ES/ER/TM-162/R2

Preliminary Remediation Goals for Ecological Endpoints

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Preliminary Remediation Goals for Ecological Endpoints

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PREFACE

This technical memorandum was prepared to present preliminary remediation goals (PRGs) for ecological endpoints for risk assessments and decision making at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites. This work was performed under Work Breakdown Structure 1.4.12.2.3.04.05.02 (Activity Data Sheet 8304). Publication of this document meets an Environmental Restoration Risk Assessment Program milestone for FY 96. PRGs are upper concentration limits for specific chemicals in specific environmental media that are anticipated to protect human health or the environment. They can be used for multiple remedial investigations at multiple facilities.

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ACRONYMS

ARARs	Applicable or Relevant and Appropriate Requirements
DQOs	data quality objectives
EPA	United States Environmental Protection Agency
FACR	final acute-chronic ratios
FAV	final acute values
LOAEL	lowest-observed-adverse-effects level
NAWQC	National Ambient Water Quality Criteria
NOAEL	no-observed- adverse-effects level
ORNL	Oak Ridge National Laboratory
PELs	Probable Effects Levels
PRGs	Preliminary Remediation Goals
RBRAO	risk-based remedial action objective
RGOs	Remedial Goal Options
RI/FS	remedial investigation/feasibility study
SQAGs	Sediment Quality Assessment Guidelines
TELs	Threshold Effects Levels

EXECUTIVE SUMMARY

Preliminary remediation goals (PRGs) are useful for risk assessment and decision making at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites. PRGs are upper concentration limits for specific chemicals in specific environmental media that are anticipated to protect human health or the environment. They can be used for multiple remedial investigations at multiple facilities. In addition to media and chemicals of potential concern, the development of PRGs generally requires some knowledge or anticipation of future land use.

In *Preliminary Remediation Goals for Use at the U. S. Department of Energy Oak Ridge Operations Office* (Energy Systems 1995), PRGs intended to protect human health were developed with guidance from *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual, Part B* (RAGS*)* (EPA 1991). However, no guidance was given for PRGs based on ecological risk. The numbers that appear in this volume have, for the most part, been extracted from toxicological benchmarks documents for Oak Ridge National Laboratory (ORNL) and have previously been developed by ORNL. The sources of the quantities, and many of the uncertainties associated with their derivation, are described in this technical memorandum.

1. INTRODUCTION

Preliminary remediation goals (PRGs) are useful for risk assessment and decision making at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites. PRGs are upper concentration limits for specific chemicals in specific environmental media that are anticipated to protect human health or the environment. They can be used for multiple remedial investigations at multiple facilities. In addition to media and chemicals of potential concern, the development of PRGs generally requires some knowledge or anticipation of future land use. The development of PRGs at Oak Ridge National Laboratory (ORNL) is proceeding as two separate exercises among experts in environmental and human health sciences, but the goals are brought together during remedial investigations.

In *Preliminary Remediation Goals for Use at the U. S. Department of Energy Oak Ridge Operations Office*, PRGs intended to protect human health were developed with guidance from *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual, Part B* (RAGS*)*. However, no guidance was given for PRGs based on ecological risk. The numbers that appear in this volume have, for the most part, been extracted from toxicological benchmarks documents for ORNL. The sources of the quantities, and many of the uncertainties associated with their derivation, are described in this technical memorandum.

PRGs are intended to correspond to minimal and acceptable levels of effects on the general ecological assessment endpoints as defined in the data quality objectives (DQO) process for ecological risk assessments on the Oak Ridge Reservation (Suter et al. 1994). In general, they correspond to small effects on individual organisms which would be expected to cause minimal effects on populations and communities. The PRGs may not be sufficiently protective of species of special concern which are based on effects on individual organisms (Suter et al. 1994). Remedial goals for such species should be developed ad hoc and should be based on no-observed-adverse-effects levels (NOAELs).

1.1 TOXICOLOGICAL BENCHMARKS AND ARARS

Toxicological benchmarks have previously been developed at ORNL for the initial screening of contaminants for potential consideration in risk assessments. Some of these are Applicable or Relevant and Appropriate Requirements (ARARs) for remedial action, and others are quantities derived from toxicity test endpoints. Although selected benchmarks are used as PRGs in various media, the two quantities should not be confused. The major differences are:

1. Benchmarks are specific to a receptor or endpoint that is to be protected. PRGs are medium-specific.

2. PRGs are single values for each combination of chemical and medium; benchmarks differ with the assessment endpoint.

3. Benchmarks are conservative, since they are designed to exclude or to screen out only those contaminants for which there is no potential ecological concern. PRGs are regulatory values or thresholds for significant effects.

The guidance document for human health PRGs (Energy Systems 1995) requires that remedial goals be based on ARARs or concentrations determined by risk assessment (EPA 1991). For ecological endpoints, the only federal or state ARARs are National Ambient Water Quality Criteria (NAWQC), available for more than a dozen contaminants in surface waters, and sediment quality criteria available for only five organic contaminants. The United States Environmental Protection Agency (EPA) guidance document provides no equations to protect ecological endpoints or suggested levels of protection analogous to the 10^{-6} risk for human carcinogens (EPA 1991).

1.2 ENVIRONMENTAL MEDIA

Three environmental media are considered here: surface water, sediment (including pore water), and soil. Groundwater contamination has greater consequences for human health than for nonhuman organisms. Data on microscopic and other small biota of groundwater are scarce. Therefore, ecologically-based groundwater PRGs are not presented in this technical memorandum. Although contaminants of potential concern at a site can be identified based on concentrations in food for wildlife or in the organism’s tissues, ultimately one of the three media mentioned previously will be remediated. Therefore, the media examined do not include “foods” and are limited to surface water, sediments, and soil.

1.3 LAND USE SCENARIOS

A major difference between this document and the guidance provided in RAGS and used in the human health PRGs guidance report (Energy Systems 1995) is that this report lacks emphasis on land use scenarios. For human health, land use determines human activities which determine exposure. Exposure pathways for humans can change, for example, depending on whether the land is industrial or not. Bathing may occur in residential areas and not in industrial areas; ingestion of plants (by humans) may not occur in industrial areas; and inhalation of particulates should not be significant in residential areas. Therefore, because humans engage in different activities in different locations, exposure will depend on land use.

Plants and animals, however, tend to inhabit a particular location and engage in all activities on that particular site. If a site is current or future habitat, then the PRG applies. The streams that flow through agricultural, residential, or industrial lands have the potential to support invertebrates and fish, regardless of land use. Land use types will only indirectly influence aquatic life, for example, through nutrient inputs to a stream. Similarly, exposure pathways for wildlife are not expected to change, depending on land use, though the relative emphasis of one pathway over another may be somewhat altered. If a site contains no habitat, such as a parking lot, it should be screened out during the conceptual development phase for an operable unit (i.e., before a remedial investigation is undertaken).

For lower organisms that are immersed in a medium, the spatial scale is so small that issues of land use do not usually arise (an exception may be soil organisms, as discussed in the following text). The physical habitat for organisms in a stream need not be substantially changed when land uses change. In these cases, correlations between concentrations and effects are used more often than detailed exposure equations. It is notable that ARARs (NAWQC and sediment quality criteria) are not attached to any particular land use scenario. The emphasis for ecological PRG development is on summary statistics for a wide range of effects on a wide range of organisms in a wide range of laboratory and field environments.

Among organisms that are exposed to aquatic contaminants, land use is probably most important to piscivorous wildlife, such as osprey or mink. For some contaminants in water, PRGs are based on aquatic-feeding species. PRGs for water account for both bioaccumulation through the food chain and drinking water. Piscivores may not feed as frequently under industrial land use scenarios. However, this document recommends the same PRGs for water in all contexts because of the paucity of information on piscivore behavior.

A second exceptional case where land use may be important is during the development of PRGs for soils. Soil microbial, invertebrate, and plant communities will be dependent on the management and nutrient additions and extractions from soil. Therefore, PRGs presented for soil may be modified according to land use.

