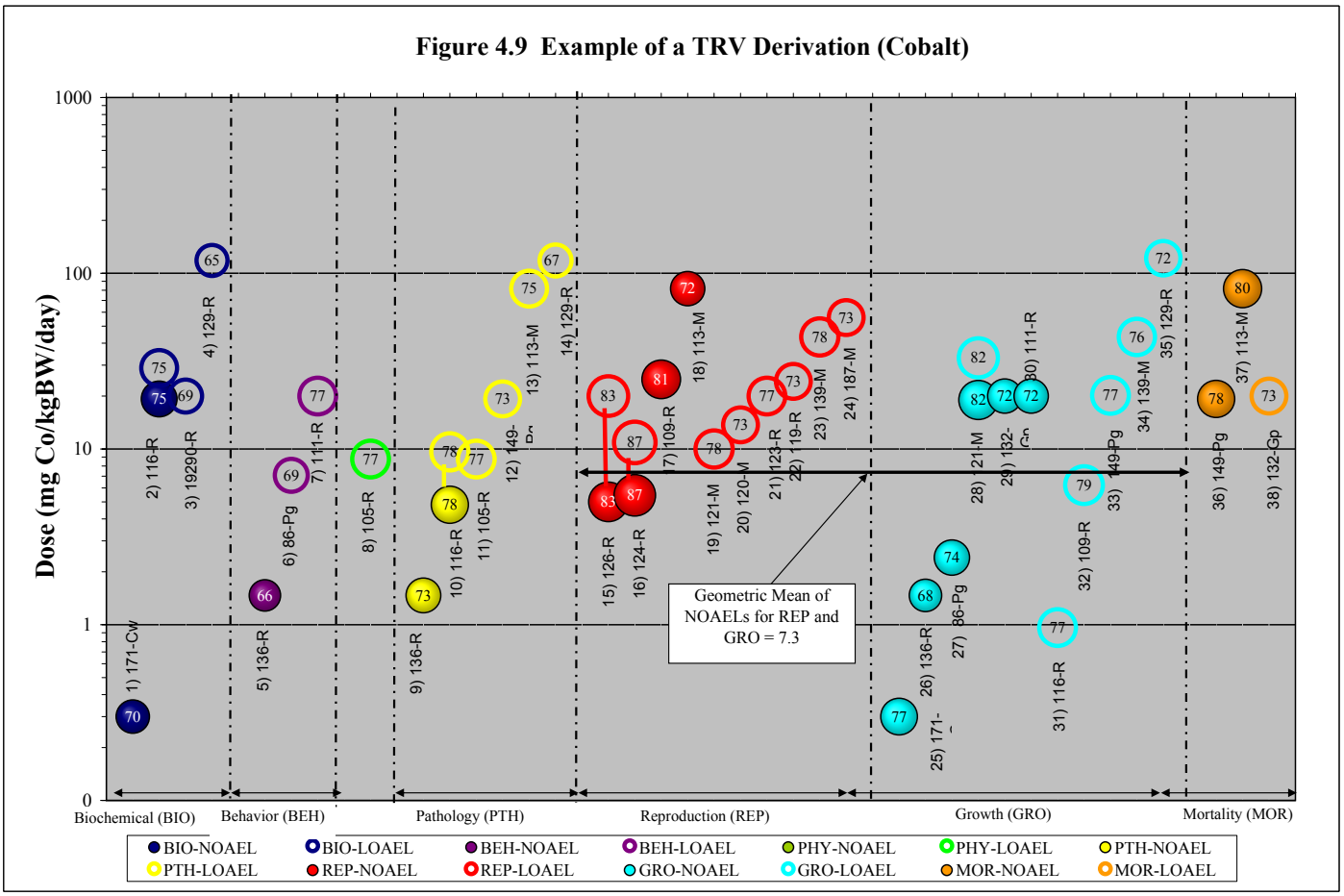


Figure 4.8 Procedure for Deriving the Wildlife Toxicity Reference Value (TRV)

Figure 4.9 Example of a TRV Derivation (Cobalt)



Result number → 1) 10 - C ← Test Species

Reference Number

Test Species Key

R = rat
M = mouse
Pg = pig
Gp = guinea pig
Cw = cow

83 — Lowest Observed Adverse Effect Dose

Paired values from same study when joined by line

No Observed Adverse Effect Dose

Wildlife TRV Derivation Process

1) There are at least three results available for two test species within the GRO, REP and MOR effect groups. There is enough data to derive TRV.

