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Ecological Soil Screening Level Guidance

DRAFT

Eco-SSL
Ecological Soil Screening Levels

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LIST OF ACRONYMS AND ABBREVIATIONS

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
BMD	Benchmark dose
BTAG	Biological Technical Assistance Group
BW	Body weight
CCME	Canadian Council of Ministers of the Environment
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLP	Contract Laboratory Program
COPC	Contaminant of Potential Concern
CSEM	Conceptual Soil Exposure Model
CSM	Conceptual Site Model
DDT	1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane
DQO	Data Quality Objective
DW	Dry weight
EA	Exposure area
Eco-SSL	Ecological Soil Screening Level
EPA	U.S. Environmental Protection Agency
EPC	Exposure Point Concentration
ERA	Ecological Risk Assessment
ERAGS	Ecological Risk Assessment Guidance for Superfund
FIR	Food ingestion rate
HQ	Hazard Quotient
HQ_j	Hazard Quotient for contaminant (j)
IR_{soil}	Soil ingestion rate
kg	kilograms
LOEC	Lowest-Observed Effect Concentration
LOAEL	Lowest-Observed Adverse Effect Level
mg	milligrams
NOAEL	No-Observed Adverse Effect Level
NOEC	No-Observed Effect Concentration
NPL	National Priorities List
OERR	Office of Emergency and Remedial Response

OM	Organic Matter
ORNL	Oak Ridge National Laboratory
OSWER	Office of Solid Waste and Emergency Response
P_i	Proportion of biota type (i) in diet
P_s	Soil ingestion as proportion of diet
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RIVM	Dutch National Institute of Public Health and the Environment
RME	Reasonable Maximum Exposure
ROD	Record of Decision
SAB	Science Advisory Board
SAP	Sampling and Analysis Plan
SMDP	Scientific Management Decision Point
SOP	Standard operating procedure
SSL	Soil screening level
T_{ij}	Soil-to-biota bioaccumulation factor for contaminant (j) for biota type (i)
TNT	Trinitrotoluene
TRV	Toxicity Reference Value
VOC	Volatile organic compound

1.0 INTRODUCTION

This guidance provides a set of risk-based soil screening levels (Eco-SSLs) for many of the soil contaminants that are frequently of ecological concern for terrestrial plants and animals at hazardous waste sites. It also describes the process used to derive these levels and provides guidance for their use. The Eco-SSL derivation process represents the collaborative 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 Emergency and Remedial Response (OERR). 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). **The Eco-SSLs are not designed to be used as cleanup levels and EPA emphasizes that it would be inappropriate to adopt or modify these Eco-SSLs as national cleanup standards.**

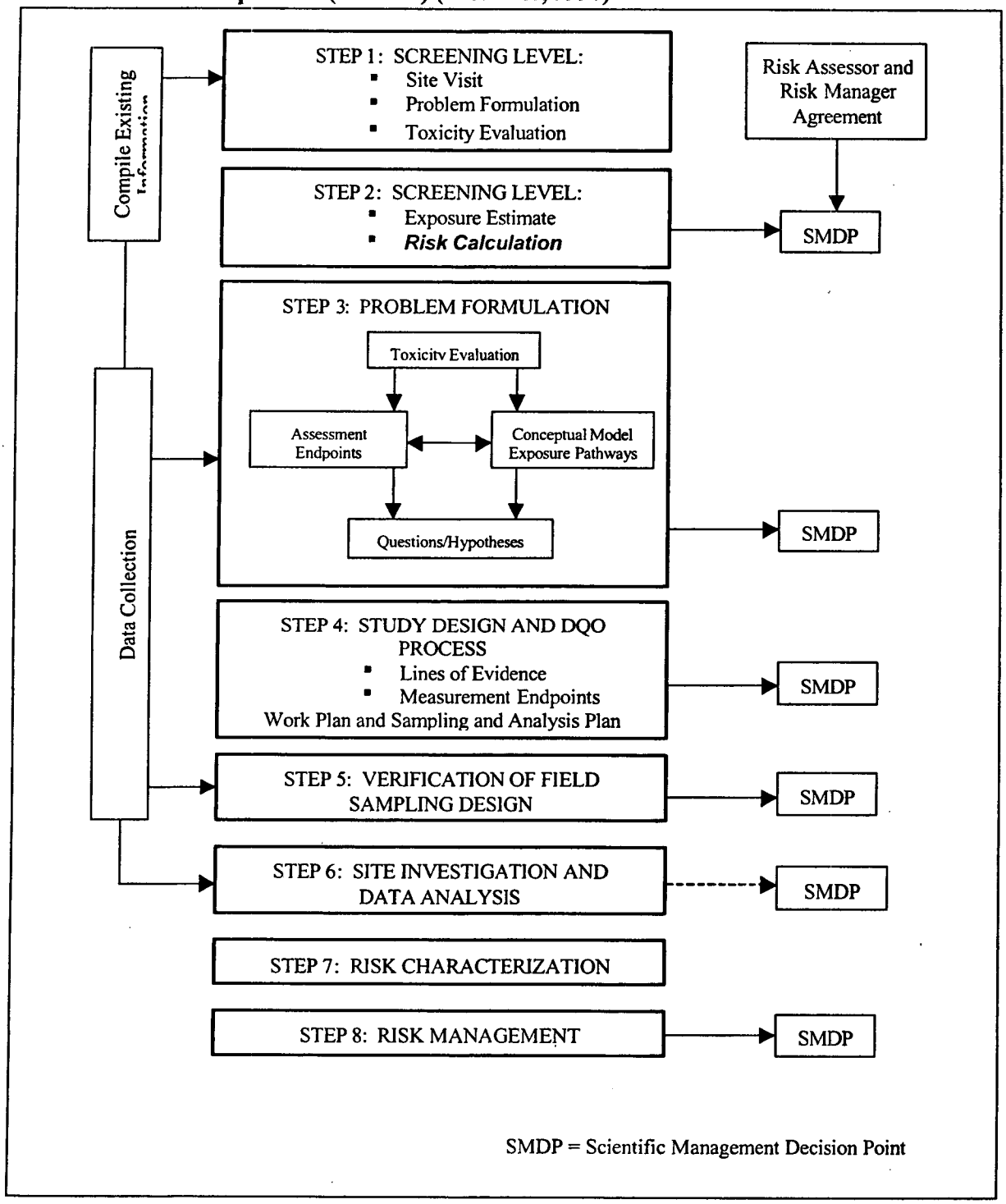
This document provides guidance and is designed to communicate national policy on identifying contaminants in soil that may present an unacceptable ecological risk to terrestrial receptors. The document does not, however, substitute for EPA's statutes or regulations, nor is it a regulation itself. Thus, 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 may change this guidance in the future, as appropriate.

What are Eco-SSLs?

Eco-SSLs are concentrations of contaminants in soils 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. As such, these values are presumed to provide adequate protection of terrestrial ecosystems.

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 is written with the assumption that the reader is familiar with Superfund's guidance on performing ERAs (ERAGS, U.S. EPA, 1997, Figure 1.1) and with the EPA risk assessment guidelines (U.S.EPA, 1998).

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



The Eco-SSLs presented here 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 recognizes that for many soil types and conditions, the Eco-SSLs may be conservative, but none the less, provide an appropriate balance of protectiveness and reasonableness.

Why are Eco-SSLs Needed?

EPA derived the Eco-SSLs in order to conserve resources by eliminating 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 will also 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 stakeholder workgroup examined currently available soil screening guidelines (see text box) for their use within the Superfund process. Because these existing guidelines were developed in response to country-specific legislation and policies not totally consistent with current EPA policies, EPA chose not to adopt any established set of values. A summary and evaluation of the available guidelines is available from the Eco-SSL Web Site [http://www.epa.gov/oerrpage/superfund/programs/risk/ecossl] as Exhibit 1-1.

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, 1997a).

The Dutch National Institute of Public Health and the Environment (RIVM). Maximum permissible concentrations (MPCs), maximum permissable 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).

How Were the Eco-SSLs Derived?

Eco-SSLs were derived by the work groups 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 4.0. The wildlife Eco-SSLs are 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 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 (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 includes contaminants nominated by the EPA regional Biological Technical Assistance Groups (BTAGs). The list of 24 Eco-SSL contaminants contains 17 metals and seven organics (see Figure 1.2).

The omission of other contaminants, such as phthalates and cyanides, does not imply that all 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

Figure 1.2. Eco-SSL Contaminants

Organics

- Dieldrin
- Total Polychlorinated Biphenyls (PCBs)
- Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)
- Trinitrotoluene (TNT)
- 1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane (DDT)
- Pentachlorophenol (PCP)
- Polycyclic Aromatic Hydrocarbons (PAHs)

Metals

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

in soil. **The process and procedures established for the Eco-SSLs are intended to be sufficiently transparent to derive Eco-SSL values for additional contaminants, as needed.**

Ecological Receptors of Concern

The Eco-SSLs apply only 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, terrestrial plants and soil microbial processes. After investigation, the toxicity data for amphibians and reptiles were deemed insufficient to derive Eco-SSLs. Eco-SSLs protective of soil microbial processes have not been derived here either. Like amphibians and reptiles, the agency recognizes their importance within terrestrial systems, but concurs with the workgroup recommendation that data are insufficient and the interpretation too uncertain for establishing risk-based thresholds in a regulatory context. While Eco-SSLs for microbial processes are not established at this time, they may be considered in the future as the science develops and appropriate studies are completed. Exhibit 1-2 provides the discussion concerning establishing Eco-SSLs for soil microbial processes.

Eco-SSLs were derived for four general groups of ecological receptors: mammals, birds, terrestrial plants and soil invertebrates. By deriving conservative soil screening values protective of these groups, it is assumed that the terrestrial ecosystem will be protected from possible adverse effects associated with soil contamination. This 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". If any of these conditions are missing, the pathway is considered to be incomplete. Exposure pathways can be classified as incomplete, complete, or potentially complete. An exposure pathway is not considered complete if habitat for ecological receptors is not present.

The Eco-SSLs for terrestrial plants consider direct contact of contaminants in soils under conditions of high bioavailability. The Eco-SSLs for soil invertebrates consider ingestion of soil and direct contact exposures also under conditions of high bioavailability.

The Eco-SSLs for birds and mammals consider 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. The exposure model for wildlife is fully described in Chapter 4. Two potentially complete exposure pathways (dermal contact and inhalation) were not considered in the derivation of wildlife Eco-SSLs for the 24 selected contaminants. The rationale for this decision is summarized in the following bullets:

- Burrowing animals could be exposed to relatively high concentrations of volatile organic compounds (VOCs) in their burrows via inhalation. With the exception of some of the PAHs, none of the Eco-SSL contaminants are VOCs and this exposure pathway was not considered. However, at sites with high VOC and/or certain PAH concentrations in soils with burrowing mammals present, the inhalation exposure pathway may need to be considered in the baseline ERA.

- Soil particles containing non-VOC contaminants (by either adsorption or absorption) could also be inhaled by wildlife. Respirable particles (>5 um) are, however, most likely ingested as a result of mucocilliary clearance rather than being inhaled (Witschi and Last, 1996). As discussed in Exhibit 1-3, 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.

- Birds and mammals may also be exposed to contaminants in soils via dermal contact. Studies investigating dermal exposures to birds resulting 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 1% to 11% of the total risk (Exhibit 1-3) compared to oral exposures.

This approach is consistent with Section 9.2.4 of ERAGS, 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 these Eco-SSLs does not preclude their inclusion in the site-specific baseline ERA. If it is expected that receptors may be more exposed to some contaminants 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.

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 Types for Which Eco-SSLs are Applicable

Eco-SSLs are applicable to all sites where key soil parameters fall within a certain range of chemical and physical parameters. The Eco-SSLs 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%.

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 broadly applicable (i.e., conservative enough for most soils) as preference was given to studies with high bioavailability of the chemicals 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. Site-specific considerations related to the presence of wetland soils and sediments are discussed in Chapter 7.

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

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

1.2 Peer Review Process

Two peer reviews were 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 which time members of the SAB provided verbal comments to several members of the Eco-SSL Steering Committee. 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. The results of this peer review are summarized in ----------, which is included as Exhibit 1-4.

2.0 SOIL PROPERTIES

2.1 Introduction

Soil properties influence the exposure of invertebrates, plants, and wildlife to contaminants in soils. Therefore, they are important to consider in the development of Eco-SSLs and to 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. The soil parameter 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 exposure to and accumulation of contaminants in plants and soil invertebrates. The absorption of contaminants bound to incidentally ingested soil particles in the animal gut, is influenced by other parameters including residence time as well as toxicokinetic and physiological factors that may affect the uptake of contaminants in wildlife.

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 insure that Eco-SSLs are adequately conservative for a broad range of soils, an effort was made to select studies that favored the bioavailability of the selected contaminants. To accomplish this, it was first necessary to develop a basic understanding of how various soil properties may influence bioavailability. Several authors have stressed the importance of physical and soil properties on the bioavailability of contaminants in soils and the influence they have on exposure (Linz and Nakles, 1997; Alexander, 1995; Loehr and Webster, 1996; Allen et al., 1999). The behavior and bioavailability of contaminants are greatly influenced by their interactions with soil constituents, such that not all contaminants are equally available to biota. However, relating soil chemistry parameters as important factors in estimating the availability of metals and organic contaminants in soil to soil biota and plant toxicity is not a straightforward process.

The accessibility or availability of contaminants depends on 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 associated with soil particulates, thus removed from solution, irrespective of mechanism is generally referred to as "sorption". The exception are precipitation reactions, which are often discussed independently from generic sorption processes. Contaminants are generally considered to be

bioavailable when they are released from interactions with the soil and soil constituents, thus released into the pore-water. The exception to this rule is the direct ingestion by terrestrial wildlife.

Identifying and quantifying soil factors that control the distribution of a contaminants in soil/water systems at equilibrium is 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, 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 may be classified into the following four groups (Table 2.1).

Table 2.1. General Contaminant Classification

Contaminant Class	EcoSSL 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	DDT and metabolites, dieldrin, PCBs, PAHs, TNT, and RDX
Ionizable Organics	PCP

Metals. As identified in Table 2.1, most of the 24 contaminants considered in the Eco-SSLs are metals that typically exist as cationic species (aluminum, antimony, barium, beryllium, cadmium, cobalt, copper, iron, lead, manganese, nickel, silver, and zinc). 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 dependent. 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 cationic species.

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 (Cr (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 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, its 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 domains, thus persistent in soil, and tend to bioaccumulate and biomagnify in the food chain. The structure and degree of chlorination of these contaminants and associated congeners for each directly impacts their behavior, persistence, and bioavailability (e.g., see citations in Hansen et al., 1999). Solubility decreases, sorption increases, and thus 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, polyaromatic hydrocarbons (PAHs) and explosives (TNT and RDX) are generally

considered less persistent and therefore, are 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 C and H. PAHs can be highly retained by soil in a similar manner as PCBs, but are considered less persistent due to their higher affinity to be degraded microbially. TNT and RDX, a trinitro aromatic and trinitro nitrogen-heterocylcic respectively, are explosive materials and are more polar than either 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 Koc values (e.g., Lyman, 1990; Gertsl, 1990). The greater the affinity of a contaminant for organic matter, the larger the Koc, and a soil with higher amounts of organic matter has a higher propensity to sorb NOCs. The hydrophobicity of organic compounds, thus the Koc, increases with the size of the compound and with increasing chlorine content, in the case of chlorinated organics. Therefore, sorption by soils of PAHs 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 have been shown 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 Kow 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 Kow	Source
RDX	121824	0.87	SRC
TNT	118967	1.6	SRC
DDT	50293	6.53	U.S. EPA (1996a)
DDD	72548	6.1	U.S. EPA (1996a)
DDE	72559	6.76	U.S. EPA (1996a)
Dieldrin	60571	5.37	U.S. EPA (1996a)
Pentachlorophenol (PCP)	87865	5.09	U.S. EPA (1996a)
PCBs		4.5 (1 chlorine) >8 (10 chlorines)	Verschueren (1996) Schwarzenbach (1993)
PAHs			
Naphthalene (2 rings)	91203	3.36	U.S. EPA (1996a)
Acenaphthene (3 rings)	83329	3.92	U.S. EPA (1996a)
Phenanthrene (3 rings)	85018	4.55	U.S. EPA (1995)
Anthracene (3 rings)	120127	4.55	U.S. EPA (1996a)
Chrysene (4 rings)	218019	5.7	U.S. EPA (1996a)
Benzo(a)anthracene (4 rings)	56553	5.7	U.S. EPA (1996a)
Benzo(a)pyrene (5 rings)	50328	6.11	U.S. EPA (1996a)
Dibenzo(ah)anthracene (5	53703	6.69	U.S. EPA (1996a)
Benzo(b)fluoranthene (5 rings)	92240	6.2	U.S. EPA (1996a)
Benzo(k)fluoranthene (5 rings)	207089	6.2	U.S. EPA (1996a)
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 the 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 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 mmol/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 sizeranges from: 20 microns to 2 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 contaminantsk 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, 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 paritition to the organic domain of 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 (foc), 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 the organic carbon-normalized partition coefficients (K_{oc}) for estimating contaminant sorption with the soil-specific distribution coefficient estimated by Koc multiplied by foc. 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 et al., 2000). Therefore, with increasing organic matter content, retention of an organic contaminant increases and rates of release decrease, thereby, decreasing overall contaminant bioavailability.

2.3 Using Soil Properties to Guide Eco-SSL Derivation

To simplify defining 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 plants and soil invertebrates work group evaluated the current literature, they observed that CEC and clay content were not consistently reported. Thus, these parameters were not used and 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 established within what are typically found in soils. Soils with

characteristics that fall outside the selected ranges were not initially considered. Although other soil factors can be significant (discussed in Chapter 7), combinations of these two soil parameters and their ranges are sufficient to be used in this screening process as a qualitative guide in addressing how most soils from across the United States may influence bioavailability of the various contaminants. Qualitative rankings of high, medium, and low availability are used to categorize each combination of the soil parameters and their ranges. For Eco-SSL derivation, information on bioavailability is used to help select and score studies to include in the derivation of the Eco-SSL values. Greater weight is given to those studies that have 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 2.3, 2.4, and 2.5 were developed 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 within pH values between 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 2.3, 2.4, and 2.5). For example, a soil with a pH between 5.5 - 7.0, and organic matter content between 2 and 6%, would bind metal cations to a moderate extent. Therefore, assigned an availability index of 'medium' for metal cations was assigned (see Table 2.3).

These tables simplify and facilitate the use of soil chemistry information in the derivation of soil screening levels at Superfund sites for plants and soil invertebrates. The ranges given in these tables were used in selecting the most appropriate plants and soil invertebrates toxicity data for deriving Eco-SSLs (Chapter 3). To address data gaps for individual contaminants, experiments are anticipated to be conducted, which meet a specific set of quality criteria (Chapter 3) and using soils with characteristics for which the contaminants would more likely be bioavailable. Recommended plant species and soil biota for testing purposes are put forward in Chapter 7.

The information presented in Tables 2.3 through 2.5 also provide insight into how Eco-SSLs may be modified on a site-specific basis, as well as on the properties that may need to be considered if a model of exposure is eventually developed. These topics are discussed in Chapter 7.

Table 2.3. Qualitative Bioavailability of Metal Cations in Natural Soils			
Soil Type	Soil pH		
	Low Organic Matter (< 2%)	Medium Organic Matter (2 - 6%)	High Organic Matter (6 - 10%)
4 < Soil pH #5.5	V. High	High	Medium
5.5 < Soil pH < 7	High	Medium	Low
7 # Soil pH #8.5	Medium	Low	V. Low

Table 2.4. Qualitative Bioavailability of Organic Contaminants for Natural Soils				
Soil Type	Log K_{ow}	Organic Matter (%)		
		<2	2-6	6-10
4 < Soil pH #5.5	Pesticides / PCBs (Log K_{ow} > 3.5)	High	Medium	Low
	Other Organics (Log K_{ow} < 3.5)	V. High	High	Medium
5.5 < Soil pH < 7	Pesticides /PCBs (Log K_{ow} > 3.5)	Medium	Low	Low
	Other Organics (Log K_{ow} < 3.5)	High	Medium	Low
7 # Soil pH # 8 .5	Pesticides / PCBs (Log K_{ow} > 3.5)	Low	Low	Low
	Other Organics (Log K_{ow} < 3.5)	Medium	Low	Low

Table 2.5. Qualitative Bioavailability of Anionic Species for Natural Soils			
Soil Type	Soil pH		
	Low Organic Matter (< 2%)	Medium Organic Matter (2 - 6%)	High Organic Matter (6 - 10%)
4 < Soil pH #5.5	Medium	High	V. High
5.5 < Soil pH < 7	Low	Medium	High
7 # Soil pH # 8.5	V. Low	Low	Medium

3.0 DERIVATION OF PLANT AND SOIL INVERTEBRATE ECO-SSLs

The development of Eco-SSLs for plants and soil invertebrates builds upon previous efforts (CCME, 1997; Efroymson et al., 1997 a,b) and establishes additional techniques to evaluate the literature and select appropriate data from published studies. For this purpose, three sets of literature review criteria were created and used to select studies with thorough experimental designs and quality control. The selection process begins with a thorough literature and retrieval effort based on key words, and "exclusion criteria". Retrieved papers are screened using ten "acceptance criteria" designed to identify studies having appropriate information and sufficient detail to facilitate inter-study comparisons. To be included in the data set for derivation of an Eco-SSL a study must meet all acceptance criteria. Acceptable papers are then scored according to nine technical "evaluation criteria". Data sets with total scores above a specific value are considered of sufficient quality to derive an Eco-SSL. Toxicity data from these studies are then ranked by both treatment effects (e.g., reproduction, growth, etc.) and toxicity parameter (e.g., NOEC, EC10, etc.), and assigned a preference level (A to D). The Eco-SSL is then derived from this set of data based on the chronic effects values rated at the highest preference level for which there is a sufficient number of data points. The process is completed with a quality assurance review to ensure the appropriateness and accuracy of the contaminant-specific Eco-SSL derivation.

The importance of physical and chemical soil parameters to contaminant bioavailability and ecotoxicity for plants and soil invertebrates is well known (Linz and Nakles, 1997; Loehr, 1996). In order to address contaminant bioavailability, the normalization of soil organism toxicity data using soil parameters has been put forward by several authors (van Gestel, 1992; van Straalen, 1993). Typically these techniques are contaminant-specific or have been shown to be appropriate for one group of organisms. Alternatively, the Eco-SSL effort used qualitative bioavailability values as an initial step to relate physical and chemical soil parameters to soil biota toxicity.

The Eco-SSL effort also examined soil invertebrate test methods for use when literature data gaps exist, and there is a need for data sufficient to derive an Eco-SSL. A review of the available toxicity test methods showed that several soil invertebrate toxicity tests, for which standardized protocols have been developed, can effectively be used to establish ecotoxicity data from which Eco-SSLs may be derived. The task group identified three such soil toxicity tests including: 1) a 21-day chronic earthworm reproduction (cocoon production) toxicity test, 2) the enchytraeid reproduction test, and 3) the collembolan reproduction test. These specific tests were selected on the basis of their ability to measure chemical toxicity to ecologically relevant test species during chronic assays, and their inclusion of at least one reproductive component among the measurement endpoints. The draft guidelines for these methods are in the final stages of review or approval by one of several national and international organizations, including the Organization for Economic Cooperation and Development (OECD), the International Standards Organization (ISO), the American Society for Testing and Materials (ASTM), the European Community (EC), and the Federal Biology Research Cooperative (FBRC). The selection of these methods is not considered an absolute guarantee for protection of all soil biological

resources, but rather an attempt to achieve a balance between the need to utilize different assays, each addressing a specific aspect of the soil invertebrate toxicity, and practical considerations dictated by the constraints of the ERA process. In the future, this test battery may include additional tests, as methods are refined and protocols become standardized and accepted by international organizations.

The strengths of the plant and soil invertebrate Eco-SSL process include the transparency of the methods used to review and select toxicity data, the use of ecologically-relevant endpoints, and the incorporation of qualitative soil contaminant bioavailability values. The use of acceptance and evaluation criteria minimizes variations due to individual expert judgement through clearly stated evaluation parameters and a quality assurance review of the data selected for use in deriving Eco-SSLs.

The process used to derive Eco-SSLs for plants and soil invertebrates follows five steps:

1. Identify and retrieve literature studies and apply Literature Exclusion Criteria to either the retrieved abstracts or study titles.

2. Identify acceptable data by applying Literature Acceptance Criteria to retrieved studies.

3. Score the accepted studies according to the Literature Evaluation Process.

4. Perform a Quality Control Review of the scored and accepted studies.

5. Calculate soil invertebrate and plant Eco-SSLs using data from the most appropriate studies.

These five steps were used to identify relevant published data of sufficient quality to be used to derive Eco-SSLs and to remove from consideration the data that does not meet the prescribed criteria for acceptance. Some studies reviewed may have been of high quality, yet were deemed not relevant or appropriate for the intended purposes of deriving screening levels for plants and soil invertebrates and therefore were excluded for use in deriving the Eco-SSL.

3.1 Literature Search, Acquisition and Acceptability

Literature Search and Acquisition (Step 1)

A literature search was conducted to identify all published studies that reported soil toxicity to terrestrial plants or soil invertebrates for any of the 24 contaminants. The protocol for the literature search and retrieval process, including the key words used for the search, is provided as Exhibit 3-1.

The literature search included both paper-based searches and online searches. The paper-based literature search process consisted of the manual review of bibliographies, guidance documents, review articles, and key journals held in the EPA Office of Research and Development, National Health and Ecological Effects Research Laboratory, Mid-Continent Ecology Division-Duluth (MED-Duluth) library holdings. This search was not limited by publication year. Online searches were completed using electronic databases. The search protocol included the use of DIALOG, SilverPlatter and Ovid commercial database vendors. The targeted databases included AGRICOLA, BIOSIS and Chem Abstracts. In addition, the searches were supplemented with literature abstracting databases including Toxline, PolTox1, Toxnet, and Current Contents: Agriculture, Biology & Environmental Sciences. Online searches were limited to studies published since 1988, except when fewer than 20 publications were identified for a contaminant-receptor pairing (e.g., cadmium-plants), then the online search was expanded to include all publication years.