1.4 MODIFICATION OF PRGS

Non-ARARs–based PRGs may be modified during the remedial investigation/feasibility study (RI/FS) using site-specific data (EPA 1991). Modifications may be based on:

1. land use assumptions;
2. exposure assumptions and habitat considerations (e.g., fraction of land that is suitable habitat);
3. environmental assumptions used for ORNL toxicological benchmarks (e.g., water hardness, soil pH, and organic content);
4. synergistic, antagonistic, or additive effects of pollutants;
5. impacts of contamination of one medium on another (EPA 1991);
6. impacts of remediation of one medium (such as sediments) on contamination of another medium (such as surface water);
7. effects of remediation on organisms and their habitat;
8. new contaminants of concern;
9. desirable level of protection.

In addition, Remedial Goal Options (RGOs), the clean-up goals recommended in the RI/FS, can contain objectives other than concentration limits in environmental media. Two examples are to (1) prevent a contaminated plume from intersecting a stream and (2) prevent toxicity in a standard toxicity test of the contaminated medium.

2. SURFACE WATER

PRGs for surface waters were chosen by comparing the ORNL benchmarks for screening toxicity of contaminants to aquatic life (chronic NAWQC or secondary chronic values; Suter and Tsao 1996) with those for toxicity to piscivorous wildlife (LOAEL; Sample et al. 1996). The lower of the two benchmarks is the PRG listed in Table 1. If the benchmarks and therefore the PRGs are not exceeded, the contaminant concentration in water probably presents no significant ecological hazard.

Table 1. Preliminary remediation goals for surface waters

Chemical	Water Concentration (mg/L)	Endpoint	Criterion
Inorganic chemical			
Aluminum	0.087	aquatic life	chronic NAWQC
Antimony	0.03	aquatic life	secondary chronic value
Arsenic III	0.19	piscivores	chronic NAWQC
Arsenic V	0.0031	aquatic life [a]	secondary chronic value
Barium	0.004	aquatic life[a]	secondary chronic value
Beryllium	0.00066	aquatic life [a]	secondary chronic value
Boron	0.0016	aquatic life	secondary chronic value
Cadmium	0.0011[b]	aquatic life	chronic NAWQC
Chromium III	0.21 [b]	aquatic life	chronic NAWQC
Chromium VI	0.011	aquatic life	chronic NAWQC
Cobalt	0.023	aquatic life [a]	secondary chronic value
Copper	0.012 [b]	aquatic life	chronic NAWQC
Cyanide	0.0052	aquatic life [a]	chronic NAWQC
Iron	1.0	aquatic life [a]	chronic NAWQC
Lead	0.0032 [b]	aquatic life	chronic NAWQC
Lithium	0.014	aquatic life	secondary chronic value
Manganese	0.12	aquatic life	secondary chronic value

Table 1. (continued)

Chemical	Water Concentration (mg/L)	Endpoint	Criterion
Mercury, inorg. or total	0.0013	aquatic life	secondary chronic value
Mercury, methyl	0.0000026	piscivores	from river otter LOAEL
Molybdenum	0.37	aquatic life	secondary chronic value
Nickel	0.16 [b]	aquatic life	chronic NAWQC
Selenium	0.00039	piscivores	from river otter LOAEL
Silver	0.00036	aquatic life	secondary chronic value
Strontium	1.5	aquatic life [a]	secondary chronic value
Thallium	0.009	piscivores	from river otter LOAEL
Tin	0.073	aquatic life	secondary chronic value
Uranium	0.0026	aquatic life[a]	secondary chronic value
Vanadium	0.020	aquatic life	secondary chronic value
Zinc	0.11 [b]	aquatic life	chronic NAWQC
Zirconium	0.017	aquatic life [a]	secondary chronic value
Organic Chemical			
Acenaphthene	0.023	aquatic life [a]	chronic NAWQC
Acetone	1.5	aquatic life	secondary chronic value
Anthracene	0.00073	aquatic life[a]	secondary chronic value
Benzene	0.13	aquatic life	secondary chronic value
Benzidene	0.0039	aquatic life[a]	secondary chronic value
Benzo(a)anthracene	0.000027	aquatic life[a]	secondary chronic value
Benzo(a)pyrene	0.000014	aquatic life	secondary chronic value
Benzoic acid	0.042	aquatic life [a]	secondary chronic value
Benzyl alcohol	0.0086	aquatic life [a]	secondary chronic value

Table 1. (continued)

Chemical	Water Concentration (mg/L)	Endpoint	Criterion
BHC, gamma (lindane)	0.00008	aquatic life [a]	chronic NAWQC
BHC (other)	0.0000040	piscivores	from river otter LOAEL
Biphenyl	0.014	aquatic life[a]	secondary chronic value
Bis(2-ethylhexyl) phthalate	0.00012	aquatic life	from river otter LOAEL
2-Butanone	14	aquatic life [a]	secondary chronic value
Butylbenzyl phthalate	0.019	aquatic life[a]	secondary chronic value
Carbon disulfide	0.00092	aquatic life [a]	secondary chronic value
Carbon tetrachloride	0.0098	aquatic life [a]	secondary chronic value
Chlordane	0.000037	piscivores	from river otter LOAEL
Chlorobenzene	0.064	aquatic life [a]	secondary chronic value
Chloroform	0.028	aquatic life	secondary chronic value
DDD p,p'	4.1×10^{-8} [c]	piscivores	from belted kingfisher LOAEL
DDT	4.1×10^{-8} [c]	piscivores	from belted kingfisher LOAEL
Decane	0.049	aquatic life [a]	secondary chronic value
Diazinon	0.000043	aquatic life[a]	secondary chronic value
Dibenzofuran	0.0037	aquatic life [a]	secondary chronic value
1,2-Dichlorobenzene	0.014	aquatic life[a]	secondary chronic value
1,3-Dichlorobenzene	0.071	aquatic life[a]	secondary chronic value
1,4-Dichlorobenzene	0.015	aquatic life[a]	secondary chronic value
1,1-Dichloroethane	0.047	aquatic life [a]	secondary chronic value
1,2-Dichloroethane	0.91	aquatic life	secondary chronic value
1,1-Dichloroethene	0.025	aquatic life [a]	secondary chronic value
1,2-Dichloroethene	0.59	aquatic life [a]	secondary chronic value

Table 1. (continued)

Chemical	Water Concentration (mg/L)	Endpoint	Criterion
1,1-Dichloropropene	0.000055	aquatic life [a]	secondary chronic value
Di-n-butyl phthalate	0.001	piscivores	from belted kingfisher LOAEL
Diethyl phthalate	0.21	aquatic life [a]	secondary chronic value
Endosulfan	0.000051	aquatic life[a]	secondary chronic value
Endrin	0.000061	aquatic life[a]	chronic NAWQC
Ethyl benzene	0.0073	aquatic life [a]	secondary chronic value
Fluoranthene	0.0062	aquatic life [a]	chronic NAWQC
Fluorene	0.0039	aquatic life[a]	secondary chronic value
Heptachlor	0.0000069	aquatic life	secondary chronic value
Hexachloroethane	0.012	aquatic life[a]	secondary chronic value
Hexane	0.00058	aquatic life [a]	secondary chronic value
2-Hexanone	0.099	aquatic life [a]	secondary chronic value
Methoxychlor	0.000019	aquatic life[a]	secondary chronic value
1-Methylnaphthalene	0.0021	aquatic life [a]	secondary chronic value
4-Methyl-2-pentanone	0.17	aquatic life [a]	secondary chronic value
2-Methylphenol	0.013	aquatic life [a]	secondary chronic value
Methylene chloride	2.2	aquatic life [a]	secondary chronic value
Naphthalene	0.012	aquatic life [a]	secondary chronic value
4-Nitrophenol	0.30	aquatic life [a]	secondary chronic value
N-Nitrosodiphenylamine	0.21	aquatic life [a]	secondary chronic value
2-Octanone	0.0083	aquatic life [a]	secondary chronic value
PCBs total	0.0000019[d]	piscivores	from river otter LOAEL [d]
Aroclor 1016	0.00023[e]	piscivores	from river otter LOAEL

Table 1. (continued)