2) There are are at least three NOAEL results available for calculation of a geometric mean.

3) The geometric mean of the NOAEL values for GRO and REP equals 7.3 mg Co/kg BW/day.

4) The geometric mean NOAEL value is less than the lowest bounded LOAEL for REP, GRO or MOR.

5) The mammalian wildlife TRV for cobalt is equal to 7.3 mg Co/kg BW/day.

4.5 Calculation of Wildlife Eco-SSLs

Based on the assumptions described in Section 4.3, the Eco-SSL wildlife risk model (Equation 4-1) was reduced to the following after removal of the parameters set equal to 1:

$$HQ_j = \frac{[FIR * (Soil_j * P_s + B_{ij})]}{TRV_j} \qquad \textit{Equation 4-2}$$

where:

$Soil_j$	=	Concentration for contaminant (j) in soil (mg/kg [dry weight]),
FIR	=	Food ingestion rate (kg food [dry weight]/ kg bw [wet weight] / d),
P_s	=	Proportion of diet that is soil,
TRV_j	=	Toxicity reference value for contaminant (j) (mg [dry weight]/kg bw [wet weight] /d),
B_{ij}	=	Concentration of contaminant (j) in food type (i) mg/kg [dry weight].

As described previously, the concentration of contaminant (j) in biota or food type type (i) (B_{ij}) was related to the concentration in soil ($Soil_j$) by an uptake model which has one of the following forms:

Case 1) $B_{ij} = BAF_{ij} * Soil_j$ (constant)
Case 2) $\ln(B_{ij}) = I_{ij} + S_{ij} * \ln(Soil_j)$ (log-linear)
Case 3) $B_{ij} = I_{ij} + S_{ij} * Soil_j$ (linear)

where:

BAF_{ij}	=	Soil-to-biota Bioaccumulation factor (BAF) for contaminant (j) for biota type (i),
I_{ij}	=	Intercept from bioaccumulation model for contaminant (j) for food type (i)
S_{ij}	=	Slope from bioaccumulation model for contaminant (j) for food type (i)

In instances where it was necessary to estimate small mammal tissue concentrations (B_{ij}) based on dietary based BAFs or regressions, the uptake model may have one of the following forms:

Case 4) $B_{ij} = C_{diet} * BAF_{dm}$
Case 5) $\ln(B_{ij}) = I_{ij} + S_{ij} * \ln(C_{diet})$
Case 6) $B_{ij} = I_{ij} + S_{ij} * C_{diet}$

where:

B_{ij}	=	Concentration of contaminant (j) in food type (i) (where i = small mammal)

C_{diet} = Concentration of contaminant (j) in diet where diet is 100% earthworms estimated as in Case 1, 2 or 3, above

BAF_{dm} = Diet-to-biota BAF for contaminant (j) in mammal or bird tissue

The general procedure for calculating the wildlife Eco-SSL for a contaminant (j) was to solve Equation 4-2 to determine the concentration in soil ($Soil_j$) equivalent to an HQ_j equal to 1. In most cases, solution of Equation 4-2 was accomplished by use of a computer spreadsheet program.

In cases where B_{ij} was estimated using a simple BAF from soil to food type, Equation 4-2 was rearranged resulting in the following simplified equation:

$$Eco-SSL = Soil_j = \frac{TRV_j}{FIR * [P_s + BAF_{ij}]} \qquad \textit{(Equation 4-3)}$$

Conservatism of Model Parameterization

The purpose of the Eco-SSLs is to identify concentrations of contaminants in soil that may present a risk from those concentrations that clearly do not. As a screening tool, the Eco-SSLs should be conservative, but not so much so that no concentrations pass the screen. To this end, the wildlife Eco-SSL model was parameterized using a combination of conservatively skewed and non-conservatively skewed parameter values. The level of conservatism associated with the model parameter values is summarized in Table 4.4. Whereas the TRVs, food and soil ingestion rates, diet composition, area use, and bioavailability were all conservatively skewed, all bioaccumulation values were based on central tendency estimates.

