

Ecological Soil Screening Levels for Polycyclic Aromatic Hydrocarbons (PAHs) Interim Final

OSWER Directive 9285.7-78



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1.0 INTRODUCTION

Ecological Soil Screening Levels (Eco-SSLs) are concentrations of contaminants in soil that are protective of ecological receptors that commonly come into contact with and/or consume 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. Eco-SSLs are derived to be protective of the conservative end of the exposure and effects species distribution, and are intended to be applied at the screening stage of an ecological risk assessment. These screening levels should be used to identify the contaminants of potential concern (COPCs) that require further evaluation in the site-specific baseline ecological risk assessment that is completed according to specific guidance (U.S. EPA, 1997, 1998, and 1999). The Eco-SSLs are not designed to be used as cleanup levels and the United States (U.S.) Environmental Protection Agency (EPA) emphasizes that it would be inappropriate to adopt or modify the intended use of these Eco-SSLs as national cleanup standards.

The detailed procedures used to derive Eco-SSL values are described in separate documentation (U.S. EPA, 2003, 2005). The derivation procedures represent the group effort of a multi-stakeholder group consisting of federal, state, consulting, industry, and academic participants led by the U.S. EPA Office of Solid Waste and Emergency Response.

This document provides the Eco-SSL values for polycyclic aromatic hydrocarbons (PAHs) and the documentation for their derivation. This document provides guidance and is designed to communicate national policy on identifying PAH concentrations 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. EPA and state personnel may use and accept other technically sound approaches, either on their own initiative, or at the suggestion of potentially responsible parties, or other interested parties. Therefore, interested parties are free to raise questions and objections about the substance of this document and the appropriateness of the application of this document to a particular situation. EPA welcomes public comments on this document at any time and may consider such comments in future revisions of this document.

2.0 SUMMARY OF ECO-SSLs FOR PAHs

Polycyclic aromatic hydrocarbons (PAHs) (CASRN: 130498-29-2) constitute a class of organic substances made up of carbon and hydrogen atoms grouped into at least two condensed aromatic ring structures. These are divided into two categories: low molecular weight compounds composed of fewer than four rings and high molecular weight compounds of four or more rings. PAH derivatives are PAHs having an alkyl or other radical attached to a ring. Heterocyclic aromatic compounds (HACs) include PAHs having any one carbon atom in a ring replaced by a

nitrogen, oxygen, or sulfur atom PAHs are also referred to as polynuclear hydrocarbons, polynuclear aromatic hydrocarbons, or polycyclic organic matter (HSDB).

Polycyclic aromatic hydrocarbons (PAHs) are found throughout the environment in air, soil, water, and sediment. PAHs enter the environment from both natural and anthropogenic sources. Natural sources include volcanic eruptions and forest fires (ATSDR, 1995). Primary anthropogenic sources are from the extraction, transport, and refining of petroleum products and combustion products resulting from their use (International Labor Office, 1998). Other industrial sources include machine lubricating and cutting oils, and color printing oils (WHO, 2002). PAHs are also found in creosote (NTP, 2003), coal tar, roofing materials, and surface coatings. PAHs are not currently produced for commercial use in the United States, although several compounds are distributed for research purposes by specialty chemical companies (NTP, 2003) (HSDB).

The primary mode of toxicity for PAHs in soil dwelling terrestrial invertebrates is non-specific, nonpolar narcosis (Sverdrup et al., 2002a). The uptake of PAHs by earthworms occurs primarily by direct contact with the soluble phase of the soil solution (interstitial porewater) (Fairbrother, 2005). Soil porewater concentrations of PAHs are more predictive of biological responses (toxicity and/or bioaccumulation) in soil organisms than are bulk soil concentrations. Several studies show a relationship between bioaccumulation of or toxic effects of PAHs and soil porewater concentrations. The relationships are more predictable for low molecular weight compounds and show significant variability for high molecular weight PAHs (Ma et al., 1998) (Fairbrother, 2005).

The bioavailability of PAHs in soils is influenced by organic carbon quality and quantity, aging and weathering, microbial action, methylation/hydroxylation, adsorption/desorption hysteresis and ultra-violet light interaction (Fairbrother, 2005). The soil organic carbon-water partition coefficients (K_{oc}) for PAHs vary depending on the size of associated soil particles with the highest values in silt (fine particles) followed by sand and clay (Krauss and Wilcke, 2002).