Chemical	Water Concentration (mg/L)	Endpoint	Criterion
Aroclor 1221	0.00028	aquatic life[a]	secondary chronic value
Aroclor 1232	0.00058	aquatic life[a]	secondary chronic value
Aroclor 1242	0.000047	piscivores	from river otter LOAEL
Aroclor 1248	0.0000019	piscivores	from river otter LOAEL
Aroclor 1254	0.0000019	piscivores	from river otter LOAEL
Aroclor 1260	0.094	aquatic life [a]	secondary chronic value
Pentachlorobenzene	0.00047	aquatic life[a]	secondary chronic value
1-Pentanol	0.11	aquatic life [a]	secondary chronic value
Phenanthrene	0.0063	aquatic life [a]	secondary chronic value
Phenol	0.11	aquatic life [a]	secondary chronic value
2-Propanol	0.0075	aquatic life [a]	secondary chronic value
1,1,2,2-Tetrachloroethane	0.61	aquatic life [a]	secondary chronic value
Tetrachloroethene	0.098	aquatic life[a]	secondary chronic value
Toluene	0.0098	aquatic life	secondary chronic value
Tribromomethane	0.32	aquatic life[a]	secondary chronic value
1,2,4-Trichlorobenzene	0.11	aquatic life[a]	secondary chronic value
1,1,1-Trichloroethane	0.011	aquatic life [a]	secondary chronic value
1,1,2-Trichloroethane	1.2	aquatic life[a]	secondary chronic value
Trichloroethene	0.47	aquatic life	secondary chronic value
Vinyl acetate	0.016	aquatic life[a]	secondary chronic value
Vinyl chloride	0.782	piscivores[e]	from river otter LOAEL

Table 1. (continued)

Chemical	Water Concentration (mg/L)	Endpoint	Criterion
Xylene	0.013	aquatic life	secondary chronic value

Notes:

[a] Toxic concentration benchmarks are not available for piscivorous wildlife. Therefore, the PRG cannot be assumed to protect wildlife.

[b] Hardness dependent criterion for aquatic life benchmark normalized to 100 mg/L.

[c] Only a single value was available for DDT and metabolites, though different benchmarks were available for the protection of aquatic life.

[d] The lowest available concentration for the protection of piscivores from any Aroclor (1248) was used.

[e] Toxic concentration benchmarks are not available for aquatic life. Therefore, the PRG cannot be assumed to protect fish or aquatic invertebrates.

Since the NAWQC are ARARs for remedial action, they serve as the basis for screening contaminants in water. The chronic NAWQCs are EPA's calculation of final acute values (FAV) divided by final acute-chronic ratios (FACR), where the FAV is the fifth percentile of 48- to 96-hour median lethal concentration (LC50) values or equivalent median effective concentration (EC50) values for each criterion chemical. The FACR is the geometric mean of quotients of at least three LC50/CV ratios from tests of different families of aquatic organisms (Stephan et al. 1985). For several metals, NAWQC are functions of water hardness, and the default PRGs for those metals assume a water hardness of 100 mg/L. However, site-specific water hardness may be substantially different, thereby altering the magnitude or perhaps the direction of the difference between the aquatic life and piscivore toxicological benchmarks.

In this technical memorandum, as well as in the report by Suter and Tsao (1996), NAWQC are not included as potential PRGs for aquatic life if they are based on the protection of humans or other piscivores. This is because ecological PRGs should not be based on effects on humans, and the PRGs based on protection of aquatic life may be lower than the NAWQCs based on fish consumption. In addition, NAWQCs are not used as potential PRGs for piscivorous wildlife because they are not as rigorously derived or as appropriate to wildlife as the values derived by Sample et al. (1996).

Where NAWQC were not available, *secondary chronic values* were derived to be used as benchmarks for screening contaminants for toxicity to aquatic life (Suter and Tsao 1996). These values rely on fewer data than do the NAWQC. The method for calculating the secondary chronic value is described in EPA's *Proposed Water Quality Guidance for the Great Lakes System* (1993) and is explained by Suter and Tsao (1996).

For chemicals that are bioaccumulated by piscivores, benchmarks that protect these wildlife may be lower aqueous concentrations than those that protect the aquatic life within the stream. The benchmarks used for wildlife species that feed primarily on aquatic organisms were derived by Sample et al. (1996). The mammalian and avian species considered in the document are representative of wildlife found on the Oak Ridge Reservation. To obtain PRGs, lowest-observed-adverse-effects levels (LOAELS) rather than NOAELs are compared to surface water toxicological benchmarks because (1) NOAELs alone give no indication as to how much higher a concentration must be before adverse effects are observed (LOAELs are presumed to be the threshold levels at which effects become evident), (2) NOAELs often have more uncertainties associated with them than do LOAELs (see Sample et al. 1996), and (3) LOAELs for effects on individual wildlife are expected to correspond to no-effect or negligible-effect levels on wildlife populations. The equation used for calculating the LOAEL-based wildlife benchmarks is:

$$C_w = (LOAEL_w \text{ x } bw_w) / [W + (F \text{ x } BAF)] \quad \text{(Sample et al. 1996),}$$

which is equivalent to those used by the EPA (1993) where:

C_w = the benchmark concentration in water.
$LOAEL_w$ = the lowest observed adverse effects level (derived from LOAELs in individual studies),
bw_w = body weight of wildlife,
W = water consumption rate (kg/d),
F = food consumption rate (kg/d),
BAF = bioaccumulation factor (ratio of concentration of contaminant in fish tissue to concentration in water; L/kg).

For most of the analytes listed in Table 1, the chronic NAWQC or the secondary chronic value is the PRG. For several analytes, the PRG is based on the LOAEL for mink. However, one analyte, di-n-butyl phthalate, has a PRG that is derived from an avian LOAEL. For some analytes listed in Table 1, piscivore benchmarks were not available. Therefore, in these cases, the concentration cannot be assumed to protect piscivores, and the PRGs may change as the data gaps are filled.

If piscivores are not present at a site of concern, the PRGs in Table 1 that reflect toxicity to piscivores (e.g., methyl mercury, thallium, BHC) may be replaced with values from Table 3, which are benchmarks for toxicity to aquatic life.

3. SEDIMENT

Organisms that reside in sediments are exposed to different concentrations of contaminants from those in the water column. Chemicals in sediment may be present at higher concentrations and for longer time periods than chemicals dissolved in the surface water. Both the concentrations of chemicals in the solid phase of sediments and concentrations in the pore water are relevant to the exposure of benthic (sediment) organisms, and PRGs are presented for both media (Tables 2 and 3). If PRGs are available for both sediment and pore water, the PRG that is determined by the remedial investigation to be the best estimate of risk to sediment biota should take precedence. It is assumed that benthic organisms, including fish, are not significant constituents of the diets of mammalian and avian piscivores; therefore, piscivores are not determinants of PRGs for sediment, as they sometimes are for surface waters. If sediments are to be dredged and disposed of on land, PRGs for soil, as well as PRGs for sediments, should be considered. PRGs for sediments are taken from one of seven sources.

The lowest value of the following sediment toxicity benchmarks for each chemical is the PRG: (1) sediment quality criteria proposed by EPA (EPA 1993b–f); (2) sediment criteria based on the chronic NAWQC; (3) criteria calculated from the lowest chronic value for fish, daphnids, or other invertebrates in surface waters; 4) the NOAA Effects Range-Median (ER-M); (5) the Florida Department of Environmental Protection Probable Effect Level (PEL); or (6) the Probable Effects Concentration (PEC) selected from the EPA Assessment and Remediation of Contaminated Sediments (ARCS) Program Report (EPA 1996) and presented in Jones et al. (1997). All of these are described at length by Jones et al. (1996), and the lowest chronic values are not used as the PRG if they were originally estimated from acute toxicity (Suter and Tsao 1996). If these criteria are not available, the PRG is the lower of (1) the sediment benchmark calculated from the secondary chronic value for aquatic toxicity; (2) the Ontario Ministry of the Environment Severe Effect Level; or (3) the high No Effect Concentration (NEC) selected from the ARCS report and presented in Jones et al. (1997). The secondary chronic value is often one or two orders of magnitude lower than the lowest chronic values; therefore, PRGs based on this value are likely to be more conservative than other PRGs.

The five sediment quality criteria proposed in 1993 by EPA (EPA 1993b–f) are potential ARARs for assessing sediment quality with respect to acenaphthene, dieldrin, endrin, fluoranthene, and phenanthrene at hazardous waste sites. These and the ER-Ms and PELs were the only potential PRGs for organic chemicals that were not calculated based on partitioning between water and sediment.