Table 4.4 Summary of Conservatism Associated with the Wildlife Eco-SSL Risk Model Parameters.			
Parameter	**Value selected for use in calculation of Eco-SSL**	**Conservatism of Value**	**Rationale**
Toxicity Reference Value (TRV)	the geometric mean of NOAELs for REP or GRO or the highest bounded NOAEL below the lowest bounded LOAEL for REP, GRO or MOR	moderate	Represents highest dose that did not cause any adverse effects in any test species
Food Ingestion Rate (FIR)	90th percentile	high	Conservatively-skewed value selected to represent majority of individuals within population without being over protective.
Soil Ingestion as Fraction of Diet (P_s)	90th percentile	high	Conservatively-skewed value selected to represent majority of individuals within population without being over protective.
Soil to Biota Bioaccumulation Factor	median	neither conservative nor anti-conservative	Lowest uncertainty - not expected to over-predict concentrations
Diet to Biota Bioaccumulation Factor	median	neither conservative nor anti-conservative	Lowest uncertainty - not expected to over-predict concentrations
log-linear regression equations for bioaccumulation	value predicted by regression equation	neither conservative nor anti-conservative	Lowest uncertainty - not expected to over-predict concentrations
Diet composition (P_i)	100% plant, small mammal, or soil invertebrate (depending on trophic group)	high	Maximum pathway-specific exposure to allow screening of risks by pathway. Consistent with ERAGs (U.S. EPA 1997)
Area Use Factor (AUF)	100%	high	Consistent with ERAGs (U.S. EPA 1997)
Bioavailability (AF_{ij}, AF_{sj})	Equivalent to that for the chemical form used to develop the TRV	high	Consistent with ERAGs (U.S. EPA 1997)

5.0 ECO-SSL DOCUMENTS

Presented in this chapter is a description of the format and content of the Eco-SSL documents which report the results of the Eco-SSL derivation procedures as described in the previous chapters. Each document is structured with the following standard sections. However, the structure is not followed for iron and aluminum where the documents specifically review the chemistry, bioavailability, and toxicity in soils instead of providing numeric screening levels. EPA is continuing to evaluate existing toxicity studies (primarily for birds and mammals) and intends to issue additional Eco-SSL documents in the future. These documents will be posted on the afore mentioned website as they become available. The following subsections describe the basic components of each of the documents.

Introduction

The introduction to each contaminant summary provides a brief review of the contaminant including environmental forms, sources, background concentrations, mechanisms of toxicity, and essential elemental status if applicable. These summaries are intended to provide the reader with a general introduction only and do not represent an exhaustive review of the environmental fate and effects of the contaminant. It is recommended that the user of the Eco-SSL values review site-specific data concerning contaminant sources and possible fate and transport processes to evaluate as necessary the site-specific properties of the contaminant in soils. The general introductory material is based on a review of literature obtained during the search process for plants and soil invertebrates and wildlife. Some review material is based on information available from the Hazardous Substances Databank (HSDB), a database of the National Library of Medicine's TOXNET system (http://toxnet.nlm.nih.gov). Some Eco-SSLs for metals are within the range of reported background concentrations that may occur at sites without any contaminant release due to hazardous waste management activities. As part of the Eco-SSL project, available data for the background concentrations of metals are summarized in Table 2.3 (see Chapter 2) and Attachment 1-4.

Summary Table

This subsection of each document contains a summary table of the Eco-SSL values calculated for each receptor group expressed as mg contaminant per kg dw soil. If an Eco-SSL could not be calculated for a receptor group then “NC” is noted for not calculated. In some cases, the Eco-SSL is pending further review of toxicity information. In these cases, “pending” is noted. The Eco-SSL values are rounded to two significant digits.

Eco-SSL for Plants

This subsection describes the results of the derivation of an Eco-SSL value for terrestrial plants completed according to the procedures describe in Chapter 3 and appropriate Attachments.

Eco-SSL for Soil Invertebrates

This subsection describes the results of the derivation of an Eco-SSL value for soil invertebrates completed according to the procedures described in Chapter 3 and Attachments.

Eco-SSL for Avian Wildlife

This subsection describes the results of the derivation of an Eco-SSL value for avian wildlife. The subsection provides only the data used to derive the Eco-SSL according to the procedures described in Chapter 4 and Attachments. The results are provided as two parts.

- Toxicity Reference Value
- Estimation of Dose and Calculation of the Eco-SSL

Eco-SSL for Mammalian Wildlife

This subsection describes the results of the derivation of an Eco-SSL value for mammalian wildlife. The subsection provides only the data used to derive the Eco-SSL according to the procedures described in Chapter 4 and Attachments. The results are provided as two parts.