The online and paper-based literature searches identified more than 7,200 papers. These publications' abstracts and titles were screened to determine if they were likely to meet the Eco-SSL requirements. This screening consisted of a review of titles and abstracts which focused on whether or not the publication addressed terrestrial plant and soil invertebrate species and Eco-SSL chemicals. A list of 23 Literature Exclusion Criteria (see Figure 3.1) was then used to screen out those studies not appropriate for

Figure 3.1. Literature Exclusion Criteria

Biological Product	Studies of biological toxins (venoms, etc.)
Chemical Methods	Studies on methods for determination of contaminants
Drug	Testing for drug effects
Effluent	Studies of effluent, sewage, polluted run-off
Contaminant Fate	Studies of what happens to the contaminant
Human Health	Studies with human or primate subjects
In Vitro	In Vitro studies, including cell cultures and excised tissues
Methods	Studies reporting methods but no usable specific toxicity tests
Mixture	Studies of combinations of contaminants
Modeling	Only modeling results reported
No Conc.	No dose or concentration reported
No Duration	No exposure duration reported
No Effect	No effect reported for a biological test species
No Species	No viable plant or organisms present or tested
No Toxicant	No toxicant used
No Tox Data	Toxicant used, but no results reported
Nutrient	Nutrient studies
Oil	Oil and petroleum products
Publ As	Author states information in report published in another source
QSAR	Data developed only from Quantitative-Structure Activity Relationships (QSAR)
Review	Data reported are not primary data
Sediment Conc.	Only exposure concentration of toxicant is reported as sediment concentration
Survey	Assessment of toxicity in the field over a period of time.

use in deriving Eco-SSLs. These Exclusion Criteria were applied to retrieved abstracts, or to the acquired literature if the needed information was not available in the abstract. Articles that appeared to be relevant were ordered. This process resulted in the acquisition of over 4,800 papers.

Literature Acceptance Criteria (Step 2)

Acquired publications were screened using 10 Literature Acceptance Criteria (see Figure 3.2) for potential acceptability. The purpose of applying the acceptance criteria was to assure relevancy of test data for the Eco-SSL effort and to ensure that the test data were of sufficient quality to use in deriving Eco-SSLs. Application of the acceptance criteria ensured that the minimum data requirements for derivation of Eco-SSLs were included in each publication. The Standard Operating Procedure (SOP) for using the Literature Acceptance Criteria is presented as part of Exhibit 3-1.

The acceptance criteria were applied to the retrieved literature studies and an Acceptance Criteria Checklist form (Exhibit 3-1) was completed. Publications that did not meet all 10 acceptance criteria were excluded from further consideration. Approximately 7% of the retrieved papers met all ten acceptance criteria. The completed checklists for all publications (acceptable and excluded studies) are maintained as part of the ECOTOX database.

Data from accepted studies were coded and entered into the terrestrial component (TERRETOX) of the ECOTOX database. ECOTOX was developed at MED-Duluth and is a comprehensive computer-based system that provides chemical-specific toxicity information for aquatic life, terrestrial plants, and terrestrial wildlife. Complete details about the TERRETOX coding process are provided in Exhibit 3-2.

Figure 3.2. Summary of Literature Acceptance Criteria

- The document is a primary source of literature.
- The adverse effects were caused by a single chemical stressor (i.e., no mixture studies).
- The contaminant form (i.e., metal salt used) and concentration are reported by the author(s).
- The test medium used in the study is a natural or artificial soil.
- The study reports the organic matter content and it is $\leq$ 10% of the composition of the soil.
- With exception of studies on non-ionizing substances, the study reports the pH of the soil, and the soil pH is within the range of $\geq$ 4.0 and $\leq$ 8.5.
- The study includes control treatment(s).
- The duration of the exposure is reported, or a standard study method is used with duration referenced.
- For studies conducted in a laboratory setting, at least three treatment levels are used (i.e., control + two contaminant exposure).
- Biological effects are reported for ecologically relevant endpoints (ERE) (listed in Exhibit 3-2).

3.2 Literature Evaluation (Step 3)

Each publication meeting all 10 acceptance criteria was reviewed and scored using the Literature Evaluation procedure summarized in Table 3.1 and presented in Appendix 3-1. The Literature Evaluation Procedure, which consisted of nine criteria, provided a standardized process for assessing the applicability of each published study for deriving Eco-SSLs for soil invertebrates and terrestrial plants. Scoring was completed for each of nine criteria using a three- point scale: 0, 1, or 2, with 2 indicating complete agreement with a criterion (Table 3.1).

For a given contaminant-receptor combination (e.g., copper-plants), those studies with a total evaluation score > 10, out of a possible score of 18, were identified for further consideration for use in deriving Eco-SSLs. In publications that reported results for more than one applicable study or experiment, each study was scored separately. In cases where more than one toxicity value was reported for a single study, only one value was selected for possible use in deriving the corresponding Eco-SSL. Guidelines for the selection of data for possible use in deriving the Eco-SSL are provided in Appendix 3-1.

Data from studies that scored >10 in the Literature Evaluation Process (Appendix 3-1) were grouped according to bioavailability score and toxicity parameter (see Table 3.2). This grouping into "levels" allowed for the preferential use of select data to derive Eco-SSLs ensuring that each Eco-SSL was derived from the highest quality and most appropriate data available.

3.3 Identification of Data for Derivation of Eco-SSLs

Following the literature evaluation process (Step 3), studies were segregated based on their total evaluation scores. Those studies that received a total score of 10 or less (out of the possible score of 18) were deemed of insufficient quality or otherwise inappropriate for use in deriving Eco-SSLs, while studies with a review score >10 were identified for further consideration for Eco-SSL derivation.

Those studies with total evaluation scores >10 were organized into four groups based on their respective toxicity parameters and bioavailability scores. The four groups or levels (identified in Table 3.2 as Level A, B, C or D) are prioritized from highest (Level A) to lowest (Level D) for preferential use in calculating Eco-SSLs.

Table 3.1 Summary of Literature Evaluation Process for Plant and Soil Invertebrate Eco-SSLs		
Criteria	**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 based on the bioavailability matrix (see Appendix 3-1). Score 2 if bioavailability of natural soil is high or very high. Score 1 for natural soil with medium bioavailability or standard artificial soil. Score 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.	Score 2 if in complete agreement with criterion. Score 1 if some but not all of the conditions for the criterion are met. Score 0 if it fails to meet the criterion.
#3: Concentration of Test Substance in Soil is Reported.	The concentration of the contaminant tested must be reported unambiguously.	Score 2 if measured concentrations were reported. Score 1 if nominal concentrations were reported. Score 0 in all other cases.
#4: Control Responses are Acceptable.	Negative controls are critical to distinguish treatment effects from non-treatment effects.	Score 2 if in complete agreement with criterion. Score 1 if control results were not reported or ambiguous. Score 0 if it fails to meet the criterion.
#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.	Score 2 if chronic exposures were used. Score 1 if acute tests were used. Score 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 2 if in complete agreement with criterion. Score 1 if some, but not al of the conditions for the criterion were met. Score 0 if it fails to meet the criterion.
#7: A Dose-Response Relationship is Reported or can be Established from Reported Data.	Two methodologies that can be used to identify this benchmark concentration. The first method generates a no observed effect concentration (NOEC) and a lowest observed effect concentration (LOEC). 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_{xx}), usually between an EC_5 and an EC_{50}.	Score 2 if in complete agreement with criterion. Score 1 if some, but not all of the conditions were met. Score 0 if it fails to meet the criterion.
#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.	Score 2 if in complete agreement with the criterion. Score 1 if some, but not all of the conditions for the criterion were met. Score 0 if it fails to meet the criterion.
#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).	Score 2 if in complete agreement with the criterion. Score 1 if some, but not all of the conditions for the criterion were met. Score 0 if it fails to meet the criterion.

Table 3.2 Plant and Soil Invertebrate Eco-SSL Derivation Table		
Level	**Toxicity Endpoint**	**Bio availability Score**
A	EC_{20}, EC_{10}, MATC	2
B	EC_{20}, EC_{10}, MATC	1 or 2
C	EC_{20}, EC_{10}, MATC	0, 1, or 2
D*	EC_{20}, EC_{10}, MATC, EC_{50}	0, 1, or 2

EC_{XX} = Effect Concentration for defined percentages of the population (i.e., 20%, 10-19%, 21-50%),
MATC = Maximum Acceptable Threshold Concentration or the geometric mean of the No Observed Effect Concentration (NOEC) and Lowest Observed Effect Concentration (LOEC).

* Data which are used to derive Eco-SSLs at the D level were adjusted with the appropriate application factor.
If the EC_{50} > MATC then the values was divided by 5.
If the EC_{50} < MATC then the value was divided by 2.
If there were only EC_{50} values then the value was divided by 5.

3.4 Quality Control Review (Step 4)

Once the literature evaluation process was completed and the selected studies grouped into levels according to bioavailability and toxicity endpoints, a quality control review was conducted by task group members of those data identified for consideration in deriving an Eco-SSL. A description of the Quality Control Review is included in Appendix 3-2. The objectives of the Quality Control Review included: confirming that the appropriate data were selected and documented by the reviewer; resolving any comments or concerns; and, reaching consensus on which data would be used to derive an Eco-SSL. For example, for a study that reported data for multiple test species and for several endpoints, the quality control process provided a forum for review of the identified data to ensure that the most appropriate information was used to derive the Eco-SSL.

3.5 Calculation of the Plant and Soil Invertebrate Eco-SSLs (Step 5)

Following the Quality Control Review (Step 4), an Eco-SSL for a contaminant-receptor pairing (e.g., lead-invertebrates) was calculated. The Eco-SSL was calculated as the geometric mean of all toxicity values from the highest preference "level" (see Table 3-2) that had a sufficient number of data. Three toxicity data values were the minimum required to calculate an Eco-SSL. If a sufficient number of data (N=3) were available at the highest level (Level A), then the Eco-SSL was calculated using only Level A data. If Level A contained less than three values, then additional data was added from subsequent levels (B, C and D) until the minimum of three data values was obtained. For example, if a specific contaminant-receptor pairing has only two toxicity values at Level A, there would not be sufficient data to generate an Eco-SSL using only Level A data. However, if in this case there were toxicity values (one or more) at Level B, in addition to the two values at Level A, these combined values (three or more) would be used to derive an Eco-SSL as the geometric mean of the combined data set. In this

example, Level C data would only be used if there were less than three values from the combined A and B levels.

The Eco-SSL derivation process was completed separately for plants and soil invertebrates for each contaminant. Once an Eco-SSL was calculated, a technical discussion was prepared that provided additional information concerning the derivation of each Eco-SSL value. Technical discussions and the calculated Eco-SSLs for each contaminant-receptor are presented in Chapter 5. The process for derivation of plant and soil invertebrate Eco-SSLs is provided as Appendix 3-2. The completed scoring sheets and Eco-SSL derivation for each contaminant for plants and soil invertebrates are reported in Appendix 3-3 . The documents pertaining to derivation of Eco-SSLs for plants and soil invertebrates are listed in Table 3.3.

Table 3.3 Plant and Soil Invertebrate Eco-SSL Documents

Document	Location
Plant and Soil Invertebrate Standard Operating Procedure #1: Literature Search and Retrieval	Exhibit 3-1
Plant and Soil Invertebrate Standard Operating Procedure #2: Literature Review	Exhibit 3-2
Plant and Soil Invertebrate Standard Operating Procedure #3: Literature Evaluation and Data Extraction	Appendix 3-1
Plant and Soil Invertebrate Standard Operating Procedure #4: Eco-SSL Derivation, Quality Assurance Review, And Technical Write-up	Appendix 3-2
Reference List of Papers Identified by Literature Searches	Exhibit 3-3 (to be posted)
Reference List of Acceptable Papers	Exhibit 3-4 (to be posted)
Literature Evaluation Scoring Sheets for Studies Used to Derive Plant and Soil Invertebrate Eco-SSLs	Appendix 3-3

4.0 DERIVATION OF WILDLIFE ECO-SSLs

Eco-SSLs for wildlife were derived using a five step process that includes: selecting the wildlife risk model, selecting the surrogate species, parameterizing the exposure dose model, deriving wildlife toxicity reference values (TRVs), and calculating the Eco-SSLs. Wildlife Eco-SSLs were derived for two groups of wildlife receptors: mammals and birds. Eco-SSLs were not derived for amphibians or reptiles at this time due to lack of adequate toxicity and exposure data.

4.1 The Wildlife Risk Model for Eco-SSLs

The basic equation used for estimating potential risks to wildlife is as follows:

$$\text{Hazard Quotient (HQ)} = \frac{\text{Exposure Dose (mg / kgBW / day)}}{\text{Effect Dose (mg / kgBW / day)}}$$

Contaminant exposure for terrestrial wildlife is expressed as an Exposure Dose in milligram (mg) contaminant per kilogram (kg) body weight (BW) per day or mg/kg BW/day, and the Effect Dose is represented by a toxicity reference value (TRV) expressed in the same units.

The Eco-SSL is the soil concentration that results in an HQ=1, that is, when the Effect Dose (TRV) and the Exposure Dose are equal. The Exposure Dose for wildlife is equal to the amount of contaminant in the diet that is taken up or transferred from the soil. Therefore, it is necessary to model the soil concentration that would result in dietary concentrations equal to the Exposure Dose that is equal to the TRV. Estimation of the Exposure Dose is described in Section 4.3. Derivation of the Effect Dose or 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.

Steps for Establishing a Wildlife Eco-SSL

1. **Identify the Risk Wildlife 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.

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

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

where:

HQ_j	=	Hazard quotient for contaminant (j) (unitless),
$Soil_j$	=	Contaminant concentration for contaminant (j) in soil (mg/kg dry weight),
N	=	Number of different biota types in diet,
B_i	=	Contaminant concentration 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] / d),
AF_{ij}	=	Absorbed fraction of contaminant (j) from biota type (i),
AF_{sj}	=	Absorbed fraction of contaminant (j) from soil (s),
TRV_j	=	The no adverse effect dose (mg/kg BW/day) (Section 4.4),
P_s	=	Soil ingestion as proportion of diet,
AUF	=	Area use factor.

4.2 Selection of Surrogate Wildlife Species

It is 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 generic trophic groups as opposed to specific species include, but are not limited to, the following:

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

- This approach provides results that can be used to examine comparative risks associated with different exposure routes (e.g., ingestion of food versus soil ingestion) 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 is consistent with ERAGS which states: *"for the screening-level ecological assessment, 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)

Criteria for Selection of Surrogate Taxa

Three general trophic groups (e.g., herbivore, ground insectivore, and carnivore) for both mammals and birds were selected for the Eco-SSL wildlife exposure model. Within each of these trophic groups, a specific species was identified as a "surrogate" species.

Selection of specific species was necessary for parameterization of the Eco-SSL wildlife model, which requires 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 has a clear direct or indirect exposure pathway link to soil. Direct exposure pathways to soil include 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 are assumed to be the most highly exposed species to soil contamination with the exception of contaminants that biomagnify. Indirect exposure includes ingestion by carnivores of prey that have direct contact with soil.

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

3) **Diet composition can be simplistically classified.** The dietary composition of each surrogate species can be easily classified into one of the three selected trophic groups (herbivore, ground insectivore, carnivore). Clear classification of diet serves to simplify the exposure assumptions related to dietary composition into three classes: plants, invertebrates and animals. This simplification permits examination of the potential extremes in exposure by dietary type (What are the risks if an animal consumes earthworms, exclusively? Or plants?), avoiding the alternative use of variable dietary compositions and associated uncertainties. For this reason,

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

Some specific wildlife groups were not considered suitable for deriving of 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.

omnivorous wildlife were excluded as potential receptors.

Further, selection of species for which diet composition may be realistically assumed to consist 100% of a single food type allows 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) produces results that are protective of species with more varied diets. Omnivorous species will likely consume foods with differing contaminant concentrations. As a result, their total exposure will be less than that by species whose diets consist of the single most contaminated food type. By selecting surrogate species that would forage exclusively on plants, invertebrates, or vertebrates, regardless of through which pathway maximal risks are expressed for any given chemical, protectiveness of all other species is ensured.

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

Surrogate species were selected to provide a conservative representation of their respective trophic guilds. Selected species are 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 is associated with higher metabolic rates (Nagy et al., 1999) and smaller home ranges (McNab, 1963), exposure and risk for small receptors is maximized. Eco-SSLs based on these species are therefore likely to be protective of other, larger species in their trophic guild.

4.3 The Exposure Dose

Estimation of the exposure dose associated with contaminant concentrations in soil requires parameterization of the general model provided as Equation 4-1.

Wildlife Risk Model

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

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

- Bioavailability of the contaminant in both soil and food is 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}) are both equal to 1.

- The surrogate species' diet consists of 100% of one food type. Therefore, the proportion of biota type in the diet (P_i) is equal to 100% and the number of biota types (N) in diet is equal to 1.

Parameterizing the Model for Estimating Exposure Dose

Parameterization of the model includes exposure factors related to the surrogate species (see Table 4.1) and estimation of the contaminant concentrations in biota items (B_i) consumed in the diet. The identification and derivation of surrogate species-specific exposure factors for the Wildlife Eco-SSLs are described in Appendix 4-1. The food and soil ingestion rates used in the exposure model are represented by the 90th percentiles from their respective distributions. 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)	Body Weight (kg) [1]	Food Ingestion Rate (kg dw/kg BW day) [2]	Soil Ingestion (P_s)	Assumed Diet
Mammalian Herbivore (Meadow Vole)	0.039	0.58	0.029	100% foliage
Avian Grainivore (Mourning dove)	0.115	0.23	0.16	100% seed
Mammalian Ground Insectivore (Short-tailed shrew)	0.018	0.20	0.03	100% earthworms
Mammalian Carnivore (Long-tailed weasel)	0.202	0.10	0.04	100% small mammals
Avian Ground Insectivore (American woodcock)	0.159	0.17	0.12	100% earthworm
Avian Carnivore (Red-tailed hawk)	1.076	0.12	0.05	100% small mammals

Table 4.1. Parameterization of the Eco-SSL Wildlife Exposure Model				
Receptor Group (Surrogate Species)	Body Weight (kg) [1]	Food Ingestion Rate (kg dw/kg BW day) [2]	Soil Ingestion (P_s)	Assumed Diet

Parameterization Details Provided in Appendix 4-1.
[1] Mean value for both males and females. Derivation of mean presented in Appendix 4-1
[2] Mean value is presented but the full distribution of body weights (not a conservatively skewed value) was used to derive the food ingestion distributions.

Estimating Contaminant Concentrations in Biota

The contaminant concentrations in biota types (B_i) composing the wildlife diets were estimated by assuming that the concentration of the contaminant in the food type can be predicted from the concentration of the contaminant in the soil (C_{soil}) by using a Bioaccumulation Factor (BAF). The function that typically relates B_i to C_{soil} is a constant, which is referred to as the Bioaccumulation Factor (BAF):

$$B_i = BAF * C_{soil}$$

However, the concentration of the contaminant in the food item may be better described by linear or nonlinear functions that predict bioaccumulation, such as:

$$B_i = a * C_{soil} + b \qquad \text{(linear)}$$

$$\ln(B_i) = a * \ln(C_{soil}) + b \qquad \text{(logarithmic)}$$

$$B_i = a + b * (1 - \exp(-c * C_{soil})) \qquad \text{(exponential)}$$

where a, b, and c are the parameters of the best-fit equation through the paired data (soil versus soil organism or plant). These are referred to as regression models.

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

1) <u>Existing Regression Models</u>. If regression models were currently available and the r-square values are ≥ 0.2, then these were preferentially used. The primary sources of existing regression models are: Sample et al. (1999) for earthworms; Sample et al. (1998) for small mammals; and Bechtel-Jacobs (1998) for plants.

2) <u>New Regressions</u>. If paired data (contaminant concentrations in soil organism or plant versus soil) were sufficient to establish regression models and these models were significant with r-square values ≥ 0.2, then these regression models were developed and used.

3) **Ratios (BAFs).** BAFs (or ratios of the contaminant in soil to the contaminant in the food item) were identified based on existing BAFs reported in the scientific literature. If reported ratios were not identified, then paired data (contaminant in soil versus contaminant in food item) were collected from the literature to derive these ratios.

4) **Models Estimating BAFs or B_i.** If BAFs were not available in the literature or the paired data were not available to derive the BAF, then models were used. Existing models associating contaminant parameters of the contaminant with the potential for accumulation in biota or plant tissue were available and were used to estimate B_i. These existing estimation models were evaluated and reviewed in Appendix 4-1.

5) **Assumptions.** In instances where data was 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 B_i. These assumptions are discussed in Appendix 4-1.

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	BAF	BAF	NA
Arsenic	BAF	R	--	R
Barium	BAF	BAF	BAF	NA
Beryllium	BAF	BAF	BAF	NA
Cadmium	R	R	–	R
Chromium	BAF	BAF	–	R
Cobalt	BAF	BAF	–	R
Copper	R	BAF	–	R
Lead	R	R	–	R
Manganese	BAF	R	–	R
Nickel	R	BAF	–	R
Selenium	R	R	–	R
Silver	BAF	BAF	–	BAF
Vanadium	A	A	A	--
Zinc	R	R	–	R
Dieldrin	R	M	BAF	--
DDT	BAF	M	BAF	--
DDD	BAF	M	BAF	--
DDE	BAF	M	BAF	--
PCP	BAF	M	R	--
PAHs		Chemical Specific		
TNT	M	M	A	--
RDX	M	M	A	--

M = Estimated based on equation relating physical-chemical factor to bioaccumulationl (model).

R = Log-linear regression uptake model (Appendix 4-1)

BAF = Bioaccumulation Factor (Appendix 4-1)

A = Assumption

NA = Not available

How Contaminant Concentrations Are Determined for Plants and Soil Invertebrates (B_i)

The specific information concerning how contaminant concentrations were estimated for the plant and soil invertebrate components (B_i) of the diets of the surrogate species is provided as Appendix 4-1. This appendix includes descriptions of the use of any existing models. Figure 4.2 provides a summary of the type of data (from the hierarchy) used to estimate the contaminant concentrations. Some specific discussions concerning the bioaccumulation of dieldrin, DDT (and metabolites), and PAHs

from soil into plant tissue are provided in the following subsections.

How Contaminant Concentrations Were Determined for Mammals and Birds (B_i)

Empirical soil-whole body loglinear regression models and BAFs are available from Sample et al. (1998a) for 11 of the 24 contaminants. For the remaining organic contaminants for which empirical regression models or BAFs were not available, diet-to-tissue BAFs were estimated using the methods presented in Appendix 4-2.

Although many species of predatory wildlife consume both birds and mammals as prey, few data are available to estimate bioaccumulation of contaminants into birds. As a consequence, the bioaccumulation models for mammals are assumed to produce estimates that adequately represent concentrations in birds. The validity of this assumption is 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 are available for carcasses (tissue remaining after removal of the GI 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 4.3. Based on these data, concentrations in birds appear to be approximately equivalent to or less than those found in omnivorous or insectivorous small mammals.

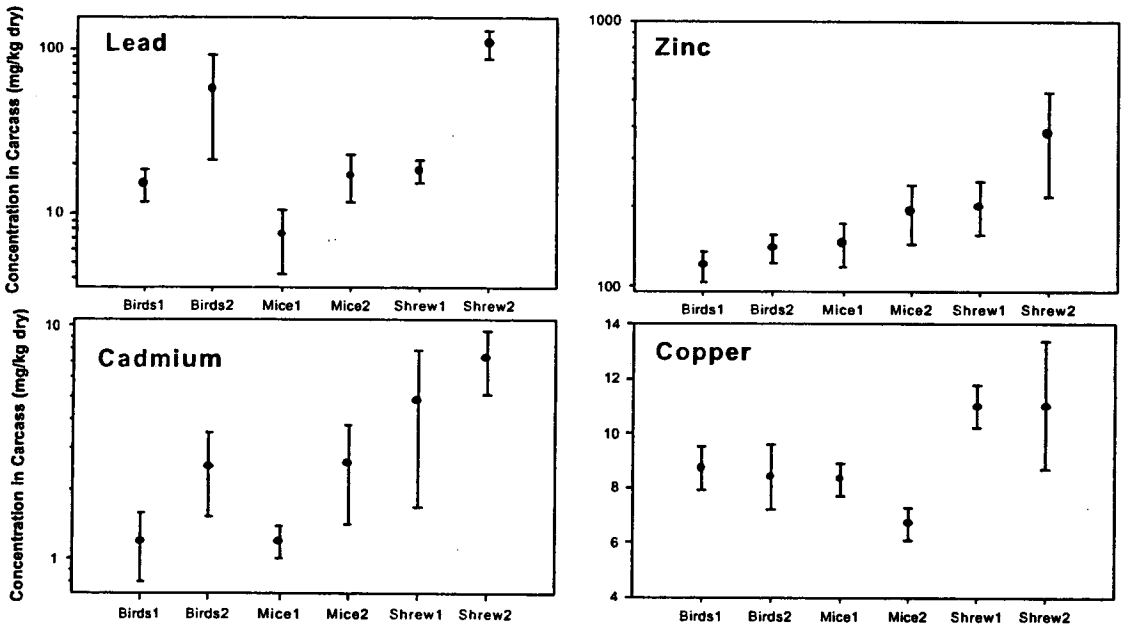


Figure 4.3. Comparison of mean concentrations in multiple species near a smelter.

What if Data were not Available to Estimate B_i?

For some contaminants and biota types (e.g., earthworms and small mammals for antimony, plants and small mammals for beryllium, and earthworms for chromium), data were not available to derive BAFs (as described in Appendix 4-2). For these contaminants, default BAFs of 1 were used. This assumption is 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).

Table 4.2. Cases where the 90th Percentile of the BAF Distribution is Greater or Less than One

	Total Number of Contaminants	BAFs < 1	BAFs > 1
Plants	21	12	9
Earthworms	31	14	17
Small Mammals	24	16	8

4.4 Toxicity Reference Values (TRVs)

As presented in Figure 4.4, a four-step process was used to select TRVs appropriate for calculation of wildlife Eco-SSLs. The four steps included: 1) a literature search, 2) literature review and data extraction, 3) literature data evaluation, and 4) TRV derivation. The TRV is defined as:

Doses 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.

Literature Search and Retrieval

A literature search was first completed for each of the Eco-SSL contaminants to identify toxicological studies for retrieval and review. The search procedure is

Figure 4.4. Wildlife TRV Derivation Process

The wildlife TRV derivation process is composed of four general steps:

- **Literature Search and Retrieval**
  Wildlife TRV SOP 1: Literature Search and Retrieval (Exhibit 4-1)
  A literature search identifies dose-response literature for retrieval.

- **Literature Review and Data Extraction**
  Wildlife TRV SOP 2: Literature Review, Data Extraction and Coding (Appendix 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 SOP 3: Data Evaluation (Appendix 4-4).
  Each of the results identified in the reviewed literature is scored for quality and applicability for TRV derivation.

- **TRV Derivation**
  Wildlife TRV SOP 4: TRV Derivation (Appendix 4-5).
  This procedure plots the collective dose-response information and establishes the process for estimating the TRV.

described in detail as Exhibit 4-1 and can be used by others to identify relevant data for other contaminants. The literature search process has been completed for eleven of the Eco-SSL contaminants including aluminum, antimony, cadmium, chromium, cobalt, copper, DDT, Dieldrin, lead, PAHs and RDX. Literature searches for the remaining Eco-SSL contaminants are currently in progress.