Table 2. Preliminary remediation goals for sediments

Chemical	Sediment Concentration (mg/kg)	Type of Benchmark[a]
Inorganic chemical		
Arsenic	42	PEL
Cadmium	4.2	PEL
Chromium	159	PEC
Copper	77.7	PEC
Lead	110	PEL
Mercury	0.7	PEL
Nickel	38.5	PEC
Silver	1.8	PEL
Zinc	270	PEL
Organic chemical		
Acenaphthene	0.089	PEL
Acenaphthylene	0.13	PEL
Acetone[b]	0.0091	LCV for daphnid
Aldrin	0.080	Ontario Ministry of the Environment—severe
Anthracene	0.25	PEL

Table 2. (continued)

Chemical	Sediment Concentration (mg/kg)	Type of Benchmark[a]
Benzene	0.16	SCV
Benzidine[b]	0.0017	SCV
Benzo(a)anthracene	0.69	PEL
Benzo(a)pyrene	0.394	PEC
Benzo(b,k)fluoranthene	4.0	NEC
Benzo(g,h,i)perylene	6.3	PEC
Benzyl alcohol[b]	0.0011	SCV
BHC	120	Ontario Ministry of the Environment—severe
Biphenyl	1.1	SCV
Bis(2-ethylhexyl)phthalate	2.7	PEL
4-Bromophenyl phenyl ether	1.2	SCV
2-Butanone[b]	0.27	SCV
Carbon disulfide	0.00086	SCV
Carbon tetrachloride	2.0	LCV for fish
Chlordane	0.0048	PEL
Chlorobenzene	0.417	SCV
Chloroform	0.96	LCV for fish
Chrysene	0.85	PEL
Decane	41	SCV
DDD p,p'	0.0078	PEL
DDE p,p'	0.027	ER-M
DDT	0.052	PEL
Diazinon	0.0019	SCV
Dibenzo(a,h)anthracene	0.0282	PEC

Table 2. (continued)

Chemical	Sediment Concentration (mg/kg)	Type of Benchmark[a]
Dibenzofuran	0.42	SCV
1,2-Dichlorobenzene	0.33	SCV
1,3-Dichlorobenzene	1.7	SCV
1,4-Dichlorobenzene	0.35	SCV
1,1-Dichloroethane	0.027	SCV
1,2-Dichloroethane	4.3	LCV for daphnid
1,1-Dichloroethylene	3.5	LCV for fish
1,2-Dichloroethylene	0.40	SCV
1,3-Dichloropropene	0.23	LCV for fish
Di-n-butyl phthalate	240	LCV for daphnid
Diethyl phthalate	0.61	SCV
Dieldrin	0.0043	PEL
Endosulfan	0.0055	SCV
Endrin	0.045	ER-M
Ethyl benzene	5.4	LCV for fish
Fluoranthene	0.834	PEC
Fluorene	0.14	PEL
Heptachlor	13	LCV for fish
Hexachloroethane	1.0	SCV
Hexane	0.040	SCV
2-Hexanone[b]	0.023	SCV
Indeno(1,2,3-c,d)pyrene	0.837	PEC
Lindane (gamma BHC)	0.00099	PEL

Table 2. (continued)

Chemical	Sediment Concentration (mg/kg)	Type of Benchmark[a]
Methoxychlor	0.019	SCV
Methylene chloride	18	LCV for fish
4-Methyl-2-pentanone[b]	15	LCV for fish
2-Methylphenol[b]	0.012	SCV
Mirex	1.30	Ontario Ministry of the Environment—severe
Naphthalene	0.39	PEL
2-Octanone[b]	0.018	SCV
PAH, total	13.66	PEC
PAH, total high molecular wt.	4.354	PEC
PAH, total low molecular wt.	3.369	PEC
PCBs total	0.18	ER-M
Aroclor 1016	0.530	Ontario Ministry of the Environment—severe
Aroclor 1221	0.12	SCV
Aroclor 1232	0.60	SCV
Aroclor 1242	29	LCV for fish
Aroclor 1248	1.0	SCV
Aroclor 1254	72	LCV for fish
Aroclor 1260	63	LCV for fish
Pentachlorobenzene	0.70	SCV
1-Pentanol[b]	0.034	SCV
Phenanthrene	0.54	PEL
Phenol	0.032	chronic NAWQC
2-Propanol[b]	0.000084	SCV

Table 2. (continued)

Chemical	Sediment Concentration (mg/kg)	Type of Benchmark[a]
Pyrene	1.4	PEL
1,1,2,2-Tetrachloroethane	5.4	LCV for fish
Tetrachloroethylene	3.2	LCV for daphnid
Toluene	0.050	SCV
Tribromomethane	0.66	SCV
1,2,4-Trichlorobenzene	9.7	SCV
1,1,1-Trichloroethane	9.6	LCV for fish
1,1,2-Trichloroethane	9.8	LCV for fish
Trichloroethene	52	LCV for fish
Vinyl acetate	0.00084	SCV
Xylene	0.16	SCV

Notes:

[a] PEL, Florida Department of Environmental Protection Probable Effects Level (Macdonald 1994); ER-M, NOAA Effects Range-Median (Long et al. 1995); SCV, secondary chronic value (Jones et al. 1996); LCV, lowest chronic value for daphnids, non-daphnid invertebrates, or fish; Ontario Ministry of the Environment - severe, severe effects level; PEC, Probable Effects Concentration from EPA Assessment and Remediation of Contaminated Sediments (ARCS) Program Report (EPA 1996); NEC, high No Effect Concentration selected from the ARCS report (EPA 1996).

[b] Denotes polar nonionic organic compounds, for which the equilibrium partitioning model is likely to provide a conservative model of exposure.

For nonionic organic chemicals for which octanol-water partition coefficients are available, sediment toxicity benchmarks were calculated based on equilibrium partitioning, assuming 1% organic carbon and using the benchmarks for surface waters (NAWQC, secondary chronic values, and lowest chronic values for fish, daphnids, and non-daphnid invertebrates). These benchmarks were considered as possible PRGs, with lower concentrations selected according to the priority discussed previously. An advantage of the equilibrium partitioning approach is that the PRG can be adapted to different sites by adjusting the organic carbon parameter. Both the sediment quality criteria and the equilibrium partitioning benchmarks have been used by ORNL to screen for contaminants of potential concern for ecological risk assessments (Jones et al. 1997). The equation originally used by EPA (1989) and then used by Jones et al. (1997) is:

$$SQB = f_{oc} \times K_{oc} \times WQB,$$

where:

SQB = sediment quality benchmark,
f_{oc} = mass fraction of organic carbon,
K_{oc} = organic carbon-water partition coefficient,

WQB = water quality benchmark.

The derivation of the equation is given by Jones et al. (1997). The biological assumptions of the equilibrium partitioning approach, according to Jones et al. (1997), are:

1. the sensitivities of benthic species and species tested to derive WQC, predominantly water column species, are similar;

2. the levels of protection afforded by WQC are appropriate for benthic organisms; and

3. exposures are similar regardless of feeding type or habitat (EPA 1993b).

Sediments and pore water are assumed to be in continual equilibrium (MacDonald 1994a).

Table 3. Preliminary remediation goals for pore water of sediments (to be used with Table 1)
[PRGs for pore water are presented in Table 1 except for surface water values that were based on risk in piscivores. PRGs for those chemicals are listed here and obtained from Suter and Tsao (1996).]

Chemical	Water Concentration (mg/L)	Criterion
Inorganic chemical		
Arsenic III	0.19	chronic NAWQC
Mercury, methyl	0.0000028	secondary chronic value
Selenium	0.005	chronic NAWQC
Thallium	0.012	secondary chronic value
Organic chemical		
BHC (other than gamma)	0.0022	secondary chronic value
DDD p,p'	0.000011	secondary chronic value
DDT	0.000013	secondary chronic value
Di-n-butyl phthalate	0.035	secondary chronic value
PCBs total	0.00014	secondary chronic value
Aroclor 1242	0.000053	secondary chronic value
Aroclor 1248	0.000081	secondary chronic value

Table 3. (continued)

Chemical	Water Concentration (mg/L)	Criterion
Aroclor 1254	0.000033	secondary chronic value
Xylene	0.013	secondary chronic value

PRGs for inorganic chemicals in sediments are taken from the Florida Sediment Quality Assessment Guidelines (SQAGs) (MacDonald 1994a). The SQAGs include Threshold Effects Levels (TELs), “the upper limit of the range of sediment contaminant concentrations dominated by no effects data entries . . . [and] not considered to represent significant hazards to aquatic organisms” and Probable Effects Levels (PELs), “the lower limit of the range of contaminant concentrations that are usually or always associated with adverse biological effects” (MacDonald 1994a). In this document, PELs are used as PRGs for several metals. The calculation used is:

$$\mathrm{PEL} = \sqrt{\mathrm{EDS}_m \times \mathrm{NEDS}_H} \quad ,$$

where EDS_m is the 50th percentile concentration in the effects data set, and NEDS_H is the 85th percentile concentration in the no effects data set. Few data exist on chronic effects of contaminants on organisms in sediments; therefore, many of the studies present acute responses.