- Toxicity Reference Value
- Estimation of Dose and Calculation of the Eco-SSL.

References

The references are provided as the last subsection of each document. The references are segregated by receptor with separate lists for plants and soil invertebrates and wildlife. The references for each receptor are further segregated into two lists. The first list provides the papers used to derive the Eco-SSL and the second list provides the papers that were rejected for use. For each of the papers rejected the reason for the rejection is listed.

Appendices

A complete tabulation of the toxicity data used to derive the wildlife toxicity reference values (TRVs) is provided as an appendix.

6.0 REFERENCES

Abou-Donia, M.B. and D. G. Graham. 1978. Delayed neurotoxicity from long term low-level topical administration of Leptophos to the comb of hens. *Toxicology and Applied Pharmacology.* 46: 199-213.

Alexander, M. 1995. How toxic are toxic chemicals in soil? *Environ. Sci. Technol.* 29: 2713-2717.

Allen, H., S. McGrath, M. McLaughlin, W. Peijnenburg, and S. Suave. 1999. *Bioavailability of Metals in Terrestrial Ecosystems.* Draft Document.

Anderson, W.C., R. C. Loehr, and B. P. Smith. 1999. *Environmental Availability of Chlorinated Organics, Explosives, and Heavy Metals in Soils.* American Academy of Environmental Engineers.

Anderson, M. B., Lepak, K., Farinas, V., and George, W. J. 1993. Protective action of zinc against cobalt-induced testicular damage inthe mouse. *Reprod. Toxicol*. 7(1): 49-54.

Anderson, M. B., Pedigo, N. G., Katz, R. P., and George, W. J. 1992. Histopathology of testes from mice chronically treated with cobalt. *Reprod. Toxicol*. 6(1): 41-50.

Barber, S.A. 1995. *Nutrient Bioavailability - A Mechanistic Approach.* John Wiley and Sons.

Barnhart, J. 1997. Chromium Chemistry and Implications for Environmental Fate and Toxicity. 1997. *Journal of Soil Contamination*. 6(6): 561-568.

Betchel-Jacobs. 1998. *Empirical Models for the Uptake of Inorganic Chemicals from Soil by Plants.* Oak Ridge National Laboratory BJC/OR-133. Bechtel Jacobs Company L.L.C.

Beyer, W. N., O. H. Pattee, L. Siteo, D. J. Hoffman, and B. M. Mulhern. 1985. Metal contamination in wildlife living near two zinc smelters. *Environ. Poll. Series A.* 38(1): 63-86.

Bohn, H., B. McNeal, and G. O'Connor. 1985. *Soil Chemistry.* 2nd ed. John Wiley and Sons.

Bourg, W. J., Nation, J. R., and Clark, D. E. 1985. The effects of chronic cobalt exposure on passive-avoidance performance in the adult rat. *Bull. Psychon. Soc.* 3(6): 527-530.

Canadian Council of Ministers of the Environment (CCME). 1997. *Recommended Canadian Soil Quality Guidelines.* March 1997.

Chetty, K. N., Subba, R. A. O. D SV, Drummond, L., and Desaiah, D. 1979. Cobalt-induced *changes in immune response and atpase activities in rats. J Environ. Sci. Health Part B*

Pestic. Food. Contam. Agric. Wastes. 14(5): 525-544.

Corrier, D. E., Mollenhauer, H. H., Clark, D. E., Hare, M. F., and Elissalde, M. H. 1985. Testicular degeneration and necrosis induced by dietary cobalt. *Vet Pathol*. 22(6): 610-6.

Cullen, A.C. and H.C. Frey. 1999. *Probabilistic Techniques in Exposure Assessment. A Handbook for Dealing with Variability and Uncertainty in Models and Inputs.* New York: Plenum Press.

Derr, R. F., Aaker, H., Alexander, C. S., and Nagasawa, H. T. 1970. Synergism between cobalt and ethanol on rat growth rate. *J. Nutr*. 100(5): 521-524.