Literature Review and Data Extraction

Dose-response studies from retrieved literature were reviewed. Literature exclusion criteria (similar to those discussed in Chapter 3 for plants and soil invertebrates) were applied to the retrieved wildlife literature. Additional literature exclusion criteria for wildlife toxicological studies include:

- Genotoxicity and mutagenicity studies
- Carcinogenicity studies
- Physiology studies
- Acute studies
- Non-oral routes of exposure (inhalation, injection, dermal, etc.)
- Studies unrelated to the contaminant and receptor groups of interest

Where possible, the exclusion criteria were applied to identified titles and abstracts prior to retrieval of the paper. For retrieved studies that passed the exclusion criteria, the relevant toxicological data were extracted and entered into an electronic database according to established extraction and coding procedures detailed as Appendix 4-3.

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.

Table 4.3 Results of the Wildlife Toxicological Literature Search and Review					
Contaminant	**Studies Identified from Search**	**Studies Rejected**	**Studies with Data Extracted**	**Studies not retrieved**	**Studies Pending Review**
Aluminum	210	49	0	86	75
Antimony	46	34	10	2	0
Cadmium	544	228	7	150	159
Chromium	113	63	27	22	0
Cobalt	115	71	30	2	0
Copper	382	53	5	143	181
DDT	565	331	85	120	29
Dieldrin	276	151	101	24	0
Lead	463	48	1	70	344
RDX	30	11	16	3	0
Selenium	471	140	58	155	121

Data Evaluation

Each test result extracted during the literature review process was scored for quality and applicability for TRV derivation. The data evaluation process is provided as Appendix 4-4. In instances where more than one "experiment" (i.e., different combinations of receptor, dose, exposure route, exposure duration, and endpoint) was reported in a study, 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 is based on evaluation of ten attributes of the toxicological study (Figure 4.5) 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 optimal for the narrow goal of deriving an oral TRV. The total score was calculated by adding the results of the evaluation of each attribute.

The total score is 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

The results of the scoring process were used to evaluate and weight the toxicological study results used in the derivation of TRVs according to procedures specified in Appendix 4-5.

A web-based data entry system and database was created as a tool to facilitate efficient and accurate data extraction from individual reviewed toxicological studies as well as data evaluation. Extraction of the data directly into an electronic database facilitates necessary sorting, searching and presentation of the data for the purposes of TRV derivation. The TRV database is focused on extracting the no observed adverse effect level (NOAEL) and lowest observed adverse effect level (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 identified for each class using an established procedure. The process is fully described in Appendix 4-5. The following general steps were completed to derive the TRVs:

Dose-Response Data Sorted The toxicity data 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

Figure 4.5. 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 are 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. Sublethal changes are scored lower and biomarkers scored lowest.
7. **Dose Range**
   Studies with both NOAEL and LOAEL values scored higher than studies which report only one value. Narrower ranges between NOAEL and LOAEL scored higher.
8. **Statistical Power**
   The statistical power of a NOAEL is scored.
9. **Exposure Duration**
   Exposure durations encompassing multiple generations and critical lifestages scored higher than chronic, subchronic, and acute.
10. **Test Conditions**
    Studies that report standard exposure conditions scored higher then those that report fewer or none.

tables provide 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.

Dose-Response Data Plotted. The data were downloaded from the database and were used to produce summary plots depicting the NOAELs and LOAELs for each contaminant. Summary plots were constructed for each mammalian and avian data set for each contaminant. The data plots were organized by General Effect Group in order from left to right as:

- Biochemical (BIO)
- Behavioral (BEH)
- Physiological (PHY)
- Pathology (PTH)
- Reproduction (REP)
- Growth (GRO)
- Morality (MOR)

Figure 4.6 provides an example plot showing the mammalian data for cobalt.

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

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 Type were recorded on the plots.

TRV Selected. The general steps and conditional statements of the derivation process are outlined in Figure 4.7. These steps are an *a priori* framework for selection of the TRV value based on the results of the toxicological plots. The flow chart was used with the toxicity data plots to derive the TRV according to the described steps. If there were enough data, the TRV was equal to the geometric mean of the NOAEL values for growth (GRO) and reproductive (REP) effects adjusted and weighted by the Data Evaluation Score. In cases where the geometric mean NOAEL was higher than the lowest reported LOAEL for mortality (MOR), the TRV was equal to the highest NOAEL below the lowest LOAEL for mortality effects. An example is provided with the mammalian cobalt plot depicted on Figure 4.6.

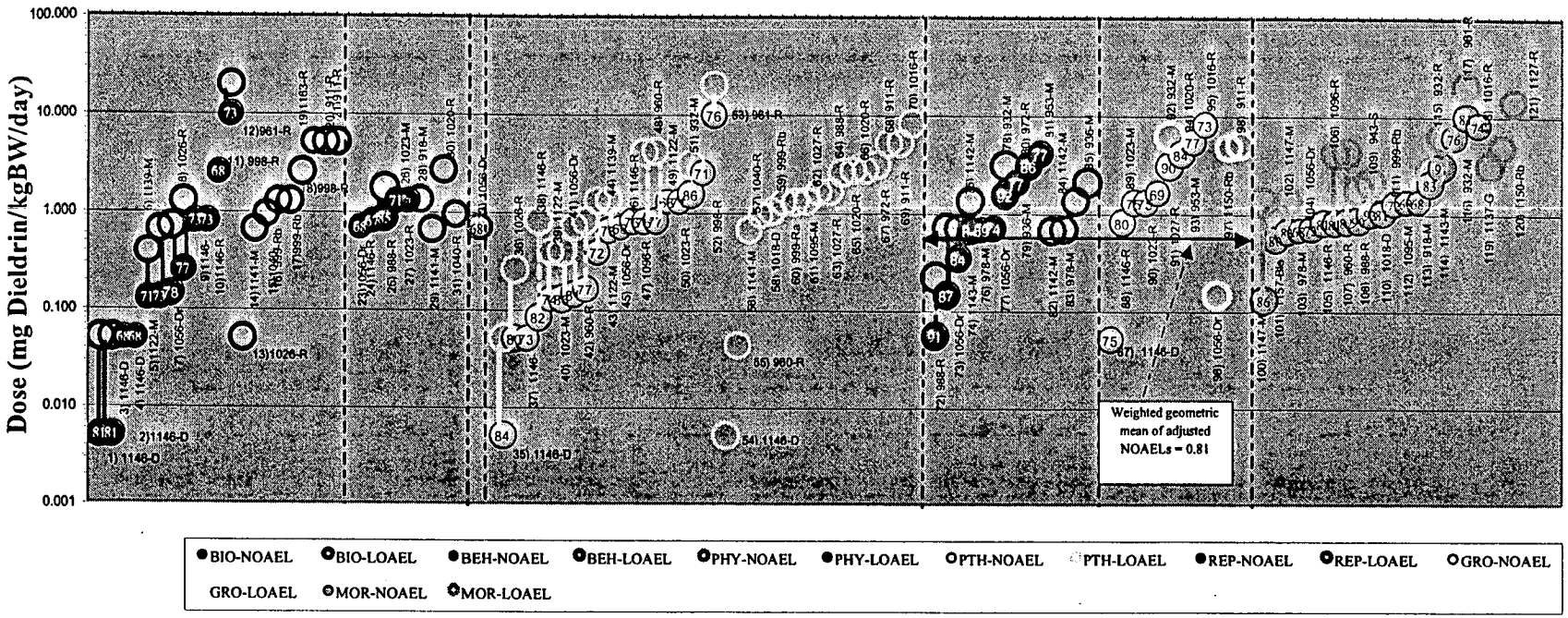
Table 4.4
Example of Extracted and Scored Toxicity Data for Wildlife

TEST INFORMATION		EXPOSURE INFORMATION										EFFECT INFORMATION						DATA EVALUATION SCORES										
Result #	Test ID	Species	# of Conc/ Doses	Method of Chem Analyses	Route of Exposure	Exposure Duration	Duration Units	Age	Age Units	Lifestage	Sex	General Effect Group	Effect Type	Effect Measure	Response Site	NOAEL Dose (mg/kg/day)	LOAEL Dose (mg/kg/day)	Data Source	Dose Route	Test Substance	Chemical form	Dose Quantification	Endpoint	Dose Range	Statistical Power	Exposure Duration	Test Conditions	Total
1	1146-Did-Walke-ML-OR-2-BIO-3	dog	3	M	OR	104	w	5.5	mo	MU	BH	BIO	CHM	TOPR	SR	0.005	0.05	10	8	10	10	10	1	8	10	10	4	81
2	1146-Did-Walke-ML-OR-2-BIO-1	dog	3	M	OR	104	w	5.5	mo	MU	BH	BIO	ENZ	ALPH	PL	0.005	0.05	10	8	10	10	10	1	8	10	10	4	81
3	1146-Did-Walke-ML-OR-2-BIO-2	dog	3	M	OR	104	w	5.5	mo	MU	BH	BIO	CHM	HMGL	BL	0.05		10	8	10	10	10	1	4	1	10	4	68
4	1146-Did-Walke-ML-OR-2-BIO-4	dog	3	M	OR	104	w	5.5	mo	MU	BH	BIO	ENZ	CEST	ER	0.05		10	8	10	10	10	1	4	1	10	4	68
5	1122-Did-Steve-ML-FD-1-BIO-6	mouse	4	U	FD	28	d	4	w	NR	M	BIO	ENZ	EROD	LI	0.127	0.3812	10	10	5	10	5	1	10	10	6	4	71
6	1139-Did-van R-ML-FD-1-BIO-1	mouse	4	U	FD	14	mo	4.5	w	JV	F	BIO	ENZ	AATT	LI	0.13	0.64	10	10	5	10	5	1	8	10	10	4	73
7	1056-Did-Murph-ML-FD-1-BIO-7	deer	3	U	FD	3	y	1	y	MU	F	BIO	ENZ	ALPH	SR	0.14	0.69	10	10	5	10	10	1	8	10	10	4	78
8	1026-Did-Kramp-ML-GV-1-BIO-3	rat	5	M	GV	13	d	NR	NR	NR	M	BIO	ENZ	Other	LI	0.25	1.25	10	8	10	10	10	1	8	10	6	4	77
9	1146-Did-Walke-ML-FD-1-BIO-5	rat	4	M	FD	104	w	5	w	MU	BH	BIO	CHM	HMGL	BL	0.79		10	10	10	10	6	1	4	10	10	2	73
10	1146-Did-Walke-ML-FD-1-BIO-6	rat	4	M	FD	104	w	5	w	MU	BH	BIO	ENZ	ALPH	PL	0.79		10	10	10	10	6	1	4	10	10	2	73
11	998-Did-Hurka-ML-GV-1-BIO-4	rat	2	M	GV	100	d	NR	NR	NR	NR	BIO	ENZ	ALPH	LI	2.5		10	8	10	10	10	1	4	1	10	4	68
12	961-Did-Foste-ML-FD-1-BIO-1	rat	3	U	FD	6	w	NR	NR	NR	M	BIO	HRM	CORT	AR	9.8	19.6	10	10	5	10	7	1	10	10	6	4	73
13	1026-Did-Kramp-ML-GV-1-BIO-4	rat	5	M	GV	13	d	NR	NR	NR	M	BIO	ENZ	PNAD	LI		0.05	10	8	10	10	10	1	4	10	6	4	73
14	1141-Did-Virgo-ML-FD-1-BIO-2	mouse	5	U	FD	10	w	13	w	NR	F	BIO	CHM	TOPR	MC		0.64	10	10	5	10	5	1	4	10	10	4	69
15	1040-Did-Mehro-ML-FD-1-BIO-5	rat	2	U	FD	60	d	NR	NR	NR	M	BIO	ENZ	Other	BR		0.92	10	10	5	10	6	1	4	10	6	4	66
16	999-Did-Hurka-ML-GV-1-BIO-4	rabbit	2	M	GV	100	d	NR	NR	NR	NR	BIO	CHM	CHOL	LI		1.25	10	8	10	10	10	1	4	10	6	4	73
17	999-Did-Hurka-ML-GV-1-BIO-5	rabbit	2	M	GV	100	d	NR	NR	NR	NR	BIO	ENZ	ALPH	LI		1.25	10	8	10	10	10	1	4	10	6	4	73
18	998-Did-Hurka-ML-GV-1-BIO-3	rat	2	M	GV	100	d	NR	NR	NR	NR	BIO	CHM	GLYC	LI		2.5	10	8	10	10	10	1	4	10	10	4	77
19	1163-Did-Zemai-ML-FD-1-BIO-1	rat	2	U	FD	8	w	NR	NR	MA	F	BIO	ENZ	CEST	PL		5	10	10	5	10	6	1	4	10	6	4	66
20	911-Did-Bandy-ML-GV-1-BIO-5	rat	2	M	GV	15	d	NR	NR	YO	M	BIO	CHM	Other	LI		5	10	8	10	10	10	1	4	10	6	4	73
21	911-Did-Bandy-ML-GV-1-BIO-4	rat	2	M	GV	15	d	NR	NR	YO	M	BIO	ENZ	Other	LI		5	10	8	10	10	10	1	4	10	6	4	73
22																												
23	1056-Did-Murph-ML-FD-1-BEH-1	deer	3	U	FD	3	y	1	y	MU	F	BEH	FDB	FCNS	WO	0.69		10	10	5	10	10	4	4	1	10	4	68
24	1146-Did-Walke-ML-FD-1-BEH-3	rat	4	M	FD	104	w	5	w	MU	BH	BEH	FDB	FCNS	WO	0.79		10	10	10	10	6	4	4	1	10	2	67
25	988-Did-Harr -ML-FD-1-BEH-3	rat	11	M	FD	400	d	28	d	MU	BH	BEH	FDB	FCNS	WO	0.85	1.7	10	10	10	10	7	4	10	10	10	4	85
26	1023-Did-Kolai-ML-FD-1-BEH-3	mouse	5	M	FD	90	d	8	w	NR	M	BEH	FDB	FCNS	WO	1.27		10	10	10	10	5	4	4	1	10	7	71
27	1023-Did-Kolai-ML-FD-2-BEH-1	rat	5	M	FD	90	d	8	w	NR	M	BEH	FDB	FCNS	WO	1.27		10	10	10	10	5	4	4	1	10	7	71
28	918-Did-Bilds-ML-FD-1-BEH-2	mouse	2	U	FD	3	mo	3.5	mo	NR	NR	BEH	BEH	FRZG	WO		1.3	10	10	5	10	5	4	4	10	10	4	72
29	1141-Did-Virgo-ML-FD-1-BEH-3	mouse	5	U	FD	10	w	13	w	NR	F	BEH	BEH	INST	WO		0.64	10	10	5	10	5	4	4	10	10	4	72
30	1020-Did-Kimbr-ML-FD-1-BEH-3	rat	3	U	FD	8	w	3.5	mo	AD	M	BEH	BEH	INST	WO		2.64	10	10	5	10	10	4	4	10	6	4	73
31	1040-Did-Mehro-ML-FD-1-BEH-3	rat	2	U	FD	60	d	NR	NR	NR	M	BEH	FDB	FCNS	WO		0.92	10	10	5	10	6	4	4	10	6	4	69
32																												
33	1056-Did-Murph-ML-FD-1-PHY-10	deer	3	U	FD	3	y	1	y	MU	F	PHY	PHY	OTHR	KI	0.69		10	10	5	10	10	4	4	1	10	4	68
34																												
35	1146-Did-Walke-ML-OR-2-PTH-8	dog	3	M	OR	104	w	5.5	mo	MU	M	PTH	ORWT	ORWT	SP	0.005	0.05	10	8	10	10	10	4	8	10	10	4	84
36	1026-Did-Kramp-ML-GV-1-PTH-1	rat	5	M	GV	13	d	NR	NR	NR	M	PTH	ORWT	SMIX	LI	0.05	0.25	10	8	10	10	10	4	8	10	6	4	80
37	1146-Did-Walke-ML-OR-2-PTH-6	dog	3	M	OR	104	w	5.5	mo	MU	BH	PTH	ORWT	ORWT	KI	0.05		10	8	10	10	10	4	4	3	10	4	73
38	1146-Did-Walke-ML-FD-1-PTH-1	rat	4	M	FD	104	w	5	w	MU	BH	PTH	HIS	GLSN	KI	0.082	0.79	10	10	10	10	6	4	8	10	10	4	82
39	1122-Did-Steve-ML-FD-1-PTH-4	mouse	4	U	FD	28	d	4	w	NR	M	PTH	HIS	GHIS	LI	0.127	0.3812	10	10	5	10	5	4	10	10	6	4	74
40	1023-Did-Kolai-ML-FD-1-PTH-1	mouse	5	M	FD	90	d	8	w	NR	M	PTH	ORWT	SMIX	LI	0.127	0.3812	10	10	10	10	5	4	10	10	10	7	86
41	1056-Did-Murph-ML-FD-1-PTH-8	deer	3	U	FD	3	y	1	y	MU	F	PTH	ORWT	ORWT	LI	0.14	0.69	10	10	5	10	10	4	8	10	10	4	81
42	960-Did-Fitzh-ML-FD-1-PTH-3	rat	7	U	FD	2	y	NR	NR	JV	M	PTH	ORWT	SMIX	LI	0.16	0.79	10	10	5	10	6	4	8	10	10	4	77
43	1122-Did-Steve-ML-FD-1-PTH-2	mouse	4	U	FD	28	d	4	w	NR	M	PTH	ORWT	SMIX	LI	0.3812	1.27	10	10	5	10	5	4	8	10	6	4	72
44	1139-Did-van R-ML-FD-1-PTH-2	mouse	4	U	FD	14	mo	4.5	w	JV	F	PTH	HIS	GSLN	LI	0.64	1.3	10	10	5	10	5	4	8	10	10	4	76
45	1056-Did-Murph-ML-FD-1-PTH-9	deer	3	U	FD	3	y	1	y	MU	F	PTH	ORWT	ORWT	KI	0.69		10	10	5	10	10	4	4	1	10	4	68
46	1146-Did-Walke-ML-FD-1-PTH-7	rat	4	M	FD	104	w	5	w	MU	BH	PTH	ORWT	ORWT	BR	0.79		10	10	10	10	6	4	4	10	10	2	76
47	1096-Did-Reube-ML-FD-1-PTH-2	rat	8	U	FD	2	y	3	w	NR	BH	PTH	HIS	NPHR	KI	0.79	3.96	10	10	5	10	5	4	8	10	10	4	76
48	960-Did-Fitzh-ML-FD-1-PTH-4	rat	7	U	FD	2	y	NR	NR	JV	BH	PTH	HIS	GHIS	LI	0.80	4.1	10	10	5	10	6	4	8	10	10	4	77
49	1122-Did-Steve-ML-FD-1-PTH-5	mouse	4	U	FD	28	d	4	w	NR	M	PTH	HIS	GHIS	LI	1.27		10	10	5	10	5	4	4	10	6	4	68
50	1023-Did-Kolai-ML-FD-2-PTH-3	rat	5	M	FD	90	d	8	w	NR	M	PTH	ORWT	SMIX	LI	1.27		10	10	10	10	5	4	4	1	10	7	71
51	932-Did-Chern-ML-GV-1-PTH-5	mouse	4	M	GV	10	d	NR	NR	SM	F	PTH	ORWT	SMIX	LI	1.5	3	10	8	10	10	10	4	10	10	10	4	86
52	998-Did-Hurka-ML-GV-1-PTH-2	rat	2	M	GV	100	d	NR	NR	NR	NR	PTH	HIS	NCRO	LI	2.5		10	8	10	10	10	4	4	1	10	4	71
53	961-Did-Foste-ML-FD-1-PTH-2	rat	3	U	FD	6	w	NR	NR	NR	M	PTH	ORWT	ORWT	AR	9.8	19.6	10	10	5	10	7	4	10	10	6	4	76
54	1146-Did-Walke-ML-OR-2-PTH-7	dog	3	M	OR	104	w	5.5	mo	MU	BH	PTH	ORWT	ORWT	HE		0.005	10	8	10	10	10	4	4	10	10	4	80
55	960-Did-Fitzh-ML-FD-1-PTH-2	rat	7	U	FD	2	y	NR	NR	JV	F	PTH	ORWT	SMIX	LI		0.043	10	10	5	10	6	4	4	10	10	4	73
56	1141-Did-Virgo-ML-FD-1-PTH-1	mouse	5	U	FD	10	w	13	w	NR	F	PTH	ORWT	ORWT	LI		0.64	10	10	5	10	5	4	4	10	10	4	72
57	1040-Did-Mehro-ML-FD-1-PTH-2	rat	2	U	FD	60	d	NR	NR	NR	M	PTH	ITX	INTX	WO		0.92	10	10	5	10	6	4	4	10	6	4	69
58	1018-Did-Keane-ML-OR-1-PTH-1	dog	3	M	OR	85	d	25.5	mo	AD	NR	PTH	ITX	CONV	WO		1	10	8	10	10	10	4	4	10	6	4	76
59	999-Did-Hurka-ML-GV-1-PTH-2	rabbit	2	M	GV	100	d	NR	NR	NR	NR	PTH	HIS	NCRO	LI		1.25	10	8	10	10	10	4	4	10	6	4	76
60	999-Did-Hurka-ML-GV-1-PTH-1	rabbit	2	M	GV	100	d	NR	NR	NR	NR	PTH	ORWT	ORWT	LI		1.25	10	8	10	10	10	4	4	10	6	4	76
61	1095-Did-Reube-ML-FD-1-PTH-3	mouse	2	U	FD	104	w	3	w	NR	BH	PTH	HIS	Other	LI		1.3	10	10	5	10	5	4	4	10	10	4	72
62	1027-Did-Krish-ML-FD-1-PTH-5	rat	2	U	FD	24	w	NR	NR	JV	BH	PTH	HIS	HYPL	LI		1.6	10	10	5	10	7	4	4	10	10	4	74
63	1027-Did-Krish-ML-FD-1-PTH-2	rat	2	U	FD	24	w	NR	NR	JV	BH	PTH	ORWT	SMIX	LI		1.6	10	10	5	10	7	4	4	10	10	4	74
64	998-Did-Hurka-ML-GV-1-PTH-1	rat	2	M	GV	100	d	NR	NR	NR	NR	PTH	HIS	GHIS	LI		2.5	10	8	10	10	10	4	4	10	10	4	80
65	1020-Did-Kimbr-ML-FD-1-PTH-4	rat	3	U	FD	8	w	3.5	mo	AD	M	PTH	HIS	GHIS	LI		2.6	10	10	5	10	10	4	4	10	6	4	73
66	1020-Did-Kimbr-ML-FD-1-PTH-2	rat	3	U	FD	8	w	3.5	mo	AD	M	PTH	ORWT	SMIX	LI		2.6	10	10	5	10	10	4	4	10	6	4	73
67	972-Did-Gelle-ML-GV-1-PTH-2	rat	2	M	GV	7	d	NR	NR	MU	BH	PTH	ORWT	ORWT	AR		3	10	8	10	10	10	4	4	10	10	4	80
68	911-Did-Bandy-ML-GV-1-PTH-1	rat	2	M	GV	15	d	NR	NR	YO	M	PTH	HIS	NCRO	LI		5	10	8	10	10	10	4	4	10	6	4	76
69	911-Did-Bandy-ML-GV-1-PTH-2	rat	2	M	GV	15	d	NR	NR	YO	M	PTH	ORWT	ORWT	LI		5	10	8	10	10	10	4	4	10	6	4	76
70	1016-Did-Jones-ML-FD-1-PTH-3	rat	2	M	FD	8	w	5	w	NR	BH	PTH	HIS	NCRO	BR		8.0	10	10	10	10	10	4	4	10	6	4	78
71																												
72	988-Did-Harr -ML-FD-1-REP-1	rat	11	M	FD	400	d	28	d	MU	BH	REP	REP	NSNT	WO	0.054	0.21	10	10	10	10	7	10	10	10	10	4	91
73	1056-Did-Murph-ML-FD-1-REP-4	deer	3	U	FD	3	y	1	y	MU	F	REP	REP	PRWT	WO	0.14	0.69	10	10	5	10	10	10	8	10	10	4	87
74	1143-Did-Virgo-ML-FD-1-REP-1	mouse	7	U	FD	13	w	5	w	SM	F	REP	REP	RSUC	WO	0.34	0.67	10	10	5	10	5	10	10	10	10	4	84
75	1142-Did-Virgo-ML-FD-1-REP-3	mouse	4	U	FD	1	g	5	w	SM	F	REP	REP	RBEH	WO	0.65	1.29	10	10	5	10	5	10	10	10	10	4	84
76	978-Did-Good -ML-FD-1-REP-2	mouse	2	U	FD	120	d	6	w	NR	BH	REP	REP	FERT	WO	0.66		10	10	5	10	5	10	4	1	10	4	69
77	1056-Did-Murph-ML-FD-1-REP-3	deer	3	U	FD	3	y	1	y	MU	F	REP	REP	TPRD	WO	0.69		10	10	5	10	10	10	4	1	10	4	74
78	932-Did-Chern-ML-GV-1-REP-2	mouse	4	M	GV	10	d	NR	NR	SM	F	REP	REP	TERA	WO	1.5	3	10	8	10	10	10	10	10	10	10	4	92
79	936-Did-Coste-ML-GV-1-REP-1	mouse	2	M	GV	18	d	9	w	NR	F	REP	REP	PRWT	WO	2		10	8	10	10	10	10	4	1	10	4	77
80	972-Did-Gelle-ML-GV-1-REP-3	rat	2	M	GV	7	d	NR	NR	MU	BH	REP	REP	PRWT	WO	3		10	8	10	10	10	10	4	10	10	4	86
81	953-Did-Dix-ML-GV-1-REP-1	mouse	3	M	GV	9	d	7	w	SM	F	REP	REP	PLBR	WO	4		10	8	10	10	10	10	4	1	10	4	77
82	1142-Did-Virgo-ML-FD-1-REP-1	mouse	4	U	FD	1	g	5	w	SM	F	REP	REP	RSUC	WO		0.65	10	10	5	10	5	10	4	10	10	4	78
83	978-Did-Good -ML-FD-1-REP-3	mouse	2	U	FD	120	d	6	w	NR	BH	REP	REP	NTSZ	WO		0.66	10	10	5	10	5	10	4	10	10	4	78
84	1142-Did-Virgo-ML-FD-1-REP-2	mouse	4	U	FD	1	g	5	w	SM	F	REP	REP	RBEH	WO		1.29	10	10	5	10	5	10	4	8	10	4	76