The Florida SQAGs were designed for prioritizing risk management actions, interpreting and designing monitoring programs for sediment contamination, designing wetland restoration programs, supporting decisions by multiple parties relating to sediments, etc. They were not intended for use as sediment quality criteria (MacDonald 1994a). The SQAGs were designed for use in marine and estuarine systems only. In addition, factors that influence bioavailability of metals at a site, such as acid volatile sulfide for divalent cations, are not taken into account by these guidelines or PRGs (MacDonald 1994a).

Jones et al. (1997) cautions that the sediment benchmarks do not represent remedial goals, since the removal or other disturbance of sediment can affect habitat or cause toxic effects in surface water. Similarly, MacDonald (1994a) suggests that the Florida SQAGs should not be used directly as clean-up targets for hazardous sites without additional site-specific studies. The PRGs for sediments are not ideal and should be modified on a site-by-site basis. Nonetheless, they are the best and most current remedial goals available to protect nonhuman organisms and ecological systems in the absence of reliable sediment toxicity benchmarks.

Although sediments are usually identified for remediation on the basis of their bulk concentrations, in some cases pore water concentrations are the appropriate PRG because the toxicity of the sediment is more clearly associated with the pore water than bulk sediment contaminant levels. This circumstance will occur when the toxicity is primarily due to exposure to pore water, and variance in sediment properties causes the sediment/water distribution coefficient to be variable. Pore water PRGs would also be appropriate where ecological risks are associated with a contaminated groundwater plume that intersects or is predicted to intersect the bed of a stream or river. The PRGs for these cases are the potential PRGs for aquatic life in surface water (i.e., chronic NAWQCs and secondary chronic values). These values are presented in Table 1, except for those chemicals with aqueous PRGs based on wildlife risks. The values for these chemicals are presented in Table 3, since it is assumed that piscivores do not feed on sediment-associated organisms.

4. SOIL

PRGs for soil were chosen by comparing the ORNL toxicological benchmarks for plants and earthworms in soils to calculated PRGs for wildlife. ARARs for soils do not exist. Earthworms represent highly exposed invertebrates. Benchmarks for plants appear in *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants* (Efroymson et al. 1997a); benchmarks for earthworms appear in *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process* (Efroymson et al. 1997b). The procedure for calculating PRGs for wildlife endpoints is described in the following paragraphs. All benchmarks and all PRGs are based on one or more field, greenhouse, or growth chamber studies.

Benchmarks for the three types of organisms (wildlife, plants, and soil invertebrates) were compared, and the lowest value available is the PRG (Table 4). Remedial goals are rarely based on risks to microbial processes; thus, this benchmark was not a candidate for the PRG. However, it is notable that the toxicity benchmark (or in the case of wildlife, PRG) for heterotrophic processes is lower than that for plants, soil, invertebrates, or wildlife for two chemicals: fluorine and hexachlorobenzene (Efroymson et al. 1997b). In media other than soil, if the benchmarks and therefore the PRGs are not exceeded, it is assumed that the chemical concentration in the medium presents no significant ecological hazard. In soils, the uncertainties associated with the PRGs are probably greater than in water or sediments. These uncertainties include:

1. For many chemicals in Table 4, toxicity to only one or two of the three types of organisms (plants, wildlife, invertebrates) has been studied.

2. Efroymson et al. (1997a,b) have low confidence in most of the soil benchmarks because of a limited number of studies and/or biological endpoints for almost all contaminants.

3. Soil-earthworm (Sample et al. 1997a), soil–small mammal (Sample et al. 1997b), and soil-plant (Efroymson et al. 1997c) contaminant uptake models do not account for soil and biota properties.

Although the confidence in the numbers in Table 4 is generally low, PRGs for soils are needed. As the toxicity of contaminants to additional organisms is investigated, these preliminary values will be modified. PRGs can only be based on toxicity to categories of organisms that have been studied; final remedial goals can incorporate safety factors to protect other populations.

Table 4. Preliminary remediation goals for soils

Chemical	Soil Concentration (mg/kg)	Endpoint
Inorganic chemical		
Antimony	5[a]	plant[b, c]
Arsenic	9.9	shrew, plant
Barium	283	woodcock[b]
Beryllium	10[a]	plant[b, c]
Boron	0.5[a]	plant[b, c]
Bromine	10[a]	plant[b, c]
Cadmium	4[a]	plant, woodcock[c]
Chromium	0.4[a]	earthworm[c]
Cobalt	20[a]	plant[b, c]
Copper	60[d]	earthworm[c]
Fluorine	200[a]	plant[b, c]
Iodine	4[a]	plant[b, c]
Lead	40.5	woodcock
Lithium	2[a]	plant[b, c]
Mercury	0.00051[e]	woodcock
Molybdenum	2[a]	plant [b]
Nickel	30	plant[c]
Selenium	0.21	mouse[c]
Silver	2[a]	plant[c]
Technetium	0.2[a]	plant[b, c]
Thallium	1[a]	plant [b, c]
Tin	50[a]	plant[b, c]

Table 4. (continued)

Chemical	Soil Concentration (mg/kg)	Endpoint
Uranium	5[a]	plant[b, c]
Vanadium	2[a]	plant[b, c]
Zinc	8.5	woodcock[c]
Organic chemical		
Acenaphthene	20[a]	plant[b, c]
Biphenyl	60[a]	plant[b, c]
Chlorobenzene	40[a]	earthworm[c, f]
3-Chloroaniline	20	plant[b,c]
3-Chlorophenol	7[a]	earthworm[c]
Di-n-butyl phthalate	200[a]	plant[b, c]
1,4-Dichlorobenzene	20[a]	earthworm[c, f]
3,4-dichlorophenol	20[a]	plant, earthworm[c]
Diethyl phthalate	100[a]	plant[b, c]
2,4-Dinitrophenol	20[d]	plant[b, c]
Furan	600[a]	plant[b, c]
Hexachlorocyclopentadiene	10[a]	plant[b, c]
4-nitrophenol	7[a]	earthworm[c, f]
Pentachlorophenol	3[a]	plant
Pentachlorobenzene	20[a]	earthworm[c, f]
Phenol	30[a]	earthworm[c]
PCBs	0.371	shrew[b]
Styrene	300[a]	plant[b, c]

Table 4. (continued)

Chemical	Soil Concentration (mg/kg)	Endpoint
TCDD	3.15e-06	shrew[b, f]
TCDF	0.00084	hawk[b, f]
2,3,5,6-Tetrachloroaniline	20[a]	plant[b, c]
1,2,3,4-Tetrachlorobenzene	10[a]	earthworm[c, f]
2,3,4,5-Tetrachlorophenol	20[a]	earthworm[c, f]
Toluene	200[a]	plant[b, c]
2,4,5-Trichloroaniline	20[a]	plant[b, c]
1,2,3-Trichlorobenzene	20[a]	earthworm[c, f]
1,2,4-Trichlorobenzene	20[a]	earthworm[c, f]
2,4,5-Trichlorophenol	9[a]	earthworm[c, f]
2,4,6-Trichlorophenol	4[a]	plant[c]

Notes:

[a] Efroymson et al. (1997a,b) have low confidence in this value. The level of confidence refers to the benchmark chosen for the PRG and not to the relationship between it and the benchmarks not chosen.

[b] Toxic concentration benchmarks are not available for earthworms. Therefore, the PRG cannot be assumed to protect earthworms.