Domingo, J. L., Paternain, J. L., Llobet, J. M., and Corbella, J. 1985. Effects of cobalt on postnatal development and late gestation in rats upon oral administration. *Rev Esp Fisiol.*

Driver, C.J., M. W. Ligotke, P. V. Van Voris, B. D. McVeety, and B. J. Greenspan. 1991. Routes of uptake and their relative contribution to the toxicologic response of northern bobwhite (*Colinus virginianus*) to an organophosphate pesticide. *Environ. Tox. and Chem.* 10: 21-33.

Efroymson, R. A., M. E. Will, and G. W. Suter II. 1997a. *Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil And Litter Invertebrates and Heterotrophic Process:* 1997 Revision. ES/ER/TM-126/R2. Prepared for the U.S. Department of Energy, Office of Environmental Management by Lockheed Martin Energy Systems, Inc. managing the activities at the Oak Ridge National Laboratory (ORNL).

Efroymson, R.A., M.E. Will, G. W. Suter II and A.C. Wooten. 1997b. *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants:* 1997 Revision. ES/ER/TM-85/R3. Prepared for the U.S. Department of Energy, Office of Environmental Management by Lockheed Martin Energy Systems, Inc. managing the activities at the Oak Ridge National Laboratory (ORNL).

Gershbein, L. L., Gershbein, J. D., and French, R. 1983. Behavior of male rats fed low levels of metallic salts. *Res Commun Chem Pathol Pharmacol. 39(3):507-510.*

Gertsl, Z. 1990. Estimation of Organic Chemical Sorption by Soils. *Journal of Contaminant Hydrology.* 6: 357-375.

Haga, Y., Clyne, N., Hatroi, N., Hoffman-Bang, C., Pehrsson, S. K., and Ryden, L. 1996. Impaired myocardial function following chronic cobalt exposure in an isolated rat heart model. *Trace Elements and Electrolytes*. 13(2): 69-74.

Hansen, B.G., A. B. Paya-Perez,, M. Rahman, and B. R. Larsen. 1999. QSARs for Kow and Koc of PCB congeners: a critical examination of data, assumptions, and statistical approaches. *Chemosphere* 39: 2209-2228.

Henderson, J. D., J. T. Yamamoto, D.M. Fry, J. N. Seiber, and B. W. Wilson. 1994. Oral and dermal toxicity of organophosphate pesticides in the domestic pigeon (*Columba livia*). *Bulletin of Environ. Contam. Toxicol*. 52: 633-640.

Huck, D. W. and Clawson, A. J. 1976. Excess dietary cobalt in pigs. *J Anim Sci*. 43(6): 1231-1246.

James, B.R., J.C. Petura, R.J. Vitale, and G.R. Mussoline. 1997. Oxidation-Reduction Chemistry of Chromium: Relevance to the Regulation and Remediation of Chromate-Contaminated Soils. *Journal of Soil Contamination*. 6(6): 569-580.

Jones, D.S., G. W. Suter, and R. N. Hull. 1997. *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Sediment-Associated Biota:* 1997 Revision. ES/ER/TM-95/R4. Prepared for the U.S. Department of Energy, Office of Environmental Management by Lockheed Martin Energy Systems, Inc. managing the activities at the Oak Ridge National Laboratory (ORNL).

Kuperman, R. G., Checkai, R. T., Phillips, C. T., and Simini, M. 2002. *Toxicity Assessments of Antimony, Barium, Beryllium, and Manganese for Development of Ecological Soil Screening Levels (Eco-SSL) Using Enchytraeid Reproduction Benchmark Values.* Rep.Doc.#ECBC-TR-XXX (Draft) , 81 p.

Lagrega, M. 1994. *Hazardous Waste Management.* McGraw-Hill, Inc.

Lee, L. S., P. S. C. Rao, P. Nkedi-Kizza, and J. J. Delfino. 1990. Influence of solvent and sorbent characteristics on distribution of pentachlorophenol in octanol-water and soil-water systems. *Environ. Sci. Tech.* 24: 654-661.

Lindsay, W. L. 1979. *Chemical Equilibria in Soils.* John Wiley & Sons, New York.

Linz, D. G. and D. V. Nakles. 1997. *Environmentally Acceptable Endpoints in Soil: Risk-Based Approach to Contaminated Site Management Based on Availability of Chemicals in Soil.* American Academy of Environmental Engineers. Annapolis, MD.

Loehr, R. C. and M. T. Webster. 1996. Effect of Treatment on Contaminant Availability, Mobility and Toxicity. Chapter 2. In: *Environmentally Acceptable Endpoints in Soils.* D. Linz, and D. Nakles (eds.), American Academy of Environmental Engineers. Annapolis, MD.