Table 4.4
Example of Extracted and Scored Toxicity Data for Wildlife

TEST INFORMATION		EXPOSURE INFORMATION										EFFECT INFORMATION						DATA EVALUATION SCORES										
Result #	Test ID	Species	# of Conc/ Doses	Method of Chem Analyses	Route of Exposure	Exposure Duration	Duration Units	Age	Age Units	Lifestage	Sex	General Effect Group	Effect Type	Effect Measure	Response Site	NOAEL Dose (mg/kg/day)	LOAEL Dose (mg/kg/day)	Data Source	Dose Route	Test Substance	Chemical form	Dose Quantification	Endpoint	Dose Range	Statistical Power	Exposure Duration	Test Conditions	Total
85	936-Did-Coste-ML-GV-1-REP-2	mouse	2	M	GV	18	d	9	w	NR	F	REP	REP	OTHR	WO		2	10	8	10	10	10	10	4	10	10	4	86
86																												
87	1146-Did-Walke-ML-OR-2-GRO-5	dog	3	M	OR	104	w	5.5	mo	MU	BH	GRO	GRO	BDWT	WO	0.05		10	8	10	10	10	8	4	1	10	4	75
88	1146-Did-Walke-ML-FD-1-GRO-2	rat	4	M	FD	104	w	5	w	MU	BH	GRO	GRO	BDWT	WO	0.79		10	10	10	10	6	8	4	10	10	2	80
89	1023-Did-Kolaj-ML-FD-1-GRO-2	mouse	5	M	FD	90	d	8	w	NR	M	GRO	GRO	BDWT	WO	1.27		10	10	10	10	5	8	4	1	10	7	75
90	1023-Did-Kolaj-ML-FD-2-GRO-2	rat	5	M	FD	90	d	8	w	NR	M	GRO	GRO	BDWT	WO	1.27		10	10	10	10	5	8	4	1	10	7	75
91	1027-Did-Krish-ML-FD-1-GRO-4	rat	2	U	FD	24	w	NR	NR	JV	BH	GRO	GRO	BDWT	WO	1.6		10	10	5	10	7	8	4	1	10	4	69
92	932-Did-Chern-ML-GV-1-GRO-4	mouse	4	M	GV	10	d	NR	NR	SM	F	GRO	GRO	BDWT	WO	3	6	10	8	10	10	10	8	10	10	10	4	90
93	953-Did-Dix-ML-GV-1-GRO-2	mouse	3	M	GV	9	d	7	w	SM	F	GRO	GRO	BDWT	WO	4		10	8	10	10	10	8	4	10	10	4	84
94	1020-Did-Kimbr-ML-FD-1-GRO-1	rat	3	U	FD	8	w	3.5	mo	AD	M	GRO	GRO	BDWT	WO	5.33		10	10	5	10	10	8	4	10	6	4	77
95	1016-Did-Jones-ML-FD-1-GRO-2	rat	2	M	FD	8	w	5	w	NR	BH	GRO	GRO	BDWT	WO	8.00		10	10	10	10	10	8	4	1	6	4	73
96	1056-Did-Murph-ML-FD-1-GRO-5	deer	3	U	FD	3	y	1	y	MU	F	GRO	GRO	BDWT	WO		0.14	10	10	5	10	10	8	4	10	10	4	81
97	1150-Did-Wasse-ML-DR-1-GRO-1	rabbit	2	M	DR	5	w	NR	NR	YO	M	GRO	GRO	BDWT	WO		4.6	10	5	5	10	6	8	4	10	6	4	68
98	911-Did-Bandy-ML-GV-1-GRO-3	rat	2	M	GV	15	d	NR	NR	YO	M	GRO	GRO	BDWT	WO		5	10	8	10	10	10	8	4	10	6	4	80
99																												
100	1147-Did-Walke-ML-FD-1-MOR-1	mouse	4	M	FD	132	w	3	w	MU	BH	MOR	MOR	MORT	WO	0.13	1.3	10	10	10	10	5	9	8	10	10	4	86
101	1157-Did-Wiese-ML-FD-1-MOR-1	bleshuck	6	U	FD	90	d	1	y	NR	BH	MOR	MOR	MORT	WO	0.53	0.89	10	10	5	10	6	9	10	10	6	4	80
102	1147-Did-Walke-ML-FD-2-MOR-1	mouse	6	U	FD	128	w	3	w	MU	BH	MOR	MOR	MORT	WO	0.65	1.3	10	10	5	10	5	9	10	10	10	4	83
103	978-Did-Good -ML-FD-1-MOR-1	mouse	2	U	FD	120	d	6	w	NR	BH	MOR	MOR	MORT	WO	0.66		10	10	5	10	5	9	4	1	10	4	68
104	1056-Did-Murph-ML-FD-1-MOR-2	deer	3	U	FD	3	y	1	y	MU	F	MOR	MOR	MORT	WO	0.69		10	10	5	10	10	9	4	1	10	4	73
105	1146-Did-Walke-ML-FD-1-MOR-4	rat	4	M	FD	104	w	5	w	MU	BH	MOR	MOR	MORT	WO	0.79		10	10	10	10	6	9	4	10	10	2	81
106	1096-Did-Reube-ML-FD-1-MOR-1	rat	8	U	FD	2	y	3	w	NR	BH	MOR	MOR	MORT	WO	0.79	3.95	10	10	5	10	5	9	8	10	10	4	81
107	960-Did-Fitzh-ML-FD-1-MOR-1	rat	7	U	FD	2	y	NR	NR	JV	BH	MOR	MOR	SURV	WO	0.82	4.1	10	10	5	10	6	9	8	10	10	4	82
108	988-Did-Hart -ML-FD-1-MOR-2	rat	11	M	FD	400	d	28	d	MU	BH	MOR	MOR	MORT	WO	0.85	1.7	10	10	10	10	7	9	10	10	10	4	90
109	943-Did-Davis-ML-FD-1-MOR-1	sheep	5	M	FD	32	w	NR	NR	NR	M	MOR	MOR	MORT	WO	1	2	10	10	10	10	10	9	10	10	10	4	93
110	1018-Did-Keane-ML-OR-1-MOR-2	dog	3	M	OR	85	d	25.5	mo	AD	NR	MOR	MOR	MORT	WO	1		10	8	10	10	10	9	4	10	6	4	81
111	999-Did-Hurka-ML-GV-1-MOR-3	rabbit	2	M	GV	100	d	NR	NR	NR	NR	MOR	MOR	MORT	WO	1.25		10	8	10	10	10	9	4	1	6	4	72
112	1095-Did-Reube-ML-FD-1-MOR-1	mouse	2	U	FD	104	w	3	w	NR	BH	MOR	MOR	MORT	WO	1.3		10	10	5	10	5	9	4	1	10	4	68
113	918-Did-Bilds-ML-FD-1-MOR-1	mouse	2	U	FD	3	mo	3.5	mo	NR	NR	MOR	MOR	MORT	WO	1.3		10	10	5	10	5	9	4	1	10	4	68
114	1143-Did-Virgo-ML-FD-1-MOR-3	mouse	7	U	FD	13	w	5	w	SM	F	MOR	MOR	SURV	WO	2	2.7	10	10	5	10	5	9	10	10	10	4	83
115	932-Did-Chern-ML-GV-2-MOR-1	rat	4	M	GV	10	d	NR	NR	SM	F	MOR	MOR	MORT	WO	3	6	10	8	10	10	10	9	10	10	10	4	91
116	932-Did-Chern-ML-GV-1-MOR-3	mouse	4	M	GV	10	d	NR	NR	SM	F	MOR	MOR	MORT	WO	6		10	8	10	10	10	9	4	1	10	4	76
117	961-Did-Foste-ML-FD-1-MOR-3	rat	3	U	FD	6	w	NR	NR	NR	M	MOR	MOR	MORT	WO	9.8	19.6	10	10	5	10	7	9	10	10	6	4	81
118	1016-Did-Jones-ML-FD-1-MOR-1	rat	2	M	FD	8	w	5	w	NR	BH	MOR	MOR	MORT	WO	8.00		10	10	10	10	10	9	4	1	6	4	74
119	1137-Did-Uzuuk-ML-OR-1-MOR-1	guinea pig	2	M	OR	75	d	NR	NR	NR	F	MOR	MOR	MORT	WO		3	10	8	10	10	10	9	4	10	6	4	81
120	1150-Did-Wasse-ML-DR-1-MOR-3	rabbit	2	M	DR	5	w	NR	NR	YO	M	MOR	MOR	MORT	WO		4.6	10	5	5	10	6	9	4	10	6	4	69
121	1127-Did-Snew-ML-FD-1-MOR-1	rat	2	U	FD	42	d	NR	NR	JV	BH	MOR	MOR	MORT	WO		13.5	10	10	5	10	5	9	4	10	6	4	73

Figure 4.6 Example of Mammalian TRV Derivation for Dieldrin



Result number → 1) 10 - C

Reference Number → 1)

Test Species → C

Test Species Key

D = dog
R = rat
M = mouse

Dr = deer
Rb = rabbit
Ble = blesbuck (antelope)

G = Guinea Pig
S = Sheep

Wildlife TRV Derivation Process

1) There are at least three results available for two test species within the GRO, REP and MOR effect groups.
2) There are three NOAEL results available for calculation of a weighted geometric mean.
3) The weighted geometric mean of the adjusted NOAELs for REP and GRO equals 0.80 mg dieldrin/kg BW/day.
4) The weighted geometric mean NOAEL is slightly lower than the lowest LOAEL for mortality at 0.89 mg dieldrin/kg BW/day.
5) The avian wildlife TRV for dieldrin is equal to 0.80 mg dieldrin/kg BW/day.

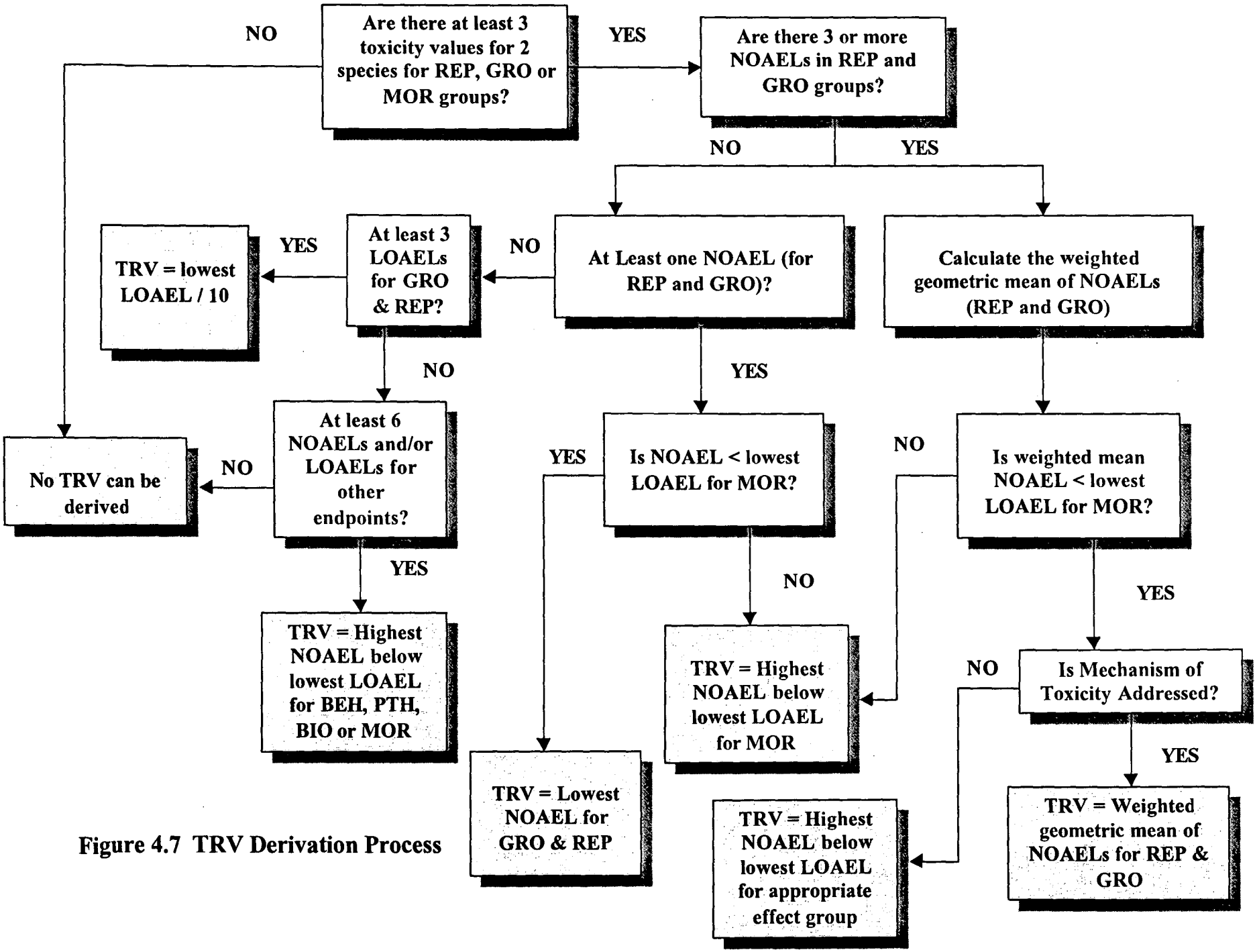


Figure 4.7 TRV Derivation Process

The results of the wildlife TRV derivation process for each contaminant are provided as Appendix 4-6.

4.5 Calculation of Wildlife Eco-SSLs

The Eco-SSL wildlife risk model (Equation 4-1) may be expressed in two forms, depending on the method used to estimate contaminant concentrations in food items (B_i).

1) If a BAF was used to estimate the contaminant concentrations in food items (bioaccumulation), then the equation was:

$$HQ_j = \frac{\left([Soil_j \times P_s \times FIR \times AF_{js}] + \sum_{i=1}^{N} (Soil_j \times T_{ij}) \times P_i \times FIR \times AF_{ij}]\right) \times AUF}{TRV_j} \qquad \textit{(Equation 4-2)}$$

where:

T_{ij} = soil-to-biota BAF (units- dry weight to dry weight) for contaminant (j) for food type (i)

2) If regression models were used, then the equation was:

$$HQ_j = \frac{\left([Soil_j \times P_s \times FIR \times AF_{js}] + \sum_{i=1}^{N} e^{B0_{ij} + \ln(Soil_j) \times B1_{ij}} \times P_i \times FIR \times AF_{ij}]\right) \times AUF}{TRV_j} \qquad \textit{(Equation 4-3)}$$

where:

e = Napierian constant (2.7182818),

$B0_{ij}$ = Intercept from log-linear bioaccumulation model for contaminant (j) for biota type (i), and

$B1_{ij}$ = slope from log-linear bioaccumulation model for contaminant (j) for biota type (i)

The general procedure for calculating the wildlife Eco-SSL involves inverting the BAF or loglinear forms of the exposure models (Equations 4-2 and 4-3, respectively) to determine the contaminant concentration in soil that is equivalent to an HQ = 1. Exposure models that employ BAFs are a simple linear function of the soil concentration and may be inverted algebraically. However, when the exposure model incorporates the loglinear bioaccumulation models, numerical methods are required.

The solution to the Eco-SSL exposure model using a simple BAF is outlined below. Equation 4-2 can be rewritten as:

$$HQ_j \; ' \; \frac{\left([P_s \; (\; FIR \; (\; AF_{js}]\% [\; \sum_{i'1}^{N} \; (T_{ij}) (\; P_i \; (\; FIR \; (\; AF_{ij}] \right) \; (Soil_j \; (AUF}{TRV_j} \qquad \textit{(Equation 4-4)}$$

Multiplication of both sides of equation 4-4 by $\frac{1}{Soil_j}$ and $\frac{1}{HQ_j}$ produces:

$$\frac{1}{Soil_j} \; ' \; \frac{\left([P_s \; (\; FIR \; (\; AF_{js}]\% [\; \sum_{i'1}^{N} \; (T_{ij}) (\; P_i \; (\; FIR \; (\; AF_{ij}] \right) \; (AUF}{TRV_j \; (\; HQ_j} \qquad \textit{(Equation 4-5)}$$

Inversion of equation 4-5 produces:

$$Soil_j \; ' \; \frac{TRV_j \; (\; HQ_j}{\left([P_s \; (\; FIR \; (\; AF_{js}]\% [\; \sum_{i'1}^{N} \; (T_{ij}) (\; P_i \; (\; FIR \; (\; AF_{ij}] \right) \; (AUF} \qquad \textit{(Equation 4-6)}$$

<u>where:</u>

$Soil_j$= the Eco-SSL for contaminant j for wildlife and TRV_j is equal to a no-effect level.

Solution of the log-linear form of the wildlife Eco-SSL model is more complex than the BAF-based model. An algorithm, implemented through a spreadsheet, was derived to facilitate the solution of this form of the model. A description of the solution to the log-linear form of the wildlife Eco-SSL model and the code for the algorithm are both presented in Appendix 4-2.

Wildlife Eco-SSLs. In order to calculate wildlife Eco-SSLs, Equation 4-6 was rearranged, with the removal of all parameters that were set to 1, resulting in the following simplified model:

$$Soil_j \; ' \; \frac{TRV_j}{FIR*[P_s\% \; T_{ij}]} \qquad \textit{(Equation 4-7)}$$

where:

$Soil_j$	=	Contaminant 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	=	Soil ingestion as proportion of diet,
TRV_j	=	Toxicity reference value for contaminant (j) (mg [dry weight]/kg BW [wet weight] /d),
T_{ij}	=	Soil-to-biota BAF for contaminant (j) for biota type (i).

In some cases where soil-to-biota BAFs were not available it was necessary to use a string of BAFs (for example: (BAF for soil to earthworm + BAF for earthworm to shrew) in which case the equation was reduced to:

$$Eco\&SSL_{pred} \; ' \; \frac{TRV_j}{FIR*[P_s\% \; (\; T_{ij} \; (\; T_{ver})]} \qquad \textit{(Equation 4-8)}$$

where:

T_{ver}	=	diet to biota BAF

Eco-SSLs were calculated for each contaminant for each surrogate receptor. The results of the calculations are presented as Appendix 4-2. The Eco-SSLs currently derived for wildlife are summarized in Chapter 5.

5.0 ECO-SSL SUMMARIES

Presented below are summaries of the Eco-SSL values derived for each contaminant and receptor group. The summaries provide a brief review of the contaminant including environmental forms, sources, background concentrations, mechanisms of toxicity, and essential element status (if applicable). Separate discussion are provided for each receptor group including plants, soil invertebrates, avian wildlife and mammalian wildlife. Some synopses are not yet complete as Eco-SSL derivation is pending receipt of toxicological studies for review. The Eco-SSLs are rounded to two significant digits.

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 disposal activities. As part of the Eco-SSL project, available data for the background concentrations of metals are summarized in a report that is further discussed in Chapter 6. It is anticipated that as the user of the Eco-SSLs performs other site specific studies as part of the baseline risk assessment, the resulting soil contaminant concentrations found to be protective may be substantially higher.

5.1 Antimony

Table 5.1 Antimony Eco-SSLs (mg/kg dry weight in soil)

Plants	Soil Invertebrates	Wildlife	
		Avian	Mammalian
Pending	NA	NA	21

NA = Not Available. Data was either not available or insufficient to derive Eco-SSL.

Antimony (Sb, stibium) is a semi-metallic element belonging to group VA of the periodic table and sharing some chemical properities with lead, arsenic, and bismuth (U. S. EPA, 1992). In nature, antimony is associated with sulfur as stibnite. Antimony also occurs in ores with arsenic, and the two metals share similar chemical and physical properties. Antimony is a common component of lead and copper alloys and is used in the manufacture of ceramics, textiles, paints, explosives, batteries, and semiconductors. Major sources of environmental contamination are smelters, coal combustion, and incineration of waste and sewage sludge. In the past, antimony compounds have been used therapeutically as an anti-helminthic and anti-protozoic treatment. This practice has been largely discontinued as a result of antimony toxicity.

Antimony exists in valences of 0, -3, +3, +5. The tri- and pentavalent forms are the most stable forms of antimony (U.S. EPA, 1992) and are of the most interest in biological systems. The toxicokinetics and toxicity of the tri- and pentavalent forms vary, with the trivalent form considered to be more toxic.

Ingested antimony is absorbed slowly, and many antimony compounds are reported to be gastrointestinal irritants. Trivalent antimony is absorbed more slowly than the pentavalent form. Approximately 15-39% of trivalent antimony is reported to be absorbed in the gastrointestinal tract of animals (Rossi et al., 1987). The toxic effects of antimony in mammals involves cardiovascular changes. Observed changes include degeneration of the myocardium, arterial hypotension, heart dysfunction, arrhythmia, and altered electrocardiogram patterns (Rossi et al. 1987). The mode of action for antimony-induced cardiotoxicity is unknown.

The Eco-SSL values derived to date for antimony are summarized in Table 5.1. Eco-SSL values for antimony are not available for plants and soil invertebrates or avian wildlife. For these receptor groups, data was insufficient to derive soil screening values. An Eco-SSL value for antimony is available for mammalian wildlife.

Plant Eco-SSL for Antimony

An Eco-SSL value could not be derived for plants at this time. The literature search process (Exhibit 3-1) identified thirteen papers for review. Six of these studies did not pass the Literature Acceptance Criteria. The remaining seven papers have not been received for review.

Soil Invertebrate Eco-SSL for Antimony

An Eco-SSL value could not be derived for soil invertebrates at this time. The literature search process (Exhibit 3-1) did not identify any acceptable literature studies for the toxicity of antimony in soil to soil invertebrates.

Avian Eco-SSLs for Antimony

The literature search process for wildlife TRVs (described in Exhibit 4-1) did not identify any toxicological studies of antimony and birds. At this time an Eco-SSL can not be derived for avian receptors for antimony.

Mammalian Eco-SSLs for Antimony

The electronic and manual literature search process for wildlife toxicity data (Exhibit 4-1) for antimony identified 46 studies. Of these, ten studies contained data used to derive the TRVs used to calculate the Eco-SSL, 34 studies were rejected for use and two studies could not be located for review. As described in Chapter 4, three separate Eco-SSL values are calculated for mammalian wildlife, one each for three surrogate species representing different trophic levels: herbivores (vole), ground insectivores (shrew) and carnivores (weasel). The lowest value for these three species is the mammalian Eco-SSL.

The mammalian Eco-SSLs for antimony derived for the following surrogate species are as calculated as follows:

Calculation of Wildlife Eco-SSLs Antimony						
Surrogate Receptor Group	**TRV_j (mg dw/kg BW/d)**	**FIR (kg/kg/d)**	**P_s**	**T_{ij}**	**T_{ver}**	**Eco-SSL (mg/kg dw) (*Soil*$_j$)**
Mammalian herbivore (vole)	4.4	0.58	0.029	Estimated by log-linear uptake model solved for HQ =1		120
Mammalian ground insectivore (shrew)	4.4	0.2	0.03	1	NA	21
Mammalian carnivore (weasel)	4.4	0.1	0.04	1	0.001	1100*

Sources and derivatio n of the exposure parameters (FIR, P, and T) are provided in Appendix 4-1.
The process for derivation of wildlife TRVs is described in Appendix 4-5 and the results are provided in Appendix 4-6.

$$\text{Eco-SSL} = Soil_j - TRV_j / FIR * [P_s + T_{ij}]$$
$$*\text{Eco-SSL}_{pred} = TRV_j / FIR * [P_s + (T_{ij} + T_{ver})]$$

$Soil_j$	=	Contaminant 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	=	Soil ingestion as proportion of diet,
TRV_j	=	Toxicity reference value for contaminant (j) (mg [dry weight]/kg BW [wet weight] /d) for contaminant (j),
T_{ij}	=	Soil-to-biota BAF for contaminant (j) for biota type (i),
T_{ver}	=	Diet to biota BAF.

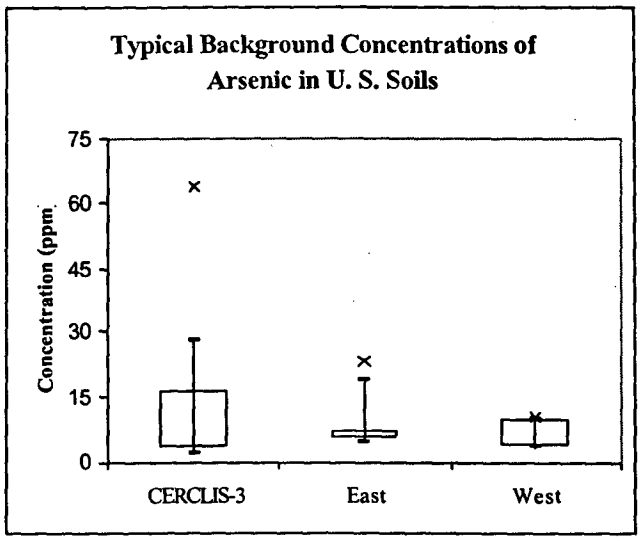
5.2 Arsenic

Table 5.2 Arsenic Eco-SSLs (mg/kg dry weight in soil)			
Plants	**Soil Invertebrates**	**Wildlife**	
		Avian	**Mammalian**
37	Pending	Pending	Pending

Arsenic is naturally present in rock and soils with concentrations in soils reflecting by the geology of the region as well as anthropogenic inputs. Higher concentrations are associated with igneous and sedimentary rocks, particularly with sulfidic ores (API, 1998). Extensive discussions of the sources, concentrations and chemical species are presented in NAS (1977) and Cullen and Reimer (1989).

Arsenic is used in multiple manufacturing and industrial processes including the production of wood treating chemicals, herbicides, pesticides, desiccants, metal alloys, glass, pharmaceuticals and semi-conductors. Elevated arsenic soil concentrations are often associated with mining activities, smelters, pesticide/herbicide manufacturing facilities and agricultural lands (API, 1998).

Arsenic can exist in four oxidation stats: +5, +3, 0 and -3. In soil, arsenic is a constituent of numerous minerals and is found frequently associated with sulfur, most commonly as arsenopyrite (FeAsS). Inorganic arsenate can also be bound to iron and aluminum cations, or any other cation that may be present (e.g., calcium, zinc, magnesium, lead) as well as organic matter in soils (API, 1998).



Arsenic occurs in contaminated soils primarily as the inorganic arsenic (V) and arsenic (III) but soil microorganisms can produce organic forms (Cullen and Reimer, 1989; Huang, 1994; CCME, 1996a). Transformations among inorganic and organic forms are controlled by the oxidation-reduction, precipitation/adsorption, and biomethylation processes in addition to the biological production and volatilization of the arsines (API, 1998). The availability or solubility of arsenic in soils depends on the source (natural vs. anthropogenic) and the soil's clay content, redox potential and pH. Generally, factors that tend to increase arsenic availability are anthropogenic source (e.g., pesticides), low clay content, low redox potential (reducing conditions) and high pH (alkaline conditions) (Cullen and Reimer, 1989, API, 1998).