[c] Soil-plant uptake models, soil-earthworm uptake models or LOAELs were not available for this chemical for at least one wildlife endpoint (see Table 6). Therefore, the PRG cannot be assumed to protect wildlife.

[d] Efroymson et al. (1997a,b) have moderate confidence in this value.

[e] This value is so low that it may often be within background soil concentrations. We do not recommend that remedial goals be set within the range of background concentrations.

[f] Toxic concentration benchmarks are not available for plants in soils. Therefore, the PRG cannot be assumed to protect plants.

Wildlife PRGs for soil were derived by iteratively calculating exposure estimates using different soil concentrations and soil-to-biota contaminant uptake models. The soil concentrations were manipulated to produce an exposure estimate equivalent to the wildlife endpoint-specific and contaminant-specific LOAEL, which were obtained from Sample et al. (1996). Uptake models for plants were obtained from Efroymson et al. (1997); those for earthworms, from Sample et al. (1997a); and those for small mammals, from Sample et al (1997b). Because different diets may dramatically influence exposures and sensitivity to contaminants varies among species, PRGs were developed for six species present on the Oak Ridge Reservation: short-tailed shrew, white-footed mouse, red fox, white-tailed deer, American woodcock, and red-tailed hawk.

Log-log regression models were used for particular chemicals and diet items if the regressions were significant in the three documents above. The regressions included data from published literature and unpublished datasets if the addition of the latter did not make the regression insignificant. For some chemicals and diet items, only unpublished data were available from which to construct the regression. Median uptake factors (UFs); concentration of chemical in biota divided by concentration in soil) were used if the log-log regression was not significant. Copies of the spreadsheets used to calculate wildlife PRGs appear in the appendix. Intercept and slope parameters are listed if the log-log regression model was used; the median UF parameter is listed if the uptake factor was used.

For each chemical, the PRG for each of the wildlife species was compared, and the lowest value was selected as the final wildlife PRG. This PRG appears in Table 4 if this calculated concentration in soil is lower than the toxicity benchmarks for earthworms and plants. Estimates of oral exposure to contaminants were generated using the generalized exposure model (Sample and Suter 1994):

$$E_j = \sum_{i=1}^{m} p_{ik} \left(\frac{IR_i \text{ x } C_{ijk}}{BW} \right)$$

where:

E_j = total exposure to contaminant (j) (mg/kg/d),
m = total number of ingested media (e.g., food or soil),
IR_i = ingestion rate for medium (i) (kg/d or L/d),
p_{ik} = proportion of type (k) of medium (i) consumed (unitless),
C_{ijk} = concentration of contaminant (j) in type (k) of medium (i) (mg/kg or mg/L),
BW = body weight of endpoint species (kg).

PRGs were calculated for only those chemicals for which both uptake models and LOAELs were available. The 90th percentile of the soil-to-biota uptake factor was used as a conservative estimate of the chemical concentrations in wildlife food types (earthworms, plants, or small mammals). Species-specific life history parameters needed to estimate exposure were obtained from Sample and Suter (1994) and are presented in Table 5. The model accounts for the ingestion of soil as well as food. Summaries of the derivation of PRGs for each species are presented in the appendix.

Soil PRGs for each wildlife species and the recommended final PRG for protection of wildlife, generally, are presented in Table 6. For most chemicals the final PRG for protection of wildlife was based on the PRG for either short-tailed shrew or American woodcock (Table 6). This result is due to the large quantity of soil ingested by these wildlife and the relatively high chemical uptake rates for their food (earthworms).

Table 5. Life history parameters used to estimate PRGs for wildlife

Species	Body Weight (kg)	Ingestion Rate (kg/d)		Percent of diet		
		Food	Soil	Earthworm	Plant	Small Mammal
Short-tailed Shrew	0.015	0.009	0.00117	100%	0%	0%
White-footed Mouse	0.022	0.0034	0.000068	50%	50%	0%
Red Fox	4.5	0.45	0.0126	9%	10%	81%
White-tailed Deer	56.5	1.74	0.0348	0%	100%	0%
American Woodcock	0.198	0.15	0.0156	100%	0%	0%
Red-tailed Hawk	1.126	0.109	0	0%	0%	100%

Table 6. Summary of species-specific and final soil PRGs for wildlife

Analyte	Preliminary Remedial Goal (mg/kg in soil)						
	Red Fox	White-tailed Deer	White-footed Mouse	Short-tailed Shrew	American Woodcock	Red-tailed Hawk	Final
Arsenic	92	144	149	9.9	102	143000	9.9
Barium	1220	1020	1775	329	283	10350	283
Cadmium	147	273	63	6	4.2	UND[b]	4.2
Chromium	1090	1970	880	110	16.1	UND[b]	16.1
Copper	3000	7000	10100	370	515	UND[b]	370
Lead	7150	18600	6250	740	40.5	55000	40.5
Lithium[c]	2900	8600	5650	390	ND[a]	ND[a]	390
Mercury	0.83	5.4	7.1	0.146	0.00051	12.3	`0.00051
Molybdenum [c]	64	635	36.5	4.75	44	165000	4.75
Nickel	3330	18800	1830	246	121	UND[b]	121
PCB [c]	3.05	138	1.6	0.371	0.655	15.5	0.371
Selenium	0.93	1.66	0.21	UND[d]	UND[d]	420	0.21
Thallium [e]	3.56	34	48.5	2.1	ND[a]	ND[a]	2.1
Uranium [e]	615	1480	2100	92	ND[a]	ND[a]	92
Vanadium[f]	267	710	1120	55	ND[a]	ND[a]	55
Zinc	32500	19100	35000	1600	8.5	UND[b]	8.5
TCDD[c]	3.06e-05	0.00455	2.23e-05	3.15e-06	1.58e-05	1.25e-03	3.15e-06
TCDF	ND[g]	ND[g]	ND[g]	ND[g]	ND[g]	0.00084	0.00084

[a] ND = No data. LOAEL for birds not available for this chemical.

[b] UND = Undefined. Due to characteristics of soil-small mammal uptake model, soil concentration cannot be raised sufficiently high to produce exposure equivalent to LOAEL.

[c] Uptake model for plants not available. PRGs for fox and mice for exposure from soil, earthworms, and small mammals (for fox) only. PRG for deer reflects exposure from soil only.

[d] UND = Undefined. Due to characteristics of soil-earthworm uptake model, soil concentration cannot be reduced sufficiently low to produce exposure equivalent to LOAEL.

[e] Uptake model available for small mammals only. PRG for fox for exposure from soil and small mammals only. PRG for deer, mice, and shrews reflect exposure from soil only.

[f] Uptake model for earthworms not available. PRGs for fox, deer, and mice for exposure from soil, plants, and small mammals (for fox) only. PRG for shrews reflects exposure from soil only.

[g] ND = No Data. LOAEL for mammals not available for this chemical.

Remedial goals for soils should be modified based on the bioavailability of the contaminants of concern. The bioavailable fraction of a chemical in soil is probably lower than the total concentration. Toxicity tests in soil on which the PRGs are based sometimes begin with known concentrations of a chemical or may assume a relationship between what is extractable by an arbitrary solvent and what is bioavailable. The organic fraction and pH of soil are two major factors that influence the uptake of chemicals by plants. “Aged” organic contaminants may not be as available for uptake as freshly added chemicals. 2,4-Dinitrophenol is an example of a chemical that is more toxic to plants under acidic conditions (Efroymson et al. 1997a). The context of the studies from which the toxicological benchmarks for soil were derived is available in the Efroymson et al. reports (1997a,b), Sample et al. (1996), and in greater detail in the original publications. As more is known about the bioavailability of contaminants in soils, the default PRGs should be modified.

PRGs for soil, more than for other media, are likely to be influenced by different land use scenarios. Uses of soil will affect the fraction of land that is suitable for habitat and the necessity of protecting various organisms. The PRGs in Table 4 and the calculations for wildlife assume that habitat is 100% available for the organisms in the assessed region. This assumption is reasonable for relatively immobile organisms such as plants, earthworms, and microorganisms. However, for wildlife, the role of habitat will be important for determining exposure. For example, if the availability of habitat at a site is minimal, use of the site by wildlife, and therefore contaminant exposure, is likely to be minimal.