Lyman, W. J., W. F. Reehl, and D. H. Rosenblatt. 1990. *Handbook of Chemical Property Estimation Methods.* McGraw-Hill, New York.

McNab, B. K. 1963. Bioenergetics and the determination of home range size. *Am. Nat.* 97:133-140.

Maro, J. K., Kategile, J. A., and Hvidsten, H. 1980. Studies on copper and cobalt in dairy calves. *British Journal of Nutrition*. 44(1): 25-31.

Miller, R.W. and D. T. Gardiner. 1998. *Soil in Our Environment*, 8th edition, Prentice Hall, Upper Saddle River, NJ.

Mohiuddin, S. M., Taskar, P. K., Rheault, M., Roy, P. E., Chenard, J., and Morin, Y. 1970. Experimental cobalt cardiomyopathy. *Am Heart J.* 80(4): 532-543.

Mollenhauer, H. H., Corrier, D. E., Clark, D. E., Hare, M. F., and Elissalde, M. H. 1985. Effects of dietary cobalt on testicular structure *Virchow Arch* [Cell Pathol]. 49(3): 241-248.

Nagy, K. A., I. A. Girard, and T. K. Brown. 1999. Energetics of free-ranging mammals, reptiles, and birds. *Ann. Rev. Nutr.* 19: 247-277.

Nation, J. R., Bourgeois, A. E., Clark, D. E., and Hare, M. F. 1983. The effects of chronic cobalt exposure on behavior and metallothionein levels in the adult rat. *Neurobehav Toxicol Teratol*. 5(1): 9-15.

Paternain, J. L., Domingo, J. L., and Corbella, J. 1988. Developmental toxicity of cobalt in the rat. *J. Toxicol. Environm. Health*. 24(2):193-200.

Pedigo, N. G. and Vernon, M. W. 1993. Embryonic losses after 10-week administration of cobalt to male mice. *Reprod. Toxicol.* 7: 111-116.

Pedigo, N. G., George, W. J., and Anderson, M. B. 1988. Effects of acute and chronic exposure to cobalt on male reproduction in mice. *Reprod Toxicol* . 2(1): 45-53.

Pignatello, J. J. 2000. The measurement and interpretation of sorption and desorption rates for organic compounds in soil media. In: *Advances in Agronomy*, Vol. 69, Academic Press, San Diego, CA.

Phillips, C. T., Checkai, R. T., Kuperman, R. G., and Simini, M. 2002. *Toxicity Assessment of Antimony, Barium, Beryllium, and Manganese for Development of Ecological Soil Screening Levels (Eco-SSL) Using Folsomia Reproduction Benchmark Values*. Rep.Doc.#ECBC-TR-XXX (Draft) , 98 p.

Rijksinstituut Voor Volksgezondheid en Milieu (RIVM). 1997a. National Institute of Public Health and Environment. *Maximum Permissible Concentrations and Negligible Concentrations for Pesticides*. T. Crommentuijn, D.F. Kalf, M.D. Polder, R. Posthumus and E.J. van de Plassche. October, 1997.

Rijksinstituut Voor Volksgezondheid en Milieu (RIVM). 1997b National Institute of Public Health and Environment. *Maximum Permissible Concentrations and Negligible Concentrations for Metals.* T. Crommentuijn, D.F. Kalf, M.D. Polder, R. Posthumus and E.J. van de Plassche.

Sample, B. E., J. J. Beauchamp, R. Efroymson, and G. W. Suter, II. 1999. Literature-derived bioaccumulation models for earthworms: development and validation. *Environmental Toxicology and Chemistry*. 18: 2110-2120.

Sample, B. E., D. M. Opresko, and G. W. Suter II. 1996. *Toxicological Benchmarks for Wildlife: 1996 Revision.* ES/ER/TM-86/R3. Prepared for the U.S. Department of Energy, Office of Environmental Management by Lockheed Martin Energy Systems, Inc. managing the activities at the Oak Ridge National Laboratory (ORNL).

Sample, B. E, J. J. Beauchamp, R. A. Efroymson, and G. W. Suter, II. 1998a. *Development and Validation of Bioaccumulation Models for Small Mammals.* Oak Ridge National Laboratory ES/ER/TM-219. Lockheed Martin Energy Systems Environmental Restoration Program.