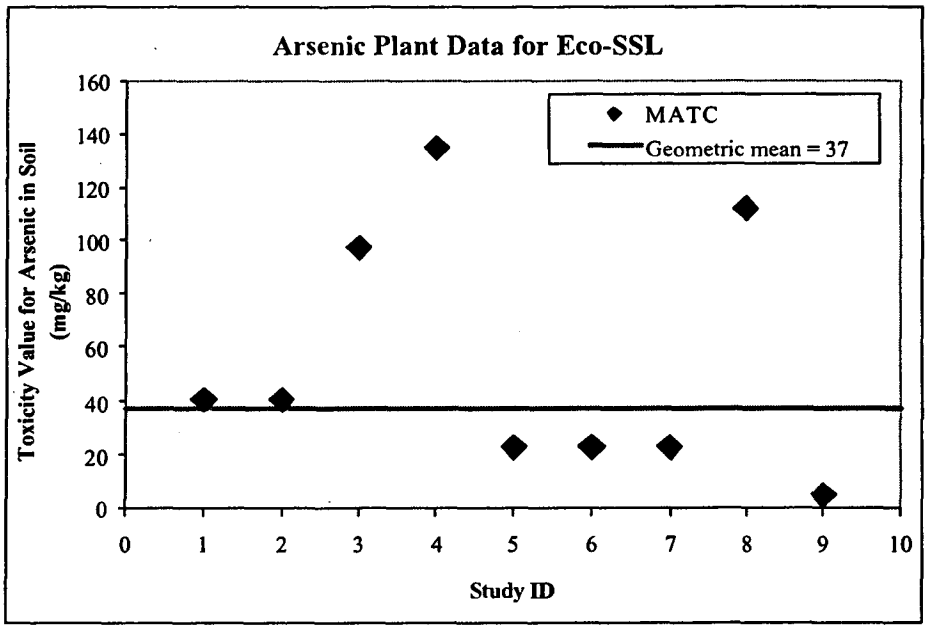
The Eco-SSL values derived to date for arsenic are summarized in Table 5.2. Eco-SSL values for arsenic are not yet available for soil invertebrates, avian wildlife or mammalian wildlife. An Eco-SSL value for arsenic is available for plants.

Plant Eco-SSL for Arsenic

The following table and graph summarize the data used to derive the plant Eco-SSL for arsenic.

Summary of Data used to Derive Plant Eco-SSL for Arsenic							
Study ID	Reference	Test Organism	Bio-availability Score	ERE	Tox Parameter	Soil Conc. (mg/kg dw)	Level
1	Jacobs (1970)	*Zea mays*	2	GRO	MATC	40	A
2	Jacobs (1970)	*Phaseolus vulgaris*	2	GRO	MATC	40	A
3	Jacobs (1970)	*Pisium sativum*	2	GRO	MATC	97	A
4	Jacobs (1970)	*Solanum tuberosum*	2	GRO	MATC	135	A
5	Jiang (1994)	*Lolium perenne*	2	GRO	MATC	22	A
6	Jiang (1994)	*Lolium perenne*	2	GRO	MATC	22	A
7	Jiang (1994)	*Hordeum vulgare*	2	GRO	MATC	22	A
8	Jiang (1994)	*Hordeum vulgare*	2	GRO	MATC	112	A
9	Jiang (1994)	*Hordeum vulgare*	2	GRO	MATC	4	A

ERE = Ecologically Relevant Endpoint, described in Appendix 3-1
Tox Parameter = Maximum Acceptable Threshold Concentration (MATC) or EC_{xx} described in Appendix 3-1
Soil Conc. = Concentration of contaminant in soil (mg/kg) for the corresponding ERE and Tox parameter.
Level = Preference level (described in Appendix 3-1).



The plant Eco-SSL for arsenic was derived from "A" level data (described in Chapter 3 and Appendix 3-1). The data set of nine records was obtained from two papers and six species. All of the toxicity data were based on growth (GRO) effects, a chronic endpoint. The experiments were conducted with natural soils under conditions of high or very high bioavailability.

The plant Eco-SSL for arsenic of 37 mg/kg dw is greater than the background concentration of arsenic in most locations (Exhibit 5-1), and higher than most other soil screening values (Exhibit 1-1).

Soil Invertebrate Eco-SSL for Arsenic

An Eco-SSL value for arsenic could not be derived for soil invertebrates at this time. The literature search process (Exhibit 3-1) identified some acceptable literature studies but the review of these is not yet complete.

Avian and Mammalian Eco-SSLs for Arsenic

The literature search process for avian and mammalian toxicity data (Exhibit 4-1) is in progress for arsenic.

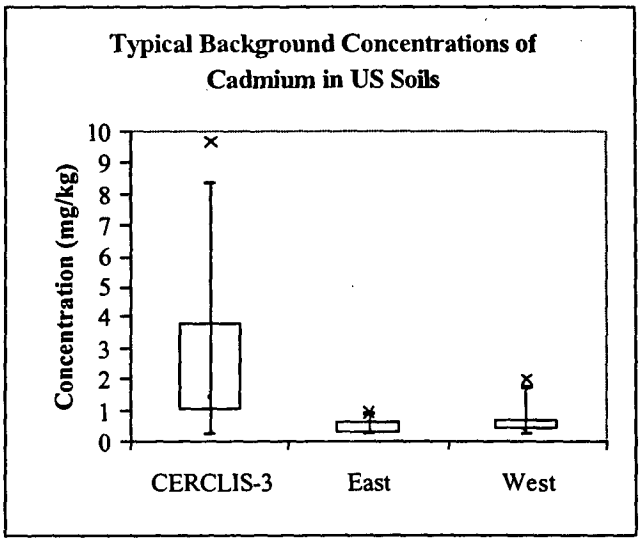
5.3 Cadmium

Table 5.3 Cadmium Eco-SSLs (mg/kg dry weight in soil)

Plants	Soil Invertebrates	Wildlife	
		Avian	Mammalian
29	110	Pending	Pending

Pending = Derivation not complete

Cadmium is a naturally occurring rare element that does not have any known essential or beneficial biological function (Eisler, 1985; OSHA, 1992). Cadmium is used as an anticorrosive electroplated onto steel, as an electrode component in alkaline batteries, as a component of solders and welding electrodes and as a stabilizer of plastics, ceramics and paint. Cadmium is also released to the environment by anthropogenic activities including mining, and the production of sewage-sludges and phosphate fertilizers (Hutton, 1983; Shore and Douben, 1994 and Van Enk, 1983).



Cadmium is a divalent metal that is insoluble in water but its chloride and suphate salts are freely soluble. The availability of cadmium to organisms in the environment is dependant on a number of factors including pH, Eh, and chemical speciation (Eisler, 1985). Cadmium is taken up by plants from

soils and translocated with subsequent transfer through the terrestrial food chain (Shore and Douben, 1994). The main routes of cadmium absorption for mammals are via respiration and ingestion. Factors that are reported to affect dietary cadmium absorption from the GI tract include age, sex, chemical form, levels of protein, levels of calcium and the presence of other elements (Nriagu, 1981). Cadmium-induced effects associated with oral intake include nephrotoxicity and also possible effects on the liver, hematopoietic, reproductive organs, immune, skeletal and cardiovascular systems (Shore and Douben, 1994).

The Eco-SSL values derived to date for cadmium are summarized in Table 5.3. Eco-SSL values for cadmium are not yet available for avian or mammalian wildlife. Eco-SSLs are available for plants and soil invertebrates.

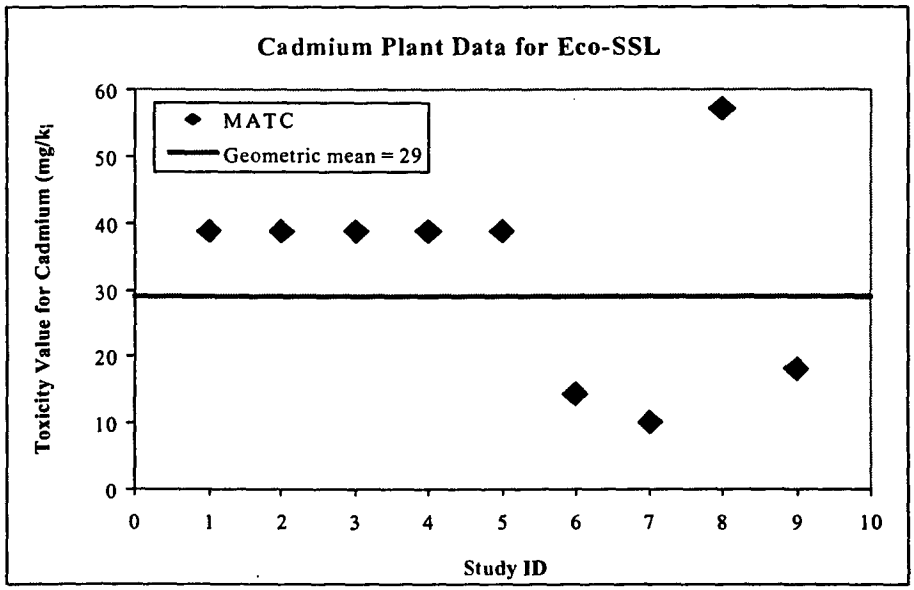
Plant Eco-SSL for Cadmium

The following table and graph summarize the data used to derive the plant Eco-SSL for cadmium:

Summary of Data used to Derive Plant Eco-SSL for Cadmium

Study ID	Reference	Test Organism	Bio-availability Score	ERE	Tox Parameter	Soil Conc. (mg/kg dw)	Level
1	Kelly (1979)	*Pinus strobus*	2	GRO	MATC	39	A
2	Kelly (1979)	*Pinus taeda*	2	GRO	MATC	39	A
3	Kelly (1979)	*Betula allenghaniensis*	2	GRO	MATC	39	A
4	Kelly (1979)	*Prunus virginiana*	2	GRO	MATC	39	A
5	Kelly (1979)	*Pinus strobus*	2	GRO	MATC	39	A
6	Dixon 1988	*Querus rubras*	2	GRO	MATC	14	A
7	Adema (1989)	*Lactuca sativa*	2	GRO	MATC	10	A
8	Adema (1989)	*Lycopersicum esculentum*	2	GRO	MATC	57	A
9	Adema (1989)	*Avena sativa*	2	GRO	MATC	18	A

ERE = Ecologically Relevant Endpoint, described in Appendix 3-1
Tox Parameter = Maximum Acceptable Threshold Concentration (MATC) or EC_{xx} described in Appendix 3-1
Soil Conc. = Concentration of contaminant in soil (mg/kg) for the corresponding ERE and Tox parameter.
Level = Preference level (described in Appendix 3-1).



The plant Eco-SSL for cadmium was derived from "A" level data (described in Chapter 3 and Appendix 3-1). The data set of nine records was obtained from three papers and eight species. All of the toxicity data were based on growth (GRO) effects, a chronic endpoint. The experiments were conducted with natural soils under conditions of high or very high bioavailability.

The plant Eco-SSL for cadmium of 29 mg/kg is greater than the reported background concentrations of cadmium (Exhibit 5-1), and higher than most other available soil screening values (Exhibit 1-1).

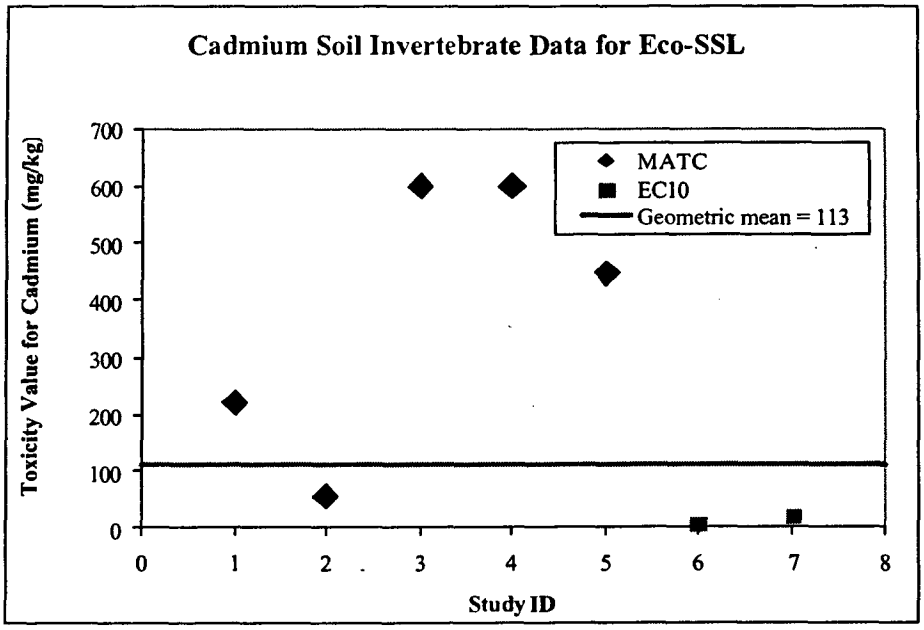
Soil Invertebrate Eco-SSL for Cadmium

The following table and graph summarize the data used to derive the soil invertebrate Eco-SSL for cadmium.

Summary of Data used to Derive Soil Invertebrate Eco-SSL for Cadmium							
Study ID	**Reference**	**Test Organism**	**Bio-availability Score**	**ERE**	**Tox Parameter**	**Soil Conc. (mg/kg dw)**	**Level**
1	Crommentuijin (1993)	*F. Candida*	1	REP	MATC	220	B
2	Kammenga (1994)	*P. acuminatus*	1	POP	MATC	57	B
3	Sandifer (1996)	*F. Candida*	1	REP	MATC	600	B
4	Sandifer (1996)	*F. Candida*	1	REP	MATC	600	B
5	Sandifer (1997)	*F. Candida*	1	REP	MATC	447	B
6	Van Gestel (1997)	*F. Candida*	1	POP	EC10	6	B
7	Van Gestel (1997)	*F. Candida*	1	POP	EC10	19	B

Summary of Data used to Derive Soil Invertebrate Eco-SSL for Cadmium							
Study ID	Reference	Test Organism	Bio-availability Score	ERE	Tox Parameter	Soil Conc. (mg/kg dw)	Level

ERE = Ecologically Relevant Endpoint, described in Appendix 3-1
Tox Parameter = Maximum Acceptable Threshold Concentration (MATC) or EC_{xx} described in Appendix 3-1
Soil Conc. = Concentration of contaminant in soil (mg/kg) for the corresponding ERE and Tox parameter.
Level = Preference level (described in Appendix 3-1).



The invertebrate Eco-SSL for cadmium was derived from "B" level data (described in Chapter 3 and Appendix 3-1). The data set of seven records was obtained from five papers and two species. The toxicity data were based on reproductive (REP) and population (POP) effects, both chronic endpoints. All of the data were from experiments conducted under conditions of medium bioavailability.

The invertebrate Eco-SSL for cadmium of 110 mg/kg is much greater than the reported background concentrations of cadmium (Exhibit 5-1), and higher than most other available soil screening values (Exhibit 1-1).

Avian and Mammalian Eco-SSLs for Cadmium

The literature searches were completed for the identification of toxicity data for cadmium and avian and mammalian wildlife. This search identified over 544 total citations for retrieval and review. To date, 228 citations have been rejected for use in deriving the wildlife TRVs. The review of the remaining literature has not, however, been completed.

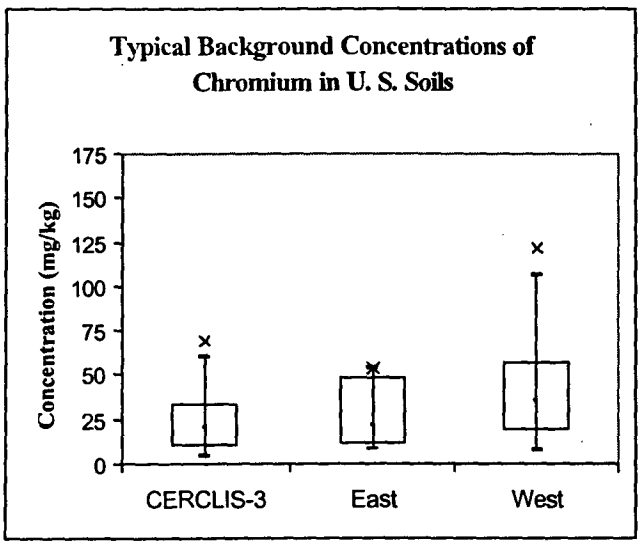
5.4 Chromium

Table 5.4 Chromium Eco-SSLs (mg/kg dry weight in soil)			
Plants	Soil Invertebrates	Wildlife	
		Avian	Mammalian
5	Pending	21- Chromium (III) NA - Chromium (VI)	360 - Chromium (III) 330 - Chromium (VI)
NA = Not Available. Data was either not available or insufficient to derive Eco-SSL.			

Chromium is the 21st most common element in the earth's crust. Chromium ore deposits are primarily used for metallurgical applications such as the production of stainless steel. Other uses include wood preservation, leather tanning, pigments and refractories (Barnhardt, 1997). In the natural environment, chromium occurs as two oxidation states or valences: chromium (III) and chromium (VI).

Chromium speciation in soils is complex. Among the factors that affect the speciation of chromium in soil and water and its uptake into animals and plants include: organic matter content, ferrous ion content, and redox state, and pH (Outridge and Scheuhammer, 1993; CCME, 1996b). In general, chromium (VI) is favored by higher pH, aerobic conditions, low amounts of organic matter and the presence of manganese and iron oxides which oxidize chromium (III). Transformation of chromium (VI) to the trivalent form tends to occur in acidic, anoxic soils with high organic content. Chromium (III) is cationic and adsorbs onto clay particles, organic matter, metal oxyhydroxides and other negatively charged particle in contrast to chromium (VI) which does not interact significantly with clay or organic matter. As a result, chromium (VI) is more water-soluble and mobile than chromium (III) (Outridge and Scheuhammer, 1993).

Plants are reported to play a major role in the geochemistry of chromium as they contain a significant fraction of the biologically active pool of chromium, approximately three orders of magnitude greater than that found in animal tissues. In contrast to animals, chromium (III) uptake by plants occurs more rapidly than chromium (VI). It is uncertain, however, if chromium is an essential element for plant nutrition although some investigators have observed a stimulatory effect of chromium on plant growth (Outridge and Scheuhammer, 1993).



Chromium has, however, been shown to be an essential nutrient for humans and animals (NRC, 1997). Several reviews are available concerning its role in nutrition (Anderson, 1987; Anderson, 1988, Borel and Anderson, 1984; Prasad, 1978 and Underwood, 1977). Chromium (III) has been shown to have antioxidative properties in vivo and it is integral in activating enzymes and maintaining the stability of proteins and nucleic acids. Its primarily metabolic role is to potentiate the action of insulin through its presence in an organometallic molecule called the glucose tolerance factor (GTF).

The hexavalent forms of chromium are absorbed three to five times better in the intestine compared to chromium (III) forms. Some evidence suggests that ingested orally, most of the chromium (VI) is believed to be reduced to chromium (III) before reaching sites of absorption in the small intestine (Outridge and Scheuhammer, 1993). Anionic forms of both chromium (III) and chromium (VI) are absorbed more rapidly than the cationic forms (Eastin et al, 1980). Chromium in synthetic organic forms is more readily absorbed and accumulated into tissues compared to the inorganic forms of chromium (NRC, 1997). Chromium toxicosis in ruminants is associated with severe congestion and inflammation of the digestive tract, kidney and liver damage with the precipitating properties of chromium believed to be the basis of the tissue damage (Thompson et al., 1991).

The Eco-SSL values derived to date for chromium are summarized in Table 5.4. Eco-SSL values for chromium (III) or chromium (VI) are not yet available for soil invertebrates. The derivation of these values is pending further review of identified literature studies. Eco-SSL values are not available for avian wildlife for chromium (VI) as no appropriate dose-response data was identified from the literature search process to derive a TRV.

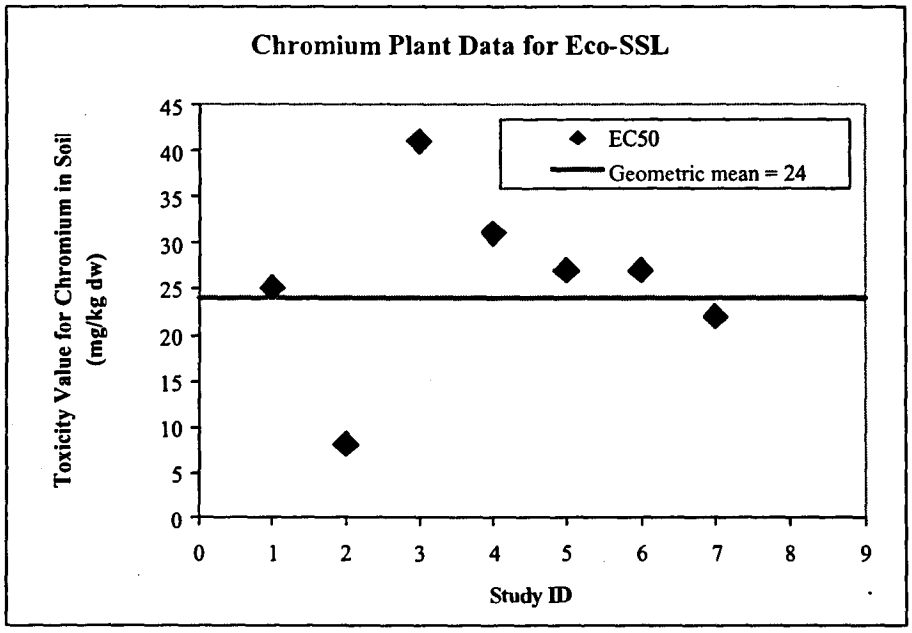
Plant Eco-SSL for Chromium

The following table and graph summarize the data used to derive the plant Eco-SSL for cadmium.

Summary of Data used to Derive Plant Eco-SSL for Chromium

Graph ID	Reference	Test Organism	Bio-availability Score	ERE	Tox Parameter	Soil Conc. (mg/kg dw)	Level
1	Gunther (1990)	*Avena sativa*	2	GRO	EC50	25	D
2	Gunther (1990)	*Brassica rapa*	2	GRO	EC50	8	D
3	Gunther (1990)	*Avena sativa*	2	GRO	EC50	41	D
4	Gunther (1990)	*Lycopersicon esculentum*	2	GRO	EC50	31	D
5	Gunther (1990)	*Avena sativa*	1	GRO	EC50	27	D
6	Gunther (1990)	*Lycopersicon esculentum*	1	GRO	EC50	27	D
7	Gunther (1990)	*Latuca sativa*	1	GRO	EC50	22	D

ERE = Ecologically Relevant Endpoint, described in Appendix 3-1
Tox Parameter = Maximum Acceptable Threshold Concentration (MATC) or EC_{xx} described in Appendix 3-1
Soil Conc. = Concentration of contaminant in soil (mg/kg) for the corresponding ERE and Tox parameter.
Level = Preference level (described in Appendix 3-1).



The plant Eco-SSL for chromium was derived from "D" level data (described in Chapter 3 and Appendix 3-1). The data set of seven records was obtained from one paper and five species. All of the toxicity data were based on growth (GRO) effects, a chronic endpoint. The experiments were conducted under conditions medium to high or very high bioavailability. The geometric mean of the data was divided by 5 to account for use of EC_{50} data in deriving the Eco-SSL. It is recommended that further testing on the effects of chromium on plants be completed to strengthen the data set.

The plant Eco-SSL for chromium of 24 mg/kg is within the range of reported background concentrations of chromium (Exhibit 5-1), and lower than most other available soil screening values for chromium (Exhibit 1-1).

Soil Invertebrate Eco-SSL for Chromium

Chromium Eco-SSL values for soil invertebrates are not yet available. The literature search process (Exhibit 3-1) identified some acceptable literature studies but the review of these is not yet complete.

Avian and Mammalian Eco-SSLs for Chromium

The electronic and manual literature search process (Exhibit 4-1) for chromium identified 113 studies. Of these, 27 studies contained data used to derive the TRV for the Eco-SSL, 63 studies were rejected for use and 22 are pending receipt for review. As described in Chapter 4, six separate Eco-SSL values are calculated for wildlife, one each for six surrogate species representing different trophic levels. Eco-SSLs are calculated separately for trivalent and hexavalent chromium.

The avian and mammalian Eco-SSLs for chromium derived for the following surrogate species are as follows:

Calculation of Wildlife Eco-SSLs Chromium						
Surrogate Receptor Group	**TRV_j (mg dw/kg BW/d)**	**FIR (kg/kg/d)**	**P_s**	**T_{ij}**	**T_{ver}**	**Eco-SSL (mg/kg dw) ($Soil_j$)**
Avian herbivore (dove)						
Chromium (III)	1.6	0.23	0.16	0.041		33
Chromium (VI)	NA	0.23	0.16	0.041		NA
Avian ground insectivore (woodcock)						
Chromium (III)	1.6	0.17	0.12	0.306		21
Chromium (VI)	NA	0.17	0.12	0.306		NA
Avian carnivore (hawk)						
Chromium (III)	1.6	0.12	0.05	Estimated by log-linear uptake model		83*
Chromium (VI)	NA	0.12	0.05			NA
Mammalian herbivore (vole)						
Chromium (III)	24.5	0.58	0.029	0.041		600
Chromium (VI)	22	0.58	0.029	0.041		540
Mammalian ground insectivore (shrew)						
Chromium (III)	24.5	0.2	0.03	0.306		360
Chromium (VI)	22	0.2	0.03	0.306		330
Mammalian carnivore (weasel)						
Chromium (III)	24.5	0.1	0.04	Estimated by log-linear uptake model		3000
Chromium (VI)	22	0.1	0.04			2700*

Sources and derivation of the exposure parameters (FIR, P, and T) are provided in Appendix 4-1.
The process for derivation of wildlife TRVs is described in Appendix 4-5 and the results are provided in Appendix

$Eco\text{-}SSL = Soil_j - TRV_j / FIR * [P_s + T_{ij}]$
$*Eco\text{-}SSL_{pred} = TRV_j / FIR * [P_s + (T_{ij} + T_{ver})]$

$Soil_j$	=	Contaminant 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	=	Soil ingestion as proportion of diet,
TRV_j	=	Toxicity reference value for contaminant (j) (mg [dry weight]/kg BW [wet weight] /d) for contaminant (j),
T_{ij}	=	Soil-to-biota BAF for contaminant (j) for biota type (i),
T_{ver}	=	Diet to biota BAF.