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APPENDIX

SOIL PRG DATA

Table A. 1. Soil PRG for red fox assumed to consume 81% small mammals, 10% plants and 9% worms - using the 1997 UFs and models

		Earthworm			Plant			Small mammal												
Analyte[a]	Soil conc (mg/kg)	Median UF	Intercept	Slope	Median UF	Intercept	Slope	Median UF	Intercept	Slope	Estimated worm conc (mg/kg)	Estimated plant conc (mg/kg)	Estimated mammal conc (mg/kg)	Worm exposure (mg/kg/d)	Plant exposure (mg/kg/d)	Mammal exposure (mg/kg/d)	Soil exposure (mg/kg/d)	Total exposure (mg/kg/d)	LOAEL (mg/kg/d)	Form
Arsenic	92		-1.421	0.706		-1.744	0.594		-5.0249	0.8354	5.879	2.565	0.287	0.053	0.026	0.023	0.258	0.359	0.360	Arsenite
Barium	1220	0.091			0.1561			0.0417			111.020	190.442	50.874	0.999	1.904	4.121	3.416	10.440	10.5	barium hydroxide
Cadmium	147		2.114	0.795		-0.18	0.819		-0.8408	0.392	437.639	49.758	3.051	3.939	0.498	0.247	0.412	5.095	5.094	cadmium chloride
Chromium	1090	0.306			0.041				-0.5506	0.315	333.540	44.690	5.220	3.002	0.447	0.423	3.052	6.924	6.94	Cr+6
Copper	3000		1.675	0.264		0.014	0.423		1.8533	0.1309	44.198	29.985	18.198	0.398	0.300	1.474	8.400	10.572	10.6	copper sulfate
Lead	7150	0.266				-1.866	0.787		-0.7216	0.5019	1901.900	167.088	41.792	17.117	1.671	3.385	20.020	42.193	42.25	lead acetate
Lithium	2900	0.046						0.0026			133.400		7.540	1.201	0.000	0.611	8.120	9.931	9.9	lithium carbonate
Mercury	0.83		0.078	0.337	0.25			0.054			1.015	0.208	0.045	0.009	0.002	0.004	0.002	0.017	0.017	Methyl Mercury Chloride
Molybdenum	64	0.953						0.0022			60.992		0.141	0.549	0.000	0.011	0.179	0.740	0.74	MoO4
Nickel	3330	1.059				-1.927	0.791		0.1356	0.1956	3526.470	88.995	5.596	31.738	0.890	0.453	9.324	42.405	42.25	nickel sulfate hexahydrate
PCB	3.05		1.410	1.361				1.2			18.685		3.660	0.168	0.000	0.296	0.009	0.473	0.474	n/a
Selenium	0.93		6.400	8.700		0.515	1.13		-1.1084	0.5702	14.491	1.542	0.317	0.130	0.015	0.026	0.003	0.174	0.174	Selenate (SeO4)
Thallium	3.56							0.102					0.363	0.000	0.000	0.029	0.010	0.039	0.039	thallium sulfate
Uranium	615							0.0001					0.062	0.000	0.000	0.005	1.722	1.727	1.722	Uranyl acetate
Vanadium	267				0.0049			0.0123				1.308	3.284	0.000	0.013	0.266	0.748	1.027	1.030	sodium metavanadate (NaVO3)
Zinc	32500		4.449	0.328		-0.452	0.841		4.1204	0.1096	2582.700	3964.540	192.296	23.244	39.645	15.576	91.000	169.466	169.0	zinc oxide
TCDD	3e-05		2.502	1.005					0.8113	1.0993	0.000		2.45e-05	3.20e-06	0.00e+00	1.99e-06	8.57e-08	5.27e-06	5.30e-06	na

Notes: (1) regression models: ln(biota)= intercept + slope [ln(soil)] except Se in worms: biota= intercept + slope (soil). (2) Earthworm UFs and models from Sample et al. 1997a. (3) Small mammal UFs and models from Sample et al. 1997b. (4) Plant UFs and models from Efroymson et al. 1997c

[a] HQs for all analytes are equal to 1.0.

Table A.2. Soil PRG for White-tailed Deer assumed to consume 100% plants - using the 1997 UFs and models

Analyte[a]	Soil conc. (mg/kg)	Plant			Estimated plant conc. (mg/kg)	Food exposure (mg/kg/d)	Soil exposure (mg/kg/d)	Total exposure (mg/kg/d)	LOAEL (mg/kg/d)	Form
		Median UF	Intercept	Slope						
Arsenic	144		-1.744	0.594	3.347	0.103	0.089	0.192	0.191	Arsenite
Barium	1020	0.1561			159.222	4.903	0.628	5.532	5.6	barium hydroxide
Cadmium	273		-0.18	0.819	82.612	2.544	0.168	2.712	2.706	cadmium chloride
Chromium	1970	0.041			80.770	2.487	1.213	3.701	3.69	Cr+6
Copper	7000		0.014	0.423	42.910	1.321	4.312	5.633	5.6	copper sulfate
Lead	18600		-1.866	0.787	354.579	10.920	11.456	22.376	22.44	lead acetate
Lithium	8600					0.000	5.297	5.297	5.30	lithium carbonate
Mercury	5.4	0.25			1.350	0.042	0.003	0.045	0.045	Methyl Mercury Chloride
Molybdenum	635					0.000	0.391	0.391	0.390	MoO4
Nickel	18800		-1.927	0.791	349.924	10.776	11.579	22.356	22.44	nickel sulfate hexahydrate
PCB	138					0.000	0.085	0.085	0.08	na
Selenium	1.66		0.515	1.13	2.967	0.091	0.001	0.092	0.093	Selenate (SeO4)
Thallium	34					0.000	0.021	0.021	0.02	thallium sulfate
Uranium	1480					0.000	0.912	0.912	0.92	uranyl acetate
Vanadium	710	0.0049			3.479	0.107	0.437	0.544	0.547	sodium metavanadate (NaVO3)
Zinc	19100		-0.452	0.841	2535.409	78.082	11.764	89.846	89.8	zinc oxide
TCDD	0.00455					0.00e+00	2.80e-06	2.80e-06	2.80e-06	na

Notes: (1) regression models: ln(biota)= intercept + slope [ln(soil)]. (2) Plant UFs and models from Efroymson et al. 1997c.

[a] HQs for all analytes are equal to 1.0.

Table A.3. Soil PRG for white-footed mouse assumed to consume 50% plants and 50% worms - using the 1997 UFs and models

Analyte	Soil conc (mg/kg)	Earthworm			Plant			Estimated worm conc (mg/kg)	Estimated plant conc (mg/kg)	Worm exposure (mg/kg/d)	Plant exposure (mg/kg/d)	Soil exposure (mg/kg/d)	Total exposure (mg/kg/d)	LOAEL (mg/kg/d)	Form
		Median UF	Intercept	Slope	Median UF	Intercept	Slope								
Arsenic	149		-1.421	0.706		-1.744	0.594	8.263	3.416	0.639	0.264	0.461	1.363	1.362	Arsenite
Barium	1775	0.091			0.1561			161.525	277.078	12.481	21.411	5.486	39.378	39.5	barium hydroxide
Cadmium	63		2.114	0.795		-0.18	0.819	223.138	24.859	17.243	1.921	0.195	19.358	19.264	cadmium chloride
Chromium	880	0.306			0.041			269.280	36.080	20.808	2.788	2.720	26.316	26.24	Cr+6
Copper	10100		1.675	0.264		0.014	0.423	60.895	50.108	4.706	3.872	31.218	39.796	40.0	copper sulfate
Lead	6250	0.266				-1.866	0.787	1662.500	150.302	128.466	11.614	19.318	159.398	159.77	lead acetate
Lithium	5650	0.046						259.900		20.083	0.000	17.464	37.547	37.5	lithium carbonate
Mercury	7.1		0.078	0.337	0.25			2.093	1.775	0.162	0.137	0.022	0.321	0.320	Methyl Mercury Chloride
Molybdenum	36.5	0.953						34.784		2.688	0.000	0.113	2.801	2.81	MoO4
Nickel	1830	1.059				-1.927	0.791	1937.970	55.426	149.752	4.283	5.656	159.692	159.77	nickel sulfate hexahydrate
PCB	1.6		1.410	1.361				7.765		0.600	0.000	0.005	0.605	0.607	n/a
Selenium	0.21		6.400	8.700		0.515	1.13	8.227	0.287	0.636	0.022	0.001	0.659	0.659	Selenate (SeO4)
Thallium	48.5									0.000	0.000	0.150	0.150	0.149	thallium sulfate
Uranium	2100									0.000	0.000	6.491	6.491	6.511	Uranyl acetate
Vanadium	1120				0.0049				5.488	0.000	0.424	3.462	3.886	3.894	sodium metavanadate (NaVO3)
Zinc	35000		4.449	0.328		-0.452	0.841	2646.248	4219.492	204.483	326.052	108.182	638.716	639.1	zinc oxide
TCDD	2e-05		2.502	1.005				0.0002588		0.00002	0	6.893e-08	0.0000201	2.00e-05	na

Notes: (1) regression models: ln(biota)= intercept + slope [ln(soil)] except Se in worms: biota= intercept + slope (soil). (2) Earthworm UFs and models from Sample et al. 1997a. (3) Plant UFs and models from Efroymson et al. 1997c.