Sample, B. E, J. J. Beauchamp, R. A. Efroymson, G. W. Suter, II and T.L. Ashwood. 1998b. *Development and Validation of Bioaccumulation Models for Earthworms.* Oak Ridge National Laboratory ES/ER/TM-220. Lockheed Martin Energy Systems Environmental Restoration Program.

Schwarzenbach, R. P., P.M. Gschwend, and D. M. Imboden. 1993. Environmental Organic Chemistry. In: *Methods of Soil Analysis, Part 2, Microbiological and Biochemical Properties,* 2nd Edition.. R. W. Weaver et al (eds.), Agronomy Monograph 9, Agronomy Science of America. Soil Science Society of America. Wiley-Interscience. Madison, WI. p. 63.

Seidenberg, J. M., Anderson, D. G., and Becker, R. A. 1986. Validation of an in vivo developmental toxicity screen in the mouse. *Teratog Carcinog Mutagen*. 6:361-374.

Sumner, M.E. (ed). 2000. *Handbook of Soil Science*. CRC Press, Boca, Raton. FL.

Syracuse Research Corp. (SRC). Physical Properties Database. http://esc.syrres.com/interkow /PhysProp.htm

United States Environmental Protection Agency (U.S. EPA). 2003. ECOTOX (ECOTOXicology) database http://www.epa.gov/ecotox/.

United States Environmental Protection Agency (U.S. EPA). 2002. *Role of Background in the CERCLA Cleanup Program*. U.S. EPA Office of Solid Waste and Emergency Response, Office of Emergency and Remedial Response, April 26, 2002. OSWER 9285.6-07P.

United States Environmental Protection Agency (U.S. EPA). 1999. *Ecological Risk Assessment and Risk Management Principles for Superfund Sites.* Office of Emergency and Remedial Response, Washington, DC. OSWER Directive 9285.7-28.P.

United States Environmental Protection Agency (U.S. EPA). 1998. *Guidelines for Ecological Risk Assessment.* Risk Assessment Forum. U.S. Environmental Protection Agency, Washington DC. EPA/630/R-95/002F. April. May 14, 1998 Federal Register 63(93): 26846-26924.

United States Environmental Protection Agency (U.S. EPA). 1997. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments.* Interim Final. U.S. Environmental Protection Agency, Environmental Response Team (Edison, NJ). June 5, 1997.

United States Environmental Protection Agency (U.S. EPA). 1996. *Soil Screening Guidance: Technical Background Document.* Office of Emergency and Remedial Response, Washington, D.C., EPA/540/R-95/128. May.

United States Environmental Protection Agency (U.S. EPA). 1995. *Internal Report on Summary of Measured, Calculated, and Recommended Log K_{ow} Values.* U.S. Environmental Protection Agency, Office of Water, Washington, D.C. 38 pp.

United States Environmental Protection Agency (U.S. EPA). 1993. *Wildlife Exposure Factors Handbook, Volumes 1 and II.* U.S. Environmental Protection Agency. EPA/600/R-93/187a and b.

Van Vleet, J. F., Boon, G. D., and Ferrans, V. J. 1981. Induction of lesions of selenium-vitamin E deficiency in weanling swine fed silver, cobalt, tellurium, zinc, cadmium, and vanadium. Am. J. *Vet. Res.* 42(5): 789-799.

Verschueren, K. 1996. *Handbook of Environmental Data on Organic Chemicals.* 3rd ed. Van Nostrand Reinhold, New York, NY, USA.

Weissmahr, K.W., S.B. Haderlein, and R.P. Schwarzenbach. 1998. Complex formation of soil minerals with nitroaromatic explosives and other pi-acceptors. *Soil Science Society of America Journal.* 62: 369-378.

Weissmahr, K.W., M. Hildenbrand, R. P. Schwarzenbach, and S. B.Haderlein. 1999. Laboratory and Field Scale Evaluation of Geochemical Controls on Groundwater Transport of Nitroaromatic Ammunition Residues. *Environ. Sci. Technol.* 33 (15): 2593 –2600.

Witschi, H.R., and J.A. Last. 1996. Toxic responses of the respiratory system. In: *Casarett and Doull's Toxicology,* 5th Edition, pp 443-462. C.D. Klaassen (ed.), McGraw-Hill, New York.