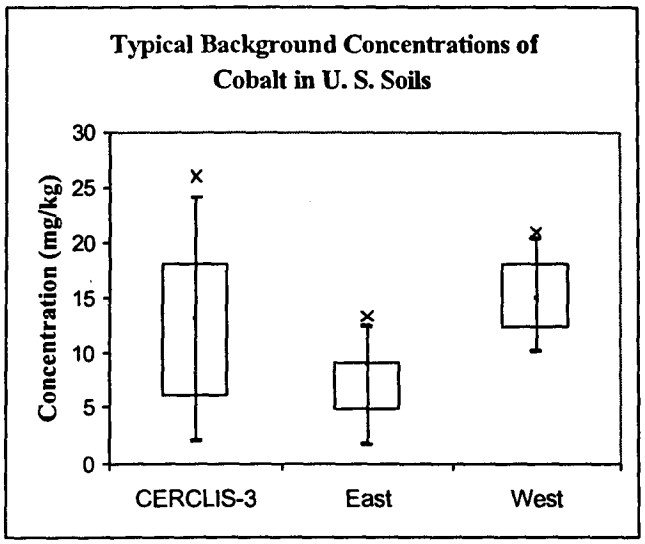
5.5 Cobalt

Table 5.5 Cobalt Eco-SSLs (mg/kg dry weight in soil)			
Plants	Soil Invertebrates	Wildlife	
		Avian	Mammalian
Pending	NA	32	340
NA = Not Available. Data was either not available or insufficient to derive Eco-SSL.			

Cobalt belongs to Group VIII of the periodic classification of elements and shares properties with nickel and iron. Cobalt is a relatively rare element in the earth's crust (0.0023%) and is usually found in association with other metals such as copper, nickel, manganese, and arsenic Release of cobalt to the environment occurs via soil and natural dust, seawater spray, volcanic eruptions, forest fires, and other continental and marine biogenic emissions. Anthropogenic sources include fossil fuel burning, processing of cobalt-containing alloys, copper and nickel smelting and refining, sewage sludge, and agricultural use of phosphate fertilizers.

Cobalt is an essential trace metal that functions as a component of vitamin B_{12}. Vitamin B_{12} acts as coenzyme in many enzymatic reactions, including some involved in hematopoiesis, and is essential to growth and normal neural function. Non-ruminant animals require dietary intake of cobalt in the physiologically active form of vitamin B_{12}. Intake of inorganic cobalt is sufficient to meet the nutritional requirements of ruminant animals, since ruminal microorganisms have the capacity to biosynthesize vitamin B_{12} (Henry, 1995). No other essential functions of cobalt have been identified.

Although cobalt is an essential nutrient, excessive oral doses result in a variety of adverse responses. The best characterized toxic responses are increases in red blood cell counts (polycythemia), cardiomyopathy, and effects on the male reproductive system (Paternain et al., 1988; Haga et al., 1996, Pedigo et al., 1988). In addition, reduced food and water intake and growth inhibition are commonly observed (Diaz et al., 1994a; 1994b). At present, the mechanisms underlying cobalt toxicity are poorly understood.



The Eco-SSL values derived to date for cobalt are summarized in Table 5.5. Eco-SSL values for cobalt are not available for plants and soil invertebrates. For these receptor groups, data was

insufficient to derive soil screening values.

Plant Eco-SSL for Cobalt

A cobalt Eco-SSL value could not be derived for plants at this time. The literature search process (Exhibit 3-1) identified 75 papers for review. Of these, 35 did not pass the Literature Acceptance Criteria. The remaining papers have not been received for review.

Soil Invertebrate Eco-SSL for Cobalt

A cobalt Eco-SSL value could not be derived for soil invertebrates at this time. The literature search process (Exhibit 3-1) identified 13 papers for review. Of these, 11 papers did not meet the Literature Acceptance Criteria, one met the criteria and one has not been received for review.

Avian and Mammalian Eco-SSLs for Cobalt

The electronic and manual literature search process (Exhibit 4-1) for cobalt identified 115 studies. Of these, 30 studies contained data extracted and used to derive the Eco-SSL, 85 studies were rejected for use and two studies could not be located for review. As described in Chapter 4, six separate Eco-SSL values are calculated for wildlife, one each for six receptor groups representing different trophic levels. The lowest value for any of the three mammalian receptor groups is equal to the mammalian Eco-SSL and the lowest of any of the three avian receptor groups is equal to the avian Eco-SSL.

The avian and mammalian Eco-SSLs for cobalt derived for the following surrogate species are as follows:

Calculation of Wildlife Eco-SSLs for Cobalt						
Surrogate Receptor Group	**TRV_j (mg dw/kg BW/d)**	**FIR (kg/kg/d)**	**P_s**	**T_{ij}**	**T_{ver}**	**Eco-SSL (mg/kg dw) ($Soil_j$)**
Avian herbivore (dove)	1.3	0.23	0.16	0.0075		34
Avian ground insectivore (woodcock)	1.3	0.17	0.12	0.122		32
Avian carnivore (hawk)	1.3	0.12	0.05	Estimated by log-linear uptake model		170
Mammalian herbivore (vole)	10.4	0.58	0.029	0.0075		490
Mammalian ground insectivore (shrew)	10.4	0.2	0.03	0.122		340

Calculation of Wildlife Eco-SSLs for Cobalt						
Surrogate Receptor Group	**TRV_j (mg dw/kg BW/d)**	**FIR (kg/kg/d)**	**P_s**	**T_{ij}**	**T_{ver}**	**Eco-SSL (mg/kg dw) ($Soil_j$)**
Mammalian carnivore (weasel)	10.4	0.1	0.04	Estimated by log-linear uptake model		1500*

Sources and derivation of the exposure parameters (FIR, P, and T) are provided in Appendix 4-1.
The process for derivation of wildlife TRVs is described in Appendix 4-5 and the results are provided in Appendix 4-6.

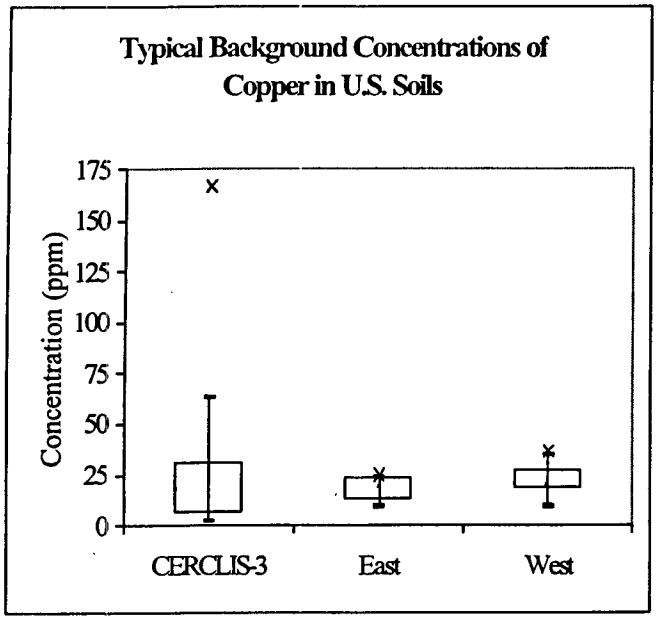
$Eco\text{-}SSL = Soil_j - TRV_j / FIR * [P_s + T_{ij}]$ or
$*Eco\text{-}SSL_{pred} = TRV_j / FIR * [P_s + (T_{ij} + T_{ver})]$

$Soil_j$	=	Contaminant 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	=	Soil ingestion as proportion of diet,
TRV_j	=	Toxicity reference value for contaminant (j) (mg [dry weight]/kg BW [wet weight] /d) for contaminant (j),
T_{ij}	=	Soil-to-biota BAF for contaminant (j) for biota type (i),
T_{ver}	=	Diet to biota BAF.

5.6 Copper

Table 5.6 Copper Eco-SSLs (mg/kg dry weight in soil)			
Plants	**Soil Invertebrates**	**Wildlife**	
		Avian	**Mammalian**
Pending	61	Pending	Pending
Pending = Derivation not complete			

Copper (CAS# 744050-8) is a transition metal that belongs to Group 1B of the periodic table. Copper exists in four valence states (Cu^0, Cu^{+1}, Cu^{+2}, Cu^{+3}) with Cu^{+2} (cupric) being the most common form (CCME, 1997b). Copper is a relatively abundant mineral that occurs in a variety of mineral deposits including elemental copper, but it is most commonly found in deposits of sulphide minerals (CCME, 1997b).



Copper is released into the environment from both anthropogenic and natural sources. Anthropogenic sources include mining operations, agriculture activities, solid waste, and sludge. Natural sources of copper include forest fires and volcanic particulate (NAS, 1977). Atomospheric transport of copper is influenced by adsorption rates. Copper is adsorbed by a wide variety of material, including organic matter, clays, and Al, Fe, and Mn oxides (CCME,1997b, WHO, 1997). Copper deposited in soil is strongly adsorbed by soil particles and has very little mobility relative to other trace metals (CCME, 1997b). Soil pH is an important regulator of copper mobility, decreasing pH tends to increase copper solubility (NAS, 1977, CCME, 1997b).

Copper is an essential element that is required by wide variety of organisms. Nutrient requirements vary among species, but within the plant kingdom they typically range from 5 to 30 ppm in soil. Required levels for soil invertebrates are not readily available. Dietary requirements for birds and mammals are typically less than 10 ppm (Underwood, 1977).

Most organisms are able to regulate their copper levels. However, if the capacity to regulate uptake and distribution is exceeded, copper can interfere with electron transfer functions in plastids (plants) and mitochondria (all organisms). The disruption of electron transport, as well as other secondary toxicity actions by copper can lead to impaired growth, loss of reproductive capacity, or death. Copper concentrates in the tissues of certain organisms, but it does not tend to accumulate or magnify in higher trophic levels.

The Eco-SSL values derived to date for copper are summarized in Table 5.6. Eco-SSL values for copper are not yet available for plants, avian or mammalian wildlife. The retrieval and review of these citations is not yet complete. An Eco-SSL value is, however, available for soil invertebrates.

Plant Eco-SSL for Copper

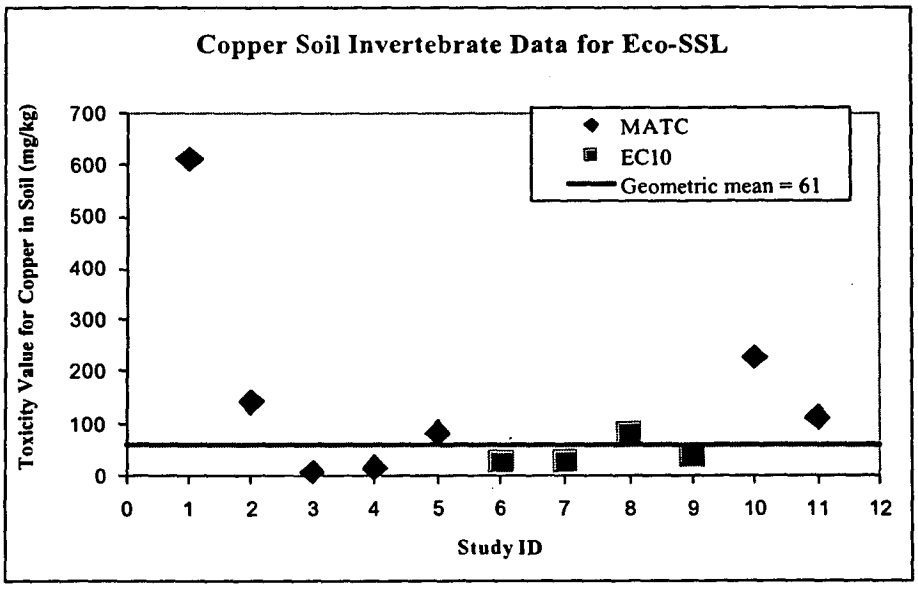
A copper Eco-SSL value for plants is not yet available. The literature search process (Exhibit 3-1) identified some acceptable literature studies but the review of these is not yet complete.

Soil Invertebrate Eco-SSL for Copper

The following table and graph summarize the data used to derive the soil invertebrate Eco-SSL for copper.

Summary of Data used to Derive Soil Invertebrate Eco-SSL for Copper							
Graph ID	Reference	Test Organism	Bio-availability Score	ERE	Tox Parameter	Soil Conc. (mg/kg dry wt.)	Level
1	Kula and Larink (1997)	*E. fetida*	2	REP	MATC[2]	18	A
2	Kula and Larink (1997)	*E. andrei*	2	REP	MATC	6	A
3	Kula and Larink (1997)	*L. rubellus*	2	REP	MATC	84	A
4	Svendsen and Weeks (1997a)	*E. andrei*	2	REP	MATC	113	A
5	Scott-Fordsmand et al. (1997)	*F. fimertaria*	2	REP	EC_{10}	38	A
6	Korthals et al. (1996)	*nematodes*	2	REP	MATC	141	A
7	Svendsen and Weeks (1997b)	*L. rubellus*	2	GRO	MATC	226	A
8	Korthals et al.(1996)	*nematodes*	2	POP	MATC	612	A
9	Ma (1988)	*A. caliginosa*	2	REP	EC10	27	A
10	Ma (1988)	*A. chlorotica*	2	REP	EC10	28	A
11	Ma (1988	*L. rubellus*	2	REP	EC10	80	A

ERE = Ecologically Relevant Endpoint, described in Appendix 3-1
Tox Parameter = Maximum Acceptable Threshold Concentration (MATC) or EC_{xx} described in Appendix 3-1
Soil Conc. = Concentration of contaminant in soil (mg/kg) for the corresponding ERE and Tox parameter.
Level = Preference level (described in Appendix 3-1).



The invertebrate Eco-SSL for plants was derived from "A" level data (described in Chapter 3 and Appendix 3-1). The data set of eleven records was obtained from five papers and seven species. The

toxicity data were based on reproductive (REP) and growth (GRO) effects, both chronic endpoints. All of the data were from experiments conducted with natural soils under conditions of high or very high bioavailability. The tests were conducted with highly soluble salts and neither aging nor weathering, which would lower bioavailability, was included in the experimental designs.

The invertebrate Eco-SSL for copper of 61 mg/kg is above the reported background concentrations of copper in most locations (Exhibit 5-1), and similar to or less than most other available soil screening values for copper (Exhibit 1-1).

Avian and Mammalian Eco-SSLs for Copper

The literature searches were completed for the identification of dose-response data for copper and mammalian and avian wildlife according to the process specified in Exhibit 4-1. This search identified over 382 papers for review. The review of this literature, however, is not complete.

5.7 Dieldrin

Table 5.7 Dieldrin Eco-SSLs (mg/kg dry weight in soil)

Plants	Soil Invertebrates	Wildlife	
		Avian	Mammalian
Pending	Pending	0.011	0.015

Pending = Derivation not complete

The Eco-SSL values derived to date for dieldrin are summarized in Table 5.7. Eco-SSL values for dieldrin are not yet available for plants and soil invertebrates. For these receptor groups, the review of the toxicity literature is not yet complete.

Plant Eco-SSL for Dieldrin

A dieldrin Eco-SSL value could not be derived for plants at this time. The literature search process (Exhibit 3-1) for dieldrin identified 89 papers for review. The review of this literature, however, is not complete.

Soil Invertebrate Eco-SSL for Dieldrin

A dieldrin Eco-SSL value could not be derived for soil invertebrates at this time. The literature search process (Exhibit 3-1) for dieldrin for soil invertebrates identified 81 papers for review. The review of this literature, however, is not complete.

Avian and Mammalian Eco-SSLs for Dieldrin

The electronic and manual literature search process (Exhibit 4-1) for dieldrin identified 276 studies. Of these, 101 studies contained data extracted and used to derive the Eco-SSL, 151 studies were rejected for use and 24 studies are pending retrieval for review. As described in Chapter 4, six separate Eco-SSL values are calculated for wildlife, one each for six receptor groups representing different trophic levels. The lowest value for any of the three mammalian receptor groups is equal to the mammalian Eco-SSL and the lowest of any of the three avian receptor groups is equal to the avian Eco-SSL.

The avian and mammalian Eco-SSLs for dieldrin derived for the following surrogate species are as follows:

Calculation of Wildlife Eco-SSLs Dieldrin						
Surrogate Receptor Group	**TRV_j (mg dw/kg BW/d)**	**FIR (kg/kg/d)**	**P_s**	**T_{ij}**	**T_{ver}**	**Eco-SSL (mg/kg dw) ($Soil_j$)**
Avian herbivore (dove)	0.48	0.23	0.16	Estimated by log-linear uptake model		10
Avian ground insectivore (woodcock)	0.48	0.17	0.12	267		0.011
Avian carnivore (hawk)	0.48	0.12	0.05	267	0.9091	0.017*
Mammalian herbivore (vole)	0.8	0.58	0.029	Estimated by log-linear uptake model		20
Mammalian ground insectivore (shrew)	0.8	0.2	0.03	267		0.015
Mammalian carnivore (weasel)	0.8	0.1	0.04	267	0.9091	0.032*

Sources and derivation of the exposure parameters (FIR, P, and T) are provided in Appendix 4-1.
The process for derivation of wildlife TRVs is described in Appendix 4-5 and the results are provided in Appendix 4-6.

$Eco\text{-}SSL = Soil_j - TRV_j / FIR * [P_s + T_{ij}]$ or
$*Eco\text{-}SSL_{pred} = TRV_j / FIR * [P_s + (T_{ij} + T_{ver})]$

$Soil_j$	=	Contaminant 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	=	Soil ingestion as proportion of diet,
TRV_j	=	Toxicity reference value for contaminant (j) (mg [dry weight]/kg BW [wet weight] /d) for contaminant (j),
T_{ij}	=	Soil-to-biota BAF for contaminant (j) for biota type (i),
T_{ver}	=	Diet to biota BAF.

5.8 RDX

Table 5.8 RDX Eco-SSLs (mg/kg dry weight in soil)			
Plants	Soil Invertebrates	Wildlife	
		Avian	Mammalian
Pending	Pending	NA	5.8
Pending = Derivation not complete			

Hexahydro-1,3,5-Trinitro-1,3,5-Triazine (RDX) is a crystalline high explosive used extensively by the military in shells, bombs and demolition charges. It is commonly referred to as cyclonite or RDX (British code name for Research Department Explosive or Royal Demolition Explosive). Manufacture in the U. S. is by the Bachmann process in which hexamine is reacted with an ammonium nitrate/nitric acid mixture in the presence of acetic acid and acetic anhydride. Military grades of RDX contain about 10% octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX). RDX is released to the environment at sites where it is manufactured as well as sites where it is converted to munitions. Other releases occur at military depot facilities through the demilitarization of obsolete munitions, deposition in landfills and open burning and detonation processes (Talmage et al., 1999).

Once released to soils, RDX does not readily adsorb to soil particles and is resistant to biodegradation under both aerobic and anaerobic conditions. RDX can undergo aerobic biodegradation under special conditions where soil microbs are adapted to RDX (Talmage et al., 1999). Plants are reported that RDX can be taken up from either soil or hydroponic solutions and translocated in plant tissue (Talmage et al., 1999 and Harvey et al., 1991). For mammals, RDX is slowly but extensively absorbed following ingestion.

The Eco-SSL values derived to date for RDX are summarized in Table 5.8. Eco-SSL values for RDX are not yet available for plants and soil invertebrates. The retrieval and review of these citations is not yet complete. An Eco-SSL value could not be derived for avian wildlife as the literature search did not identify any toxicity studies. An Eco-SSL value is, however, available for mammalian wildlife.

Plant Eco-SSL for RDX

An Eco-SSL value could not be derived for plants for RDX at this time. The literature search process (Exhibit 3-1) identified papers for review, however this review is not complete.

Soil Invertebrate Eco-SSL for RDX

An Eco-SSL value could not be derived for plants for RDX at this time. The literature search process (Exhibit 3-1) identified papers for review, however this review is not complete.

Avian Eco-SSLs for RDX

The literature search process for wildlife TRVs (described in Exhibit 4-1) did not identify any toxicological studies of RDX and birds. At this time an Eco-SSL can not be derived for avian receptors for RDX.

Mammalian Eco-SSLs for RDX

The mammalian Eco-SSLs for dieldrin derived for the following surrogate species are as follows:

Calculation of Wildlife Eco-SSLs for RDX						
Surrogate Receptor Group	**TRV_j (mg dw/kg BW/d)**	**FIR (kg/kg/d)**	**P_s**	**T_{ij}**	**T_{ver}**	**Eco-SSL (mg/kg dw) ($Soil_j$)**
Mammalian herbivore (vole)	11.6	0.58	0.029	0.242		74
Mammalian ground insectivore (shrew)	11.6	0.2	0.03	9.91		5.8
Mammalian carnivore (weasel)	11.6	0.1	0.04	9.91	1	12*

Sources and derivation of the exposure parameters (FIR, P, and T) are provided in Appendix 4-1.
The process for derivation of wildlife TRVs is described in Appendix 4-5 and the results are provided in Appendix 4-6.

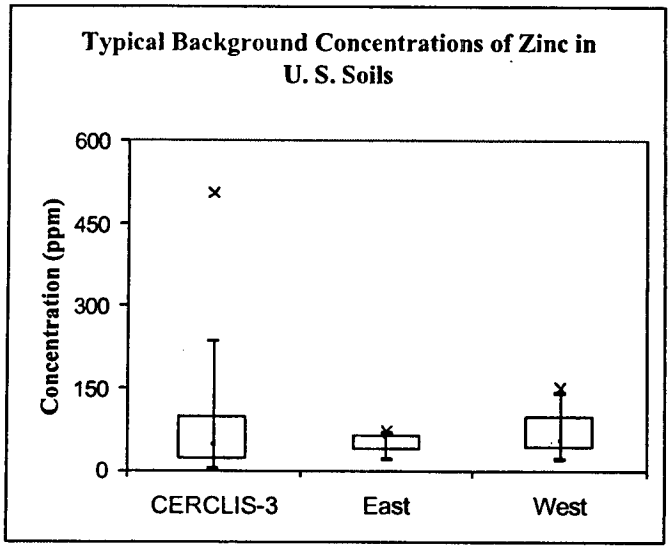
$$\text{Eco-SSL} = Soil_j - TRV_j / FIR * [P_s + T_{ij}]$$
$$*\text{Eco-SSL}_{pred} = TRV_j / FIR * [P_s + (T_{ij} + T_{ver})]$$

$Soil_j$	=	Contaminant 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	=	Soil ingestion as proportion of diet,
TRV_j	=	Toxicity reference value for contaminant (j) (mg [dry weight]/kg BW [wet weight] /d) for contaminant (j),
T_{ij}	=	Soil-to-biota BAF for contaminant (j) for biota type (i),
T_{ver}	=	Diet to biota BAF.

5.9 Zinc

Table 5.9 Zinc Eco-SSLs (mg/kg dry weight in soil)			
Plants	Soil Invertebrates	Wildlife	
		Avian	Mammalian
190	120	Pending	Pending
Pending = Derivation not complete			

Zinc is the 25th most abundant element that is used industrially in the production of galvanized materials, alloys and other products. Anthropogenic sources of zinc in the environment include electroplating, smelting and ore processing, domestic and industrial sewage, combustion of solid waste and fossil fuels, road surface runoff, corrosion of zinc alloy and galvanized surfaces, and erosion of agricultural soils (CCME, 1996c).



Zinc occurs in soil solution under the single valence state zinc (+2). Zinc is highly reactive and is present as both soluble and insoluble compounds. Zinc also forms stable combination with organic substances. Metallic zinc is insoluble while the solubility of other zinc compounds range from insoluble (oxides, carbonates, phosphates, silicates) to extremely soluble (sulphates and chlorides) (CCME, 1996c).

Zinc is an essential element for normal plant growth. Terrestrial plants primarily absorb zinc as zinc (2+) from soil solution and the uptake is dependant on the availability, solubility and movement of zinc to plant roots. Zinc availability to plants is a function of soil physico-chemical properties and plant biological characteristics. Uptake and distribution of zinc is influenced by the form of zinc, other metal ions present in the system, soil phosphorous level, cation exchange capacity, soil texture, pH and organic matter content (CCME, 1996c).

Zinc is also an essential element for animal life and is necessary for a wide variety of physiologic functions (Thompson et al., 1991 and Ammerman et al., 1995). Zinc activates several enzymes and is a component of many important metalloenzymes. The element is critically involved in cell replication and in the development of cartilage and bone (Ammerman et al. 1995).

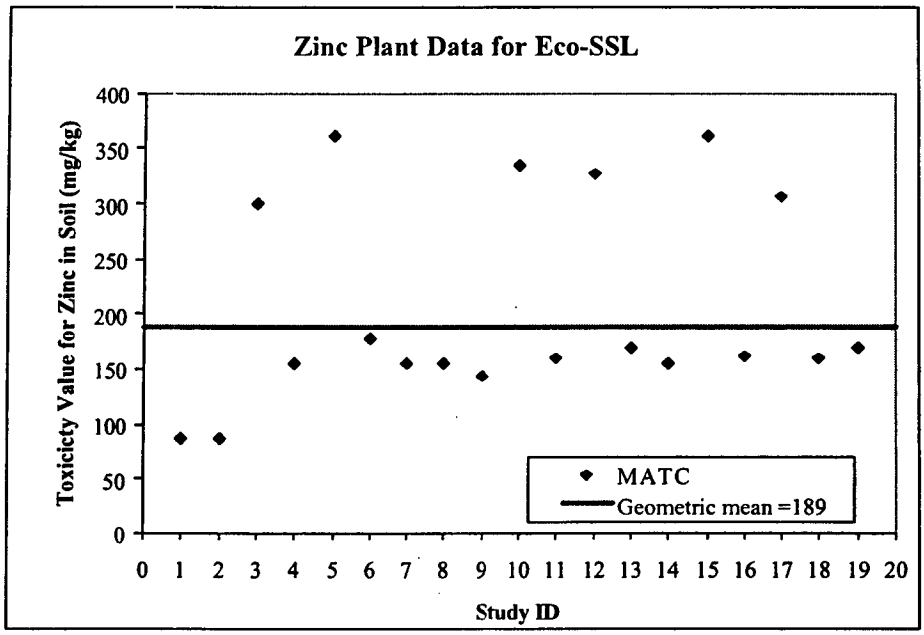
The Eco-SSL values derived to date for zinc are summarized in Table 5.7. Eco-SSL values for zinc are not yet available for avian or mammalian wildlife. Eco-SSLs are available for plants and soil invertebrates.

Plant Eco-SSL for Zinc

The following table and graph summarize the data used to derive the plant Eco-SSL for zinc.