[a] HQs for all analytes are equal to 1.0.

Table A.4. Soil PRG for Short-tailed Shrews assumed to consume 100% worms - using the 1997 UFs and models

Analyte	Soil conc (mg/kg)	Earthworm			Estimated worm conc (mg/kg)	Food exposure (mg/kg/d)	Soil exposure (mg/kg/d)	Total exposure (mg/kg/d)	LOAEL (mg/kg/d)	Form	HQ
		Median UF	Intercept	Slope							
Arsenic	9.9		-1.421	0.706	1.218	0.731	0.772	1.503	1.498	Arsenite	1.00
Barium	329	0.091			29.939	17.963	25.662	43.625	43.5	barium hydroxide	1.00
Cadmium	6		2.114	0.795	34.413	20.648	0.468	21.116	21.200	cadmium chloride	1.00
Chromium	110	0.306			33.660	20.196	8.580	28.776	28.88	Cr+6	1.00
Copper	370		1.675	0.264	25.436	15.262	28.860	44.122	44.0	copper sulfate	1.00
Lead	740	0.266			196.840	118.104	57.720	175.824	175.83	lead acetate	1.00
Lithium	390	0.046			17.940	10.764	30.420	41.184	41.3	lithium carbonate	1.00
Mercury	0.146		0.078	0.337	0.565	0.339	0.011	0.351	0.352	Methyl Mercury Chloride	1.00
Molybdenum	4.75	0.953			4.527	2.716	0.370	3.087	3.09	MoO4	1.00
Nickel	246	1.059			260.514	156.308	19.188	175.496	175.83	nickel sulfate hexahydrate	1.00
PCB	0.371		1.410	1.361	1.062	0.637	0.029	0.666	0.668	n/a	1.00
Selenium	0.000001		6.400	8.700	6.400	3.840	7.800e-08	3.840	0.725	Selenate (SeO4)	5.29
Thallium	2.1					0	0.164	0.164	0.164	thallium sulfate	1.00
Uranium	92					0	7.176	7.176	7.165	uranyl acetate	1.00
Vanadium	55					0	4.290	4.290	4.285	Na(VO3)	1.00
Zinc	1600		4.449	0.328	961.895	577.137	124.800	701.937	703.3	zinc oxide	1.00
TCDD	0.0000032		2.502	1.005	3.62e-05	2.17e-05	0.0000002	2.20e-05	2.20e-05	na	1.00

Notes: (1) regression models: ln(biota)= intercept + slope [ln(soil)] except Se in worms: biota= intercept + slope (soil). (2) Earthworm UFs and models from Sample et al. 1997a.

Table A.5. Soil PRG for American Woodcock assumed to consume 100% worms - using the 1997 UFs and models

Analyte	Soil conc (mg/kg)	Earthworm			Estimated worm conc (mg/kg)	Food exposure (mg/kg/d)	Soil exposure (mg/kg/d)	Total exposure (mg/kg/d)	LOAEL (mg/kg/d)	Form	HQ
		Median UF	Intercept	Slope							
Arsenic	102		-1.421	0.706	6.323	4.790	8.036	12.827	12.8	sodium arsenite	1.00
Barium	283	0.091			25.753	19.510	22.297	41.807	41.7	barium hydroxide	1.00
Cadmium	4.2		2.114	0.795	25.917	19.634	0.331	19.965	20.00	cadmium chloride	1.00
Chromium	16.1	0.306			4.927	3.732	1.268	5.001	5.00	Cr+3 as CrK(SO4)2	1.00
Copper	515		1.675	0.264	27.756	21.027	40.576	61.603	61.7	copper oxide	1.00
Lead	40.5	0.266			10.773	8.161	3.191	11.352	11.30	lead acetate	1.00
Lithium		0.046			0	0	0	0			ERR
Mercury	0.00051		0.078	0.337	0.084	0.064	0.000	0.064	0.064	Methyl Mercury Dicyandiamide	1.00
Molybdenum	44	0.953			41.932	31.767	3.467	35.233	35.30	sodium molybdate (MoO4)	1.00
Nickel	121	1.059			128.139	97.075	9.533	106.608	107.00	nickel sulfate	1.00
PCB	0.655		1.410	1.361	2.303	1.745	0.052	1.796	1.800	n/a	1.00
Selenium	0.000001		6.400	8.700	6.400	4.848	7.879e-08	4.848	1.000	sodium selenite	4.85
Zinc	8.5		4.449	0.328	172.594	130.753	0.670	131.423	131.0	zinc sulfate	1.00
TCDD	0.0000158		2.502	1.005	1.83e-04	1.39e-04	1.24e-06	1.40e-04	1.40e-04	na	1.00

Notes: (1) regression models: ln(biota)= intercept + slope [ln(soil)] except Se in worms: biota= intercept + slope (soil). (2) Earthworm UFs and models from Sample et al. 1997a.

Table A.6. Soil PRG for red-tailed hawk assumed to consume 100% small mammals - using the 1997 UFs and models

Analyte	Soil conc (mg/kg)	Small mammal			Estimated mammal conc (mg/kg)	Food exposure (mg/kg/d)	Total exposure (mg/kg/d)	LOAEL (mg/kg/d)	Form	HQ
		Median UF	Intercept	Slope						
Arsenic	143000		-5.0249	0.8354	133.193	12.893	12.893	12.8	sodium arsenite	1.00
Barium	10350	0.0417			431.595	41.780	41.780	41.7	barium hydroxide	1.00
Cadmium	1.00e+06		-0.8408	0.392	97.016	9.391	9.391	20.00	cadmium chloride	0.47
Chromium	1.00e+06		-0.5506	0.315	44.759	4.333	4.333	5.00	Cr+3 as CrK(SO4)2	0.87
Copper	1.00e+06		1.8533	0.1309	38.929	3.768	3.768	61.7	copper oxide	0.06
Lead	55000		-0.7216	0.5019	116.359	11.264	11.264	11.30	lead acetate	1.00
Lithium		0.0026			0	0	0			ERR
Mercury	12.3	0.054			0.664	0.064	0.064	0.064	Methyl Mercury Dicyandiamide	1.00
Molybdenum	165000	0.0022			363.000	35.139	35.139	35.30	sodium molybdate (MoO4)	1.00
Nickel	1.00e+06		0.1356	0.1956	17.080	1.653	1.653	107.00	nickel sulfate	0.02
PCB-1254	15.5	1.2			18.600	1.801	1.801	1.800	n/a	1.00
Selenium	420		-1.1084	0.5702	10.337	1.001	1.001	1.000	sodium selenite	1.00
Thallium		0.102			0	0	0			ERR
Uranium		0.0001			0	0	0	0.0	depleted metalic U	ERR
Vanadium		0.0123			0	0	0	0.000	vanadyl sulfate	ERR
Zinc	1.00e+06		4.1204	0.1096	279.941	27.099	27.099	131.0	zinc sulfate	0.21
TCDD	0.00125		0.8113	1.0993	1.45e-03	1.40e-04	1.40e-04	1.40e-04	n/a	1.00
TCDF	0.00084	0.1229			1.03e-04	9.99e-06	9.99e-06	1.00e-05	n/a	1.00

Notes: (1) regression models: ln(biota)= intercept + slope [ln(soil)]. (2) Small mammal UFs and models from Sample et al. 1997b.