Summary of Data used to Derive Plant Eco-SSL for Zinc							
Study ID	**Reference**	**Test Organism**	**Bio-availability Score**	**Tox Parameter**	**Soil Conc. (mg/kg dw)**	**ERE**	**Level**
1	Chlopeck (1996)	*Zea mays*	2	MATC	87	GRO	A
2	Chlopecka (1996)	*Hordeum vulgare*	2	MATC	87	GRO	A
3	Chlopecka (1996)	*Zea mays*	2	MATC	299	GRO	A
4	Roszyk (1988)	*Avena sativa*	2	MATC	155	GRO	A
5	Roszyk (1988)	*Avena sativa*	2	MATC	361	GRO	A
6	Roszyk (1988)	*Brassica*	2	MATC	177	GRO	A
7	Roszyk (1988)	*Brassica*	2	MATC	155	GRO	A
8	Roszyk (1988)	*Avena sativa*	2	MATC	155	GRO	A
9	Roszyk (1988)	*Avena sativa*	2	MATC	143	GRO	A
10	Roszyk (1988)	*Avena sativa*	2	MATC	335	GRO	A
11	Roszyk (1988)	*Avena sativa*	2	MATC	159	GRO	A
12	Roszyk (1988)	*Avena sativa*	2	MATC	328	GRO	A
13	Roszyk (1988)	*Avena sativa*	2	MATC	169	GRO	A
14	Roszyk (1988)	*Avena sativa*	2	MATC	155	GRO	A
15	Roszyk (1988)	*Avena sativa*	2	MATC	361	GRO	A
16	Roszyk (1988)	*Avena sativa*	2	MATC	162	GRO	A
17	Roszyk (1988)	*Avena sativa*	2	MATC	306	GRO	A
18	Roszyk (1988)	*Avena sativa*	2	MATC	159	GRO	A
19	Roszyk (1988)	*Avena sativa*	2	MATC	169	GRO	A

ERE = Ecologically Relevant Endpoint, described in Appendix 3-1
Tox Parameter = Maximum Acceptable Threshold Concentration (MATC) or EC_{xx} described in Appendix 3-1
Soil Conc. = Concentration of contaminant in soil (mg/kg) for the corresponding ERE and Tox parameter.
Level = Preference level (described in Appendix 3-1).



The plant Eco-SSL for zinc was derived from "A" level data (described in Chapter 3 and Appendix 3-1). The data set of nineteen records was obtained from two papers and four species. All of the toxicity data were based on growth (GRO) effects, a chronic endpoint. The experiments were conducted with natural soils under conditions of high or very high bioavailability.

The plant Eco-SSL for zinc of 190 mg/kg is greater than the reported background concentration of zinc in most locations (Exhibit 5-1), and is lower than most other available soil screening values (Exhibit 1-1).

Soil Invertebrate Eco-SSL for Zinc

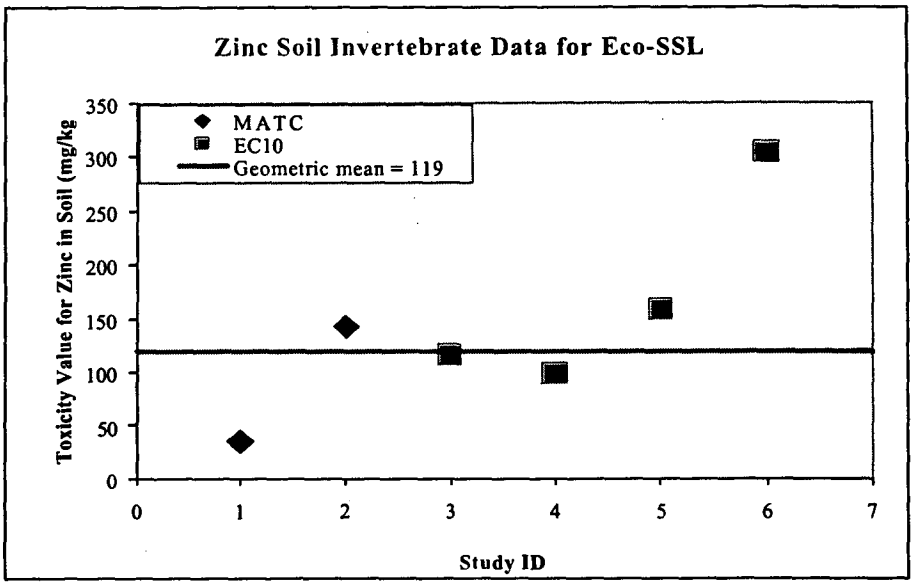
The following table and graph summarize the data used to derive the soil invertebrate Eco-SSL for zinc.

Summary of Data used to Derive Soil Invertebrate Eco-SSL for Zinc

Study ID	Reference	Test Organism	Bio-availability Score	ERE	Tox Parameter	Soil Conc. (mg/kg dw)	Level
1	Korthals (1998)	Nematode	2	REP	MATC	35	A
2	Korthals (1996)	Nematode	2	POP	MATC	141	A
3	Smit (1997)	*F. candida*	2	REP	EC10	116	A
4	Smit (1998)	*F. candida*	2	REP	EC10	99	A
5	Smit (1998)	*F. candida*	2	REP	EC10	159	A

Summary of Data used to Derive Soil Invertebrate Eco-SSL for Zinc							
Study ID	Reference	Test Organism	Bio-availability Score	ERE	Tox Parameter	Soil Conc. (mg/kg dw)	Level
6	Smit (1998)	*F. candida*	2	REP	EC10	305	A

ERE = Ecologically Relevant Endpoint, described in Appendix 3-1
Tox Parameter = Maximum Acceptable Threshold Concentration (MATC) or EC_{xx} described in Appendix 3-1
Soil Conc. = Concentration of contaminant in soil (mg/kg) for the corresponding ERE and Tox parameter.
Level = Preference level (described in Appendix 3-1).



The invertebrate Eco-SSL for zinc was derived from "A" preference level data (described in Chapter 3 and Appendix 3-1). The data set of six records was obtained from two papers and two species. The toxicity data were based on reproductive (REP) and population (POP) effects, both chronic endpoints. The experiments were conducted with natural soils under conditions of high or very high bioavailability.

The invertebrate Eco-SSL for cadmium of 120 mg/kg is greater than the reported background concentrations of zinc in most locations (Exhibit 5-1), and is lower than most other available soil screening values (Exhibit 1-1).

5.10 Aluminum

Aluminum (Al) is the most commonly occurring metallic element, comprising eight percent of the earth's crust (Press and Siever, 1974). It is a major component of almost all common inorganic soil particles, with the exceptions of quartz sand, chert fragments, and ferromanganiferous concretions. The typical range of aluminum in soils is from 1 percent to 30 percent (10,000 to 300,000 mg Al kg-1) (Lindsay,

1979 and Dragun, 1988), with naturally occurring concentrations varying over several orders of magnitude.

EPA recognizes that due to the ubiquitous nature of aluminum, the natural variability of aluminum soil concentrations and the availability of conservative soil screening benchmarks (Efroymson, 1997a; 1997b), aluminum is often identified as a COPC for ecological risk assessments. The commonly used soil screening benchmarks (Efroymson, 1997a; 1997b) are based on laboratory toxicity testing using an aluminum solution that is added to test soils. Comparisons of total aluminum concentrations in soil samples to soluble aluminum-based screening values are deemed by EPA to be inappropriate (see Exhibit 5-2).

The standard analytical measurement of aluminum in soils under CERCLA contract laboratory procedures (CLP) is total recoverable metal. The available data on the environmental chemistry and toxicity of aluminum in soil to plants, soil invertebrates, mammals and birds (summarized in Exhibit 5-1) support the following conclusions:

- Total aluminum in soil is not correlated with toxicity to the tested plants and soil invertebrates.
- Aluminum toxicity is associated with soluble aluminum.
- Soluble aluminum and not total aluminum is associated with the uptake and bioaccumulation of aluminum from soils into plants.
- The oral toxicity of aluminum compounds in soil is dependant upon the chemical form (Storer and Nelson, 1968). Insoluble aluminum compounds such as aluminum oxides are considerably less toxic compared to the soluble forms (aluminum chloride, nitrate, acetate, and sulfate). For example, Storer and Nelson (1968) observed no toxicity to the chick at up to 1.6% of the diet as aluminum oxide compared to 80 to 100% mortality in chicks fed soluble forms at 0.5% of the diet.

Because the measurement of total aluminum in soils is not considered suitable or reliable for the prediction of potential toxicity and bioaccumulation, an alternative procedure is recommended for screening aluminum in soils. The procedure is intended as a practical approach for determining if aluminum in site soils could pose a potential risk to ecological receptors. This alternative procedure replaces the derivation of numeric Eco-SSL values for aluminum. Potential ecological risks associated with aluminum are identified based on the measured soil pH. Aluminum is identified as a COPC only at sites where the soil pH is less than 5.5.

6.0 USING ECO-SSLs TO SCREEN CONTAMINATED SOILS

This Chapter provides guidance on using the Eco-SSLs to identify those soil contaminants (i.e. COPCs) and/or areas of soil contamination that warrant further consideration in a baseline ERA. Screening is completed during Steps 1 and 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 problem formulation. With the information gathered in Step 1, the risk assessor completes a screening of soils data using the Eco-SSLs in the risk calculation performed during Step 2.

6.1 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 applicable is important for adequate planning and sampling strategies for the ERA.

Soil Screening Process Using Eco-SSLs

- **Complete Site Visit, Initial Problem Formulation, Toxicity Evaluation and Exposure Assessment** (Steps 1 & 2 of ERAGS; U.S. EPA, 1997).
- **Develop a Preliminary Site-Specific Conceptual Site Model** (U.S. EPA, 1997)
- **Compare CSM to the General Eco-SSL Model**
  - T Identify pathways present at the site addressed by the Eco-SSL guidance.
  - T Identify pathways present at the site not addressed by the guidance.
- **Identify if Available Analytical Data Set for Soils is Adequate for Screening**
- **Compare Site Soil Concentrations to Eco-SSLs**
- **For Exceedances, Consider Site-Specific Modifications**
- **For Exceedances, Consider Proceeding to a Baseline ERA**

Are There Soil Exposure Pathways for Ecological Receptors?

The Eco-SSLs apply only to sites where terrestrial receptors may be exposed directly or indirectly to contaminated soil. The first step is to identify all possible, complete soil pathways present at the site in order to determine if they can be addressed by the Eco-SSL value. 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 contaminated via soil invertebrates and/or plant uptake

Soil Invertebrates and Plants

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

For surface soils (i.e., those soils within the root zone at the specific site), all the above pathways should be considered. Ecological risks from potential exposure to contaminated subsurface soils are generally not considered for ecological receptors. In some 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.

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.

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

1) What contaminants are known or suspected to exist at the site?
2) What complete exposure pathways might exist at the site?
3) Which habitats 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 the root zone at the site), then additional screening for soil effects on ecological receptors is not needed.

Are There Exposure Pathways Not Addressed by the Eco-SSL?

In some cases, the site-specific conceptual model may have identified potentially complete or complete ecological soil exposure pathways that were not considered in the derivation of the Eco-SSLs. In these instances (presented below), the additional pathways need to be considered in a separate screening analysis or as part of the baseline ERA.

- The contaminated soil is near a surface water body or wetland where there is potential for contamination of surface water and/or sediments by overland flow of soil.

- 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.

6.2 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 (i.e., birds or invertebrates) appear to be at most risk and should be the focus of the baseline ERA?

Are the Existing Site Soil Contaminant Data Adequate?

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

- Are all expected soil contaminant sources 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 PAHs are suspected as part of the deposited waste, are soil analyses available for these? 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, the maximum soil contaminant concentrations are 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.

Which Eco-SSL Should be Used?

The lowest of the four reported Eco-SSLs should 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 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 ecological risk assessment.

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 needs to recognize that new information may become available during the baseline risk assessment 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 COPC. If there are no soil contaminant concentrations that exceed the Eco-SSLs, a baseline ecological risk assessment for soils would generally not be needed for that site.

What if There is No Eco-SSL?

At this time, Eco-SSLs for all four receptor groups are not available for all the 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 these contaminants, a summary of all toxicity studies evaluated in the Eco-SSL process is available on the Eco-SSL website. The information from these studies can be used according to the process described in Section 1.3.1 of ERAGS to derive screening values. Exhibit 3-4 provides the plant and soil invertebrate toxicity data that were judged acceptable for use in deriving Eco-SSLs, but for which there were only one or two studies available (i.e., score >10).

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

Decisions concerning the derivation and use of modified Eco-SSL values are made by the risk assessor in consideration of site-specific factors. At some sites, the need to proceed to a baseline ERA to fully evaluate risks to terrestrial receptors from contaminants in soil may be obvious based on the comparison of the Eco-SSLs to the soil contaminant concentrations. For example, the screening assessment may result in hazard quotients (HQs = site soil concentration / Eco-SSL) for one of more contaminants that are very large (> 100), or there may be obvious signs of stressed vegetation. Some outcomes are, however, not clear. For example, the HQ for a receptor may be relatively small and the use of site-specific exposure information may yield an HQ value less than or equal to 1.0. In these cases, it may be appropriate to collect some limited site exposure data and use this information to redefine the risk equation, which may screen out some or all of the soil contaminants. Information on modifying Eco-SSLs is presented in Chapter 7.

6.3 Consideration of Background Soil Concentrations

Background concentrations of contaminants (i.e., naturally occurring inorganic compounds) may be considered only after the screening process for Superfund Sites. Following screening consideration can be given to site-specific background levels of contaminants in soils. Guidance on how to determine background conditions and on how to use this information in the assessment process is being developed by an EPA workgroup and is expected to be completed in early 2001.

Data on background concentrations of contaminants in soils were collected and reviewed during the Eco-SSL derivation process to examine how the Eco-SSL values compared to natural soil conditions. These comparisons were used to guide the process and are presented as Exhibit 5-1. The review also indicated that there are regions of the country where natural background levels for metals exceed Eco-SSLs. For these regions and for specific local areas, the acquisition of data on background soil concentrations is an important step toward evaluating whether observed concentrations are related to releases or are naturally occurring.

7.0 SITE-SPECIFIC CONSIDERATIONS FOR MODIFYING THE ECO-SSLS

The Eco-SSLs were derived to be broadly applicable as screening levels. In order to achieve that goal, assumptions were made about exposures and effects for plants, invertebrates, and wildlife to insure that the derived Eco-SSL values were sufficiently conservative such that they could confidently be used for screening. When contaminant concentrations in soils are lower than Eco-SSLs, it is presumed that the contaminant will not pose an ecological risk and does not need to be considered further with respect to that type of risk. However, when a contaminant concentration in soil exceeds an Eco-SSL, there may or may not be a risk depending on site-specific considerations. Guidance on how to consider site-specific factors in ecological risk assessments is given in ERAGs (U.S. EPA,1997). This chapter describes some of the site-specific considerations specific to soil issues. The intent of this chapter is to give the reader guidance on possible next steps beyond the application of Eco-SSLs that could be considered as part of a baseline risk assessment.

7.1 Site-Specific Considerations for Wildlife

Eco-SSLs for wildlife were derived using selected values for exposure assumptions. An effort was made to insure that these were adequately conservative by choosing values from either the 90th or 10th percentile of distributions of exposure parameters (which ever was more conservative). Other assumptions concerned the degree to which a local population would use a site (100%) and the relative bioavailability of contaminants in ingested soils and biota (100%). One or more of these assumptions can be modified when adequate site-specific information is available. Such information may relate to characteristics of site-specific receptors or site or soil characteristics. Examples include the relative proportions of food in a receptor's diet, the size of a receptor's foraging area, the amount of soil a receptor incidentally ingests, and the bioavailability of the contaminants.

Modifications of select exposure assumptions could be used to adjust Eco-SSLs to make them more site-specific. The modifications suggested below could also be used in the baseline risk assessment. Decisions on whether and how to modify Eco-SSLs are site-specific and should be discussed between the risk assessor and risk manager in accordance with Step 3 of ERAGS (see Section 3.2 in USEPA, 1997.) Site-specific considerations for wildlife exposed to contaminants in soils fall into two categories: wildlife characteristics and site characteristics. It is envisioned that these site-specific modifications based on these characteristics would be made after initial site screening.

The various parameters that might be modified on a site-specific basis can be identified within the general wildlife exposure and risk model (Figure 4.1):

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

where:

HQ_j	=	Hazard quotient for contaminant (j) (unitless),
$Soil_j$	=	Contaminant concentration for contaminant (j) in soil (mg/kg dry weight) **(site characteristic)**,
N	=	Number of different biota types in diet **(wildlife characteristic)**,
B_i	=	Contaminant concentration in biota type (i) (mg/kg dry weight) **(site characteristic often dependent on mobility of metals in soil)**,
P_i	=	Proportion of biota type (i) in diet **(wildlife characteristic)**,
FIR	=	Food ingestion rate (kg food [dry weight]/ kg BW [wet weight] / d) **(wildlife characteristic)**,
AF_{ij}	=	Absorbed fraction of contaminant (j) from biota type (i) **(wildlife characteristic)**,
AF_{sj}	=	Absorbed fraction of contaminant (j) from soil (s) **(wildlife and site soil characteristics that influence bioavailability)**,
TRV_j	=	The no adverse effect dose (mg/kg BW/day) (Section 4.4),
P_s	=	Soil ingestion as proportion of diet **(wildlife characteristic)**,
AUF	=	Area use factor **(wildlife and site size characteristics)**

Wildlife Characteristics

Eco-SSLs for wildlife are derived for six general receptor groups that represent different feeding strategies for birds and mammals. The degree to which these receptor groups are actually represented at a site will vary. Site-specific knowledge of the types of wildlife that may use the site can be used to modify one or more of the exposure parameters of the general wildlife Eco-SSL exposure model.

Site-Specific Receptor Species. The Eco-SSLs are calculated for surrogate receptor species that were considered to be protective of other birds and mammals (see text box). However, one or more of these species may not be present or applicable on a site-specific basis. Eco-SSLs can be calculated for site-specific species. For example, a particular site may not have habitat to support raptors. Additionally, species of birds or mammals present at a site may have different feeding habits and life history than those used to derive the Eco-SSLs. An example would be the raccoon, which ingests a varied diet and also has a different range of body weights and ingestion rates than the weasel.

Exposure Parameters. Site-specific information can also be used to adjust parameters such as ingestion rates (food or soil) or body weights. For example, site-specific or regional data may indicate that one or more of the wildlife species have higher body weights or lower ingestion rates than the conservative values used in the Eco-SSL derivation (10th and 90th percentiles, respectively).

Dietary Composition. Site-specific or a more varied dietary composition can be used to modify the wildlife exposure model. The Eco-SSLs assume that species consume only one item in the diet (the most contaminated) when many species actually have a varied diet (e.g., 50% plants, 50% invertebrates). For example, raccoons have a varied diet, ingesting soil invertebrates, reptiles, aquatic organisms, and small mammals as well as plants.

Area Use Factor. The Area Use Factor (AUF) reflects both wildlife and site characteristics and is used to judge the extent to which a wildlife species' exposure comes from the site. Where the size of the site is significantly smaller than the home range of the species being evaluated, only a fraction of total exposure may be from the site. For example, the home range of the red-tailed hawk ranges from 1 to 10 square kilometers (247 to 2471 acres). For a site that is 50 acres, the exposure could be adjusted using an AUF of 0.2 (or lower). Care must be taken when selecting an AUF because species may favor particular feeding areas out of proportion to their reported foraging areas. Therefore, the simple relationships between foraging areas and site sizes may not always hold.

Protectiveness of the Wildlife Eco-SSLs

Protectiveness of the wildlife Eco-SSLs is provided through both the surrogate species selection and the parameterization of the exposure model.

Surrogate receptor species were selected to provide a conservative representation of their respective trophic guilds. These species are 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 is associated with higher metabolic rates (Nagy et al. 1999) and smaller home ranges (McNab 1963), exposure and risk for small receptors is maximized. EcoSSLs based on these species are therefore likely to be protective of other, larger species in their trophic guild.

Parameters for the Exposure Model. The food and soil ingestion rates used in the exposure model are represented by the 90th percentiles from their respective distributions. Use of exposure parameter values from the upper tails of the distributions further ensures the protectiveness of the Eco-SSLs for other wildlife species.

Site Characteristics

Certain site characteristics can influence exposure of wildlife to contaminants in soils. These include the spatial distribution and magnitudes of exposure concentrations as well as the degree to which soil-related parameters have effects on the bioavailability of the contaminants. Obtaining site-specific information on key soil characteristics such as organic carbon, pH, cation exchange capacity, and grain size may be valuable information for judging the potential

importance of bioavailability as a factor influencing exposure. Information on parameters such as bulk density (a measure of compaction) is useful for judging the extent to which the site can support plants and soil invertebrates.

Exposure Point Concentrations. During site screening, Eco-SSLs are typically compared to the ***maximum*** soil contaminant concentrations at the site. This simple and conservative approach is appropriate since sampling for screening normally focuses on the more contaminated locations of a site. However, maximum point values might not be representative of the exposures experienced by wildlife. Therefore, as additional sampling data become available for the site (i.e., through site characterization studies), alternative exposure statistics may be considered. In accordance with USEPA guidance, these exposure statistics usually are estimates of mean exposure concentrations (e.g., 95% UCL of the mean), which account for uncertainty in the estimates. Other statistics may be appropriate depending on the extent to which exposure is resolved through spatially explicit models that account for wildlife exposure and contaminant distribution.

Bioavailability. Key considerations when judging the value of the collection of site-specific bioavailability information include:

- determining which contaminants are "driving the risk" and for which site-specific information would be most useful,
- determining which soil-related pathways (uptake in food items, incidental soil ingestion, dermal contact, etc.) are driving the risk,
- examining soil characteristics (e.g., for organic carbon or cation exchange capacity) to obtain insights into the potential that bioavailability is reduced, evaluating whether revised risk estimates (including utilizing site-specific bioavailability information) would change the risk estimate sufficiently to affect decisions.

These considerations can guide the collection of additional site-specific information. Such information is most likely to be useful when focused on the contaminants and pathways of concern at a site. Other site-specific factors that may affect exposure estimates and which can be considered when proceeding beyond screening-level assessment include: (1) more detailed evaluations of the spatial and vertical extent of contaminants in soils, (2) the distribution of available habitat, (3) utilization of area use factors (AUFs) that are specific to wildlife species, and (4) other biological and ecological characteristics of the wildlife being evaluated.

The TRVs used to calculate Eco-SSLs are generally based on studies using highly bioavailable forms of contaminants. Bioavailability of contaminants under field conditions is generally lower than in laboratory experiments. As indicated in the general wildlife exposure equation, there are a few parameters that are influenced by bioavailability: B_i (contaminant concentration in biota type (i) (mg/kg dry weight)), and AF_{sj} (absorbed fraction of contaminant (j) from soil (s)).

Soil-related effects on contaminant bioavailability are likely to be important site-specific variables influencing wildlife exposure. Bioavailability can be manifested through variable uptake into food items such as soil invertebrates and plants as well as the degree to which contaminants are released from soils that are incidentally ingested by wildlife (Figure 7-1).

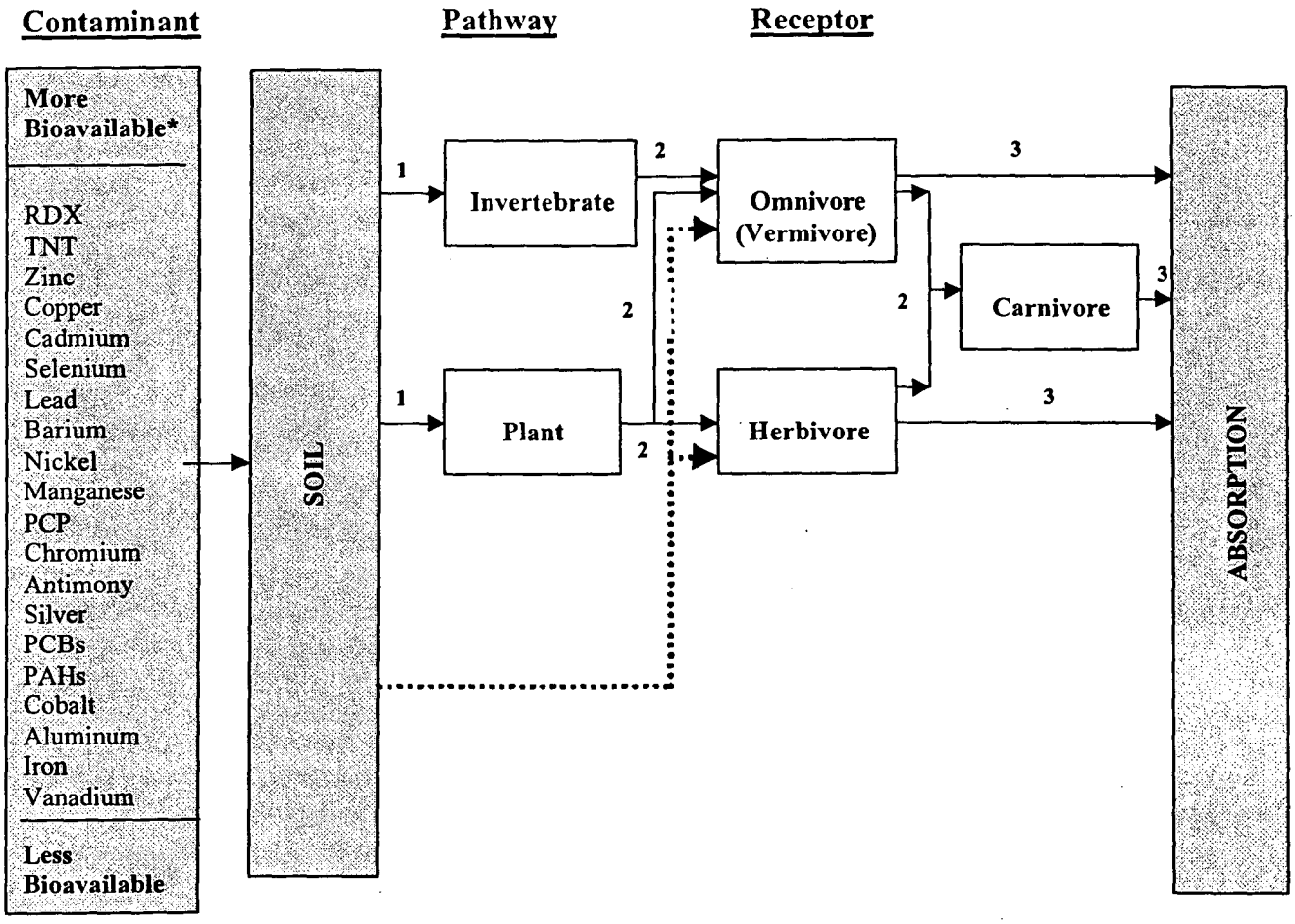
An analysis of the relative importance of various pathways (Exhibit 7-1) points to the importance of accumulation of contaminants within wildlife food items such as soil invertebrates or plants for most receptors and contaminants. The pathway can be readily addressed with available site-specific measurements of uptake into food items (i.e., tissue residue levels), and/or models that use site-specific measurements of soil properties such as organic carbon. However, because there are a number of factors that can influence bioavailability of contaminants in soils, site-specific measurements of uptake into food items and empirical models based on such measures are likely to provide more accurate information on bioavailability and exposure than that given by theoretical models. Theoretical models of uptake in plants and invertebrates can be useful for providing bounding estimates, and these estimates may be sufficient for site evaluation. However, the uncertainties associated with exposure estimates provided by currently available models must be recognized (e.g., Sample et al., 1999).

Incidental ingestion of soils by wildlife can be a relatively important source of exposure to wildlife where the overall movement of a contaminant into food is low. However, this exposure pathway is often less important than uptake into food and is typically more difficult to measure or model. For these reasons, value of information analysis is particularly important for judging the usefulness of site-specific information on the bioavailability of contaminants in incidentally ingested soils. Evaluating the incidental soil ingestion pathway also requires special consideration of the digestive systems of receptors. For example, there are different types of digestive systems (e.g., ruminant vs. mono-gastric species) that influence the bioavailability of contaminants.

An example approach for incorporating site-specific information on bioavailability is illustrated in Figure 7-2. The process would be applied to those contaminants that exceed wildlife Eco-SSL values. Because there are other factors that influence estimates of exposure to wildlife (e.g., area use factors, soil ingestion rates, other receptor or site-specific information), the range of options should be considered before deciding on the value of collecting and using bioavailability information.

The approach involves (1) identifying the pathways for which such information might be useful, (2) judging the extent to which this information might affect the risk assessment and decision, and (3) using site-specific data on soil characteristics to discern the likelihood that bioavailability might be reduced. For example, the bioavailability of organic contaminants would be expected

Figure 7-1. Bioavailability Issues in Wildlife



Significant Bioavailability Parameters:

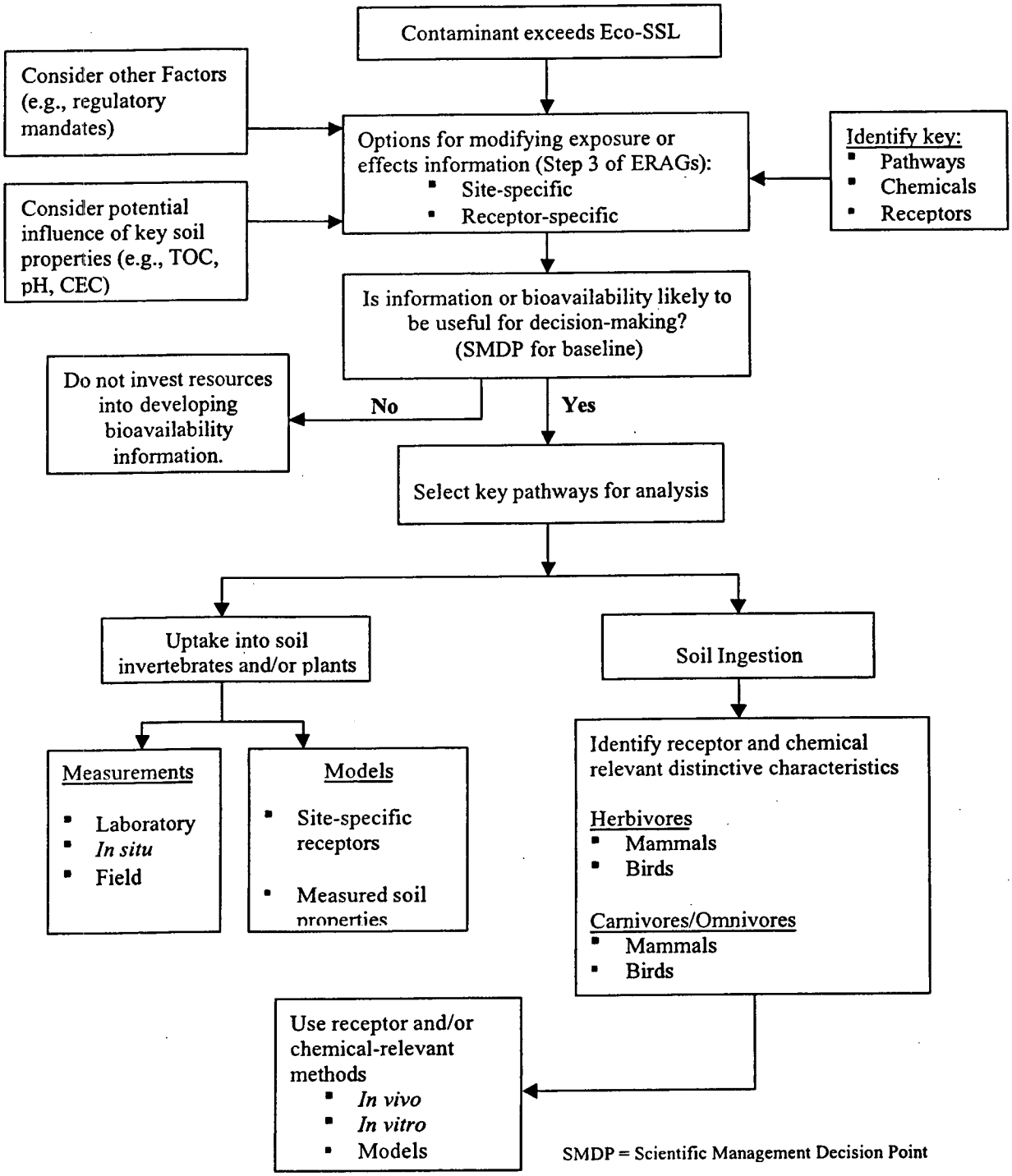
1. Uptake from soil into food items.
2. Uptake from food into receptor (dose)
3. Gastrointestinal absorption

*Based on EcoSSL assumptions

Bioavailability can be reduced by sorption, sequestration and other physical binding.

Absorption depends on anatomy and physiology of the digestive system as well as the presence and composition of materials in the gut.

Figure 7-2. Incorporating Bioavailability into Exposure Estimates



to decline as the organic content of soil increases. When judging the type and value of information on bioavailability, it is important to identify the degree to which exposure is influenced by uptake into wildlife food items such as soil invertebrates and plants as compared to incidental ingestion of soils. The outcome of this analysis might then determine which information would be most useful to confer a site-specific dimension to the Eco-SSLs.

As illustrated in Figure 7-2, options available for determining site-specific uptake into wildlife food items (plants and soil invertebrates) include measurements or models. If exposure is driven by incidental ingestion of soils, determining the relative bioavailability of the contaminants associated with ingested soil is a possible approach for refining exposure estimates. However, bioavailability of ingested soils will be affected by different types of wildlife digestive systems. Finally, there are a limited number of approaches available for assessing the relative bioavailability of contaminants on ingested soils.

7.2 Site-Specific Considerations for Plants and Invertebrates

An empirical approach has been used to derive Eco-SSLs for plants and invertebrates (Chapter 3). This involved selecting data from toxicity tests that were performed on soils that met specific physical and/or contaminant criteria. The intent was to include data from soils for which contaminants are more likely to be bioavailable. Therefore, it is expected that there may be site-specific soils within which the contaminants are less bioavailable and less toxic. Three approaches are available for making site-specific adjustments:

1) Literature values
2) Toxicity tests
3) Measurements of bioavailable contaminant fractions

Using Literature Values for Adjusting Eco-SSLs

The Eco-SSLs for plants and invertebrates are based primarily on literature values for soils with selected ranges of physical and contaminant characteristics. If a site soil falls out of this range, one option available is to examine existing toxicity data for soils that are more similar to the site soils. This could involve using studies that were conducted outside the range used to derive the Eco-SSL values and/or to parse the data set to obtain values that are most representative of the site soils. A limitation on either approach is the number of available studies. The QA and ranking principles applied to the derivation of the plant and soil invertebrate Eco-SSLs (Chapter 3) should be followed to insure that site-specific modifications derived from the literature are technically supportable.

Using Toxicity Tests for Deriving Site-Specific Eco-SSLs

This option is readily available for plants and soil invertebrates and generally acceptable. Protocols for the conduct of soil toxicity tests are discussed in Exhibit 7-2. Typically, these

would be applied to site soils in order to provide site-specific information on toxicity. Because there are a number of confounding factors associated with site-specific toxicity tests, care must be taken in the design of such studies. If the intent of the testing is to identify contaminant concentrations at which effects are manifested (e.g., an Apparent Effects Threshold Approach), then the design would need to include sampling along gradients of contamination. If testing is being performed only to determine whether or not the highest soil concentrations produce any adverse effects, then range-finding tests are adequate. Further guidance on the design and conduct of such site-specific studies can be obtained from the regional BTAG.

Using Measurements of Bioavailable Contaminant Fractions

Most measurements of contaminants in soils involve measures of "total" bulk metals or organic contaminants. Much attention is being given to identifying measures of the bioavailable fractions of the contaminants. A measure of the contaminant concentration actually available to plants or soil invertebrates could provide a more relevant estimate of exposure. To this end, a number of investigators are currently exploring various extraction techniques for measuring the bioavailable fraction of the contaminants in soils. These methods vary depending on the contaminant and receptor. Typical categories of measurements include: 1) leachability to and presence of contaminants in soil pore water (various aqueous extractions), 2) uptake of contaminants through integument (various solid and liquid extraction methods), 3) uptake of contaminants through the gut of invertebrates (simulated digestive fluids). Currently, with the possible exception of lead and mammals, there are no validated methods for measuring bioavailability that have been accepted by EPA. This is expected to change in the future.

7.3 Site-Specific Applications of Soil Chemistry Data

Site-specific studies offer more flexibility to address soil availability and toxicity issues. For example, at a given site, plant and soil biota toxicity studies can be conducted according to the established methods and endpoints (described in Exhibit 7-2) to generate site-specific screening levels for a given metal or mixture of metals. An example, presented in Table 7.1, shows how an Eco-SSL for metals established for high availability soils could be adjusted with the results from site-specific soil toxicity tests for medium and low availability soils. In addition, in this part of the process, for given soils or COPC, additional soil parameters may more appropriately explain the relationship between availability and toxicity of COPC to soil biota and plants.

Table 7.1. Use of Site-Specific Soil Toxicity Tests for Modifying Screening Levels for Metal Cations Under Designated Soil Conditions			
Soil Type	**Soil pH**		
	4 - 5.5	**5.5 - 7**	**7 - 8.5**
Low OM (<2%) Low CEC (<50 mmol/kg) Low clay content	Screening Value 22 ppm		
Medium OM (2-6 %) Medium CEC (50-500 mmol/kg) Medium clay content		Site Testing Value 51 ppm	
High OM (6-10%) High CEC (>500 mmol/kg) High clay content			Site Testing Value 130 ppm

As additional data are generated for specific contaminants, models may be developed that relate soil chemistry parameters to soil biota toxicity. Where data can support the use and validation of these techniques, they offer broadly applicable methodologies to address these issues. The literature, to date, does not present a consistent relationship of COPC concentrations in soils or soil solutions and biota toxicity to currently utilize these methods in a regulatory arena.

7.4 Soil Sampling Data Requirements

The user should examine the currently available soil data and evaluate if the extent of these data is sufficient for decision-making using the Eco-SSLs. *The Soil Screening Guidance: Users Guide* (U.S. EPA, 1996a and 1996b) provides guidance on defining data collection needs for soils including the two steps that are reviewed here.

Develop Hypothesis about Distribution of Soil Contamination. The user should identify which areas of the site may have soil concentrations in excess of the Eco-SSLs.

Develop Sampling and Analysis plan (SAP) for Determining Soil Contaminant Concentration. The sampling strategy for soils should be designed by completing the data quality objectives (DQO) process, which includes the: statement of the problem, identification of the decision, identification of inputs to the decision, definition of study boundaries, development of a decision rule, specification on decision errors and optimizing the design. Sampling should also be completed to measure soil characteristics, including bulk density, moisture content, organic carbon content, porosity, pH and cation exchange capacity (CEC).

The depth over which surface soils are sampled should reflect the type of exposure expected at the site, the type of receptors expected at the site, the depth of biological activity and the depth of potential contamination. The size, shape and orientation of sampling volume have an effect on

the reported measured contaminant concentration values.

Selection of sampling design and methods http://es/epa.gov/ncerqa/qa_docs.html can be accomplished by use of the Data Quality Objectives (DQO) process. Additional soil sampling guidance that should be consulted includes: *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies* (U.S. EPA, 1992a), and *Guidance for Data Usability in Risk Assessment* (U.S. EPA, 1992b). Reference to relevant soil sampling guidance (and other documents) is appropriate during Steps 1 and 2 of the ERAGS process for the user to understand the extent and quality of the existing soil data. These guidance documents may be used to recommend further soil sampling for application of the Eco-SSLs or completion of a baseline ERA.

7.5 Soil Properties Suggested For Routine Measurement

When soils are evaluated for potential ecological risks due to the presence of contaminant contamination, there are several soil properties that should be considered for routine measurements. These measurements indicate where the soils fall within the ranges of soil properties given in Tables 2.3 through 2.5 (Chapter 2). This provides insight into the degree to which site soils reflect the data used to derive the Eco-SSLs. It also is used to guide how to proceed beyond the application of Eco-SSLs when collecting and evaluating data during a baseline ERA. Specifically, site-specific information on soil properties indicates the extent to which contaminants may be bound in the soil matrix. Possible site-specific modifications to the Eco-SSLs that account for bioavailability are previously discussed in Chapter 7. Based on discussions within the Eco-SSL work group for plants and soil invertebrates and consideration of factors that influence exposure and bioavailability, the following soil properties are identified as important for routine measurement during the baseline ERA:

- pH
- Organic matter or organic carbon
- Cation exchange capacity (CEC)
- Soil texture (particle-size analysis)
- Bulk density as a measure of soil compaction

Other factors may also be important depending on the nature of the ecological stressor and on the need to consider multiple stressors when evaluating effects. However, the list given above represents a minimal set of information needed for site-specific assessments.

Of the soil properties suggested for routine measurement, pH, organic matter/organic carbon, and cation exchange capacity were selected for use in guiding Eco-SSL derivation, thus were previously defined and discussed in terms of their relative impact on contaminant bioavailability. The rationales for suggesting routine measurement soil texture and bulk density are provided below as well as additional comments regarding potential alterations in soil properties over time and general soil health. Additional information on the soil properties presented below can be

found in the Handbook of Soil Science (Sumner, 2000).

Soil Texture (Particle Size Analysis)

Soil texture influences the types of animals and plants that can live on or in the soil. Thus, information on soil texture helps an ecological risk assessor understand the types of biota that a soil can support. At a screening level, this can be important for developing conceptual models of receptors and exposure pathways. Soil texture also influences the bioavailability of some contaminants. Thus, a silt or clay soil may bind contaminants differently than a sand soil. Soil texture refers to the weight proportion of the separates for particles less than 2 mm as determined from a laboratory particle-size distribution. The finer sizes are called fine earth (smaller than 2mm diameter) as distinct from rock fragments (pebbles, cobbles, stones and boulders). The texture classes are sand, loamy sands, sandy loams, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. Subclasses of sand are subdivided into coarse sand, sand, fine sand, and very fine sand. Soil texture, structure, and depth all affect the water-holding capacity of the soils and need to be considered when determining water retention requirements or supplemental irrigation requirements as the wetland restores during the dry periods of the year.

Bulk Density (as a measure of soil compaction)

The bulk density of a soil influences the ability of soil burrowing invertebrates and plants to utilize that soil as habitat. Highly compacted soils such as those found on some industrial sites preclude many invertebrates and plants. Therefore, information on bulk density can be used by ecological risk assessors during the baseline risk assessment to determine a soil's ability to support flora and fauna. This information can then be used in conceptual models.

Bulk density is the weight of solids per unit volume of soil. The bulk density of a soil will increase under land uses that result in soil compaction, which is when soil particles are pressed together, reducing the pore space between them. Soil compaction occurs in response to pressure (weight per unit area) exerted by field machinery or animals. The risk for compaction is greatest when soils are wet. Soil compaction is caused by tilling, harvesting, or grazing when the soils are wet. Compaction restricts rooting depth, which reduces the uptake of water and nutrients by plants. It affects the activity of soil organisms by decreasing the rate of decomposition of soil organic matter and subsequent release of nutrients. Compacted soils can be identified by platy or weak structure, greater penetration resistance, higher bulk density, restricted plant rooting, and/or flattened, turned, or stubby plant roots.

Soil bulk density depends on the soil texture. Minimum bulk density values for which plant roots may be restricted at various soil textures are presented in Table 7.2.

Table 7.2 Minimum Bulk Density Values for Which Plant Roots May be Restricted for Various Soil Textures	
Soil Texture	**Soil Bulk Density (g/cc)**
Coarse, medium, and fine sand and loamy sands other than loamy very fine	1.8
Very fine sand, loamy, very fine sand	1.77
Loam, sandy clay loam	1.75
Clay loam	1.65
Sandy clay	1.6
Silt, silt loam	1.55
Silty clay loam	1.5
Silty clay	1.45
Clay	1.4
Silt, silt loam	

Measurement Techniques

Several federal agencies and others such as the U.S. EPA, the U.S. Department of Agriculture National Resource Conservation Service (USDA NRCS), and ASTM have developed analytical methods to measure these soil properties. The methods from these various agencies in some instances are similar while other methods are quite different because the intended use of the measurement data is different. For instance, USEPA Office of Solid Waste has a compendium of test methods for evaluating physical and contaminant properties of soils referred to SW-846. Several methods for measuring various soil physical and chemical properties can also be found in three volumes of Methods of Soil Analysis (Klute, 1986; Page et al., 1994; Sparks et al., 1996) including limitations and interferences.

7.6 Site-Specific Considerations for Wetlands

Wetland soils and sediments typically have different geochemical properties compared to upland soils. While screening levels for soils may suffice for screening wetland soils because these screening values were conservatively derived, site-specific conditions may warrant different approaches for modifying SSLs. Two questions commonly arise when considering wetland systems:

- Distinguishing wetland soils from wetland sediments, and
- Selecting the appropriate methods for site-specific evaluations.

While there is likely a gradient between wetland soils and sediments, distinguishing between these categories may be useful at a screening level as well as for more site-specific assessments. In general, screening levels developed for soils may be applicable to wetland soils, while screening levels developed for sediments may be applicable to wetland sediments. A few approaches have been proposed for distinguishing between these environments. The first and most widely accepted is the classification developed for the National Wetland Inventory (NWI) which provides some basis for distinguishing between soils and sediments within wetlands. Various states have also made this distinction in order to help manage these areas. Massachusetts, for example, includes the following descriptions in its 1996 *Guidance for Disposal Site Risk Characterization*:

> *Given the transitional nature of wetlands between terrestrial and aquatic systems, sediment and/or soil may be present in a given wetland. The MCP (310 CMR 40.0006) gives the following definition for sediment:*
>
> > *Sediment means all detrital and inorganic or organic matter situated on the bottom of lakes, ponds, streams, rivers, the ocean, or other surface water bodies. Sediments are found:*
> >
> > *a) in tidal waters below the mean high waterline as defined in 310 CMR 10.23; and*
> > *b) below the upper boundary of a bank, as defined in 310 CMR 10.54(2) which abuts and confines a water body.*
>
> *All other unconsolidated earth in wetlands, including the 10 year floodplain, is considered soil.*

Table 7.3 provides a possible approach for applying Eco-SSL values for soils in wetland systems. The approach makes use of the National Wetlands Inventory (NWI) classification system (Cowardin et al. 1979). Because the character of wetland systems varies across the country with different management types across states, Table 7-3 should be viewed only as a rough guide. The appropriate local and regional wetland regulatory personnel should be consulted concerning the applicability of soil and/or sediment screening criteria to wetlands. Application of the Eco-SSLs alone or in tandem with sediment benchmarks requires professional judgement. The regularity, depth and duration of flooding should be considered as well as the presence or absence of emergent vegetation in making the determination. If the "soils" are flooded often enough to qualify as "sediments" and are not vegetated with emergent species then Eco-SSLs should not be used.

Site-specific modifications of Eco-SSLs for wetlands would need to consider wetland flora and fauna as well as the properties of the wetland soils. A discussion of such approaches is beyond the scope of this document. Conceptually, the approach is similar to that used for upland soils.

However, the specifics of laboratory and field testing methods may differ.

Table 7.3. Recommended Application of Eco-SSLs and/or Sediment Benchmarks to NWI Categories of Wetlands and Deepwater Habitats

NWI Weland Classification: Wetlands and Deepwater Habitats			Applicability of Benchmarks		
System	Subsystem	Class	Eco-SSLs	Sediment Benchmarks	Comments
Marine	Subtidal	Rock Bottom	-	-	Assume sample not obtainable
		Unconsolidated Bottom	-	®	Eco-SSLs are Not Applicable
		Aquatic Bed	-	®	Eco-SSLs are Not Applicable
		Reef	-	®	Eco-SSLs are Not Applicable
	Intertidal	Aquatic Bed	-	®	Eco-SSLs are Not Applicable
		Reef	-	®	Eco-SSLs are Not Applicable
		Rocky Shore	-	-	Assume sample not obtainable
		Unconsolidated Shore	®	optional	Use both for regularly or irregularly flooded shores; Use only Eco-SSLs for less frequently flooded shores.
Estuarine	Subtidal	Rock Bottom	-	-	Assume sample not obtainable
		Unconsolidated Bottom	-	®	Eco-SSLs are Not Applicable
		Aquatic Bed	-	®	Eco-SSLs are Not Applicable
		Reef	-	®	Eco-SSLs are Not Applicable
	Intertidal	Aquatic Bed	-	®	Eco-SSLs are Not Applicable
		Reef	-	®	Eco-SSLs are Not Applicable
		Streambed	optional	®	Use Eco-SSLs also only for frequently dry/exposed and vegetated streambeds
		Rocky Shore	-	-	Assume sample not obtainable
		Unconsolidated Shore	®	optional	Use both for regularly or irregularly flooded shores; Use only Eco-SSLs for less frequently flooded shores.
		Emergent Wetland	®	optional	Substitute sediment benchmarks for Eco-SSLs only within regularly flooded or wetter reaches and unvegetated streambeds, tidal creeks, pools and hollows, or reaches dominated by Obligate wetland plant species
		Scrub-shrub Wetland	®	optional	Substitute sediment benchmarks for Eco-SSLs only within regularly flooded or wetter reaches and unvegetated streambeds, tidal creeks, pools and hollows, or reaches dominated by Obligate wetland plant species
		Forested Wetland	®	optional	Substitute sediment benchmarks for Eco-SSLs only within regularly flooded or wetter reaches and unvegetated streambeds, tidal creeks, pools and hollows, or reaches dominated by Obligate wetland plant species
Riverine	Tidal	Rock Bottom	-	-	Assume sample not obtainable
		Unconsolidated Bottom	-	®	Eco-SSLs are Not Applicable
		Aquatic Bed	-	®	Eco-SSLs are Not Applicable
		Streambed	optional	®	Use Eco-SSLs also only for irregularly flooded and/or frequently dry/exposed, vegetated streambeds used by foraging widlife.
		Rocky Shore	-	-	Assume sample not obtainable
		Unconsolidated Shore	®	optional	Use both for regularly or irregularly flooded shores; Use only Eco-SSLs in less frequently flooded shores supporting wildlife.
		Emergent Wetland (Non-persistent)	optional	®	Use sediment benchmarks within regularly flooded or wetter reaches dominated by aquatic macrophytes or Obligate wetland plant species, and in unvegetated streambeds, tidal creeks, pools and hollows; Consider Eco-SSLs also for irregularly flooded or drier reaches used by foraging wildlife.

Table 7.3. Recommended Application of Eco-SSLs and/or Sediment Benchmarks to NWI Categories of Wetlands and Deepwater Habitats

NWI Weland Classification: Wetlands and Deepwater Habitats			Applicability of Benchmarks		
System	Subsystem	Class	Eco-SSLs	Sediment Benchmarks	Comments
Riverine	Lower Perennial	Rock Bottom	-	-	Assume sample not obtainable
		Unconsolidated Bottom	-	®	Eco-SSLs are Not Applicable
		Aquatic Bed	-	®	Eco-SSLs are Not Applicable
		Rocky Shore	-	-	Assume sample not obtainable
		Unconsolidated Shore	®	optional	Use only Eco-SSLs in temporarily flooded or drier shores used by wildlife. Consider using both for seasonally flooded shores.
		Emergent Wetland (Non-persistent)	optional	®	Use only sediment benchmarks in seasonally flooded or wetter reaches dominated by Obligate wetland plant species, and in unvegetated streambeds; Consider Eco-SSLs also for temporarily flooded and drier reaches or during drawdown periods.
	Upper Perennial	Rock Bottom	-	-	Assume sample not obtainable
		Unconsolidated Bottom	-	®	Eco-SSLs are Not Applicable
		Aquatic Bed	-	®	Eco-SSLs are Not Applicable
		Rocky Shore	-	-	Assume sample not obtainable
		Unconsolidated Shore	®	optional	Use only Eco-SSLs in temporarily flooded or drier shores used by wildlife. Consider using both for seasonally flooded shores.
	Intermittent	Streambed	optional	®	Consider Eco-SSLs also for intermittently flooded or more frequently dry/exposed and vegetated streambeds.
Lacustrine	Limnetic	Rock Bottom	-	-	Assume sample not obtainable
		Unconsolidated Bottom	-	®	Eco-SSLs are Not Applicable
		Aquatic Bed	-	®	Eco-SSLs are Not Applicable
	Littoral	Rock Bottom	-	-	Assume sample not obtainable
		Unconsolidated Bottom		®	Eco-SSLs are Not Applicable
		Aquatic Bed	-	®	Eco-SSLs are Not Applicable
		Rocky Shore	-	-	Assume sample not obtainable
		Unconsolidated Shore	®	optional	Use only Eco-SSLs in temporarily flooded or drier shores used by wildlife. Consider using both for seasonally flooded shores.
		Emergent Wetland (Non-persistent)	optional	®	Use sediment benchmarks in seasonally flooded or wetter reaches with Obligate wetland plants, and in unvegetated streambeds; Consider using Eco-SSLs also in temporarily flooded and drier reaches or during seasonal drawdown periods.
Palustrine		Rock Bottom	-	-	Assume sample not obtainable
		Unconsolidated Bottom	-	®	Eco-SSLs are Not Applicable
		Aquatic Bed	-	®	Eco-SSLs are Not Applicable
		Unconsolidated Shore	®	optional	Use only Eco-SSLs in temporarily flooded or drier shores used by wildlife. Consider using both for seasonally flooded shores.
		Moss-Lichen Wetland	®	-	Apply Eco-SSLs for soil biota, plants, and wildlife receptors
		Emergent Wetland (Both Subclasses)	®	optional	Use only Eco-SSLs in temporarily flooded and drier reaches of the Persistent subclass; Use both types of benchmarks in seasonally flooded or wetter reaches of the Non-persistent subclass or reaches dominated by Obligate wetland plants
		Scrub-shrub Wetland	®	optional	Substitute sediment benchmarks for Eco-SSLs only in semipermanently flooded or wetter reaches, unvegetated channels, ponds, or hollows, and areas dominated by Obligate wetland plants
		Forested Wetland	®	optional	Substitute sediment benchmarks for Eco-SSLs only in semipermanently flooded or wetter reaches, unvegetated channels, ponds, or hollows, and areas dominated by Obligate wetland plants

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