Microbial degradation of PAHs is a key process in environmental fate in soils. The rate of biodegradation is dependant on the nutrient content and bacterial community in the soil. PAHs in soils undergo a weathering process such that the lighter chain fractions are removed (primarily by volatilization). Heavier fractions bind more readily to the soil organic matter and remain behind in the top soil horizon. As the mixture of PAHs age, bioavailability changes as the fraction remaining bind more tightly (Fairbrother, 2005). Aging reduces the bioavailability of PAHs in soils (Johnson et al., 2002). Chemicals in soils “age” by becoming incorporated inside the crystal lattice structure of the soil particle, or partitioning onto organic matter or soil nanopores (Nam et al., 1998), so they are no longer available for uptake by organisms. Bulk sediment chemistry methods can measure PAHs sequestered in this manner but it is not biologically available to organisms. Aging is, however, influenced by biodegradation and soil characteristics and is not a linear predictive relationship (Sverdrup et al., 2002b). PAHs that result from combustion processes are inserted into particulate lattices during formation, and appear to be “aged” even when recently deposited into soils (Fairbrother, 2005).

In general, the more-soluble a PAH, the higher the uptake by plants while the reverse is true for

uptake by earthworms and uptake in the gastrointestinal tract of animals (Wilcke, 2000). The most important source of PAHs for plants is the atmosphere where they enter via the gaseous phase or deposit bound to particles on the plant surface (Sims and Overcash, 1983; Wilcke, 2000). Shoots and leaves, above-ground plant parts and root surfaces generally contain larger PAH concentrations compared to seeds, below-ground plant parts and root interior parts (Sims and Overcash, 1983; Wilcke, 2000).

Animals may be exposed to PAHs in soils either as the result of direct ingestion or indirect ingestion in food items. In general, the acute toxicity of PAHs to animals increases as the molecular weights increase (Kulig and Pike, 2001). Animal studies have shown that exposure to PAHs can cause harmful effects on the skin, hematopoietic system, small intestine, kidneys, mammary gland and immune response (Shore and Rattner, 2001). PAHs are metabolized in the liver, where toxicity is associated with cytochrome P450-mediated conversion of the parent compound to toxic metabolic intermediates (Shore and Rattner, 2001) (HSDB).

Peer Review of Eco-SSL Methodology for PAHs

The methodology for deriving Eco-SSLs was primarily designed for deriving soil concentrations for single compounds and not a group of compounds with multiple forms. When the current Eco-SSL methods are applied to PAHs as a group (with data for all individual compounds considered together) the results for derivation of a wildlife toxicity reference value (TRV) is a focus on the most toxic PAH compound. There is no consideration of the relative toxicity of less toxic compounds. For plants and soil invertebrates, the focus is on the geometric mean of values across all PAH compounds.

In August of 2006, EPA sought a peer-review of the Eco-SSL methodology as to its applicability for derivation of values for PAHs as group of compounds with multiple forms. Five peer reviewers were identified who were experienced with either the toxicity of PAHs and/or risk assessment of these substances. The peer review process and results are summarized in Appendix 2-1. The consensus among the peer reviewers was that grouping both toxicity and exposure data into two classes based on molecular weight was a reasonable approach to derivation of Eco-SSLs. Although it would be ideal to use a toxicity equivalency approach in developing values, this is not possible due to limitations of the existing data. Grouping PAHs into the two classes (low and high molecular weight) is a means to address the differences in physical/chemical properties of individual PAHs which influence toxicity and environmental fate.

Derivation of Eco-SSLs

Eco-SSL values were derived for low molecular weight (LMW) and high molecular weight (HMW) PAHs for soil invertebrates and mammalian wildlife (Table 2.1). Eco-SSLs could not be derived for plants or avian wildlife. For these receptor groups, data were insufficient to derive soil screening values. Eco-SSL values calculated for LMW-PAHs range from 29 mg/kg dry weight (dw) for soil invertebrates to 100 mg/kg dw for mammalian wildlife. Eco-SSL values calculated for HMW-PAHs range from 1.1 mg/kg dw for mammalian wildlife to 18 mg/kg dw for soil invertebrates.

Table 2.1 PAH Eco-SSLs (mg/kg dry weight in soil)				
	Plants	Soil Invertebrates	Wildlife	
			Avian	Mammalian
Low Molecular Weight (LMW)	NA	29	NA	100
High Molecular Weight (HMW)	NA	18	NA	1.1

NA = Not Available. Data were insufficient to derive an Eco-SSL.

3.0 ECO-SSL FOR TERRESTRIAL PLANTS

Of the papers identified from the literature search process, 162 were selected for acquisition for further review. Of those papers acquired, three met all 11 Study Acceptance Criteria (U.S. EPA, 2003; Attachment 3-1). Each of these papers were reviewed and the studies were scored according to the Eco-SSL guidance (U.S. EPA, 2003; Attachment 3-2). Thirteen studies received an Evaluation Score greater than ten. These studies were either for the LMW-PAHs anthracene or a mixture of PAHs and are listed in Table 3.1.

There were no studies that were eligible to derive an Eco-SSL according to the Eco-SSL guidance (U.S. EPA, 2003; Attachment 3-2). An Eco-SSL could not be derived for plants for either group of PAHs.

4.0 ECO-SSL FOR SOIL INVERTEBRATES

Of the papers identified from the literature search process, 94 papers were acquired for further review. Of those papers acquired, five met all 11 Study Acceptance Criteria (U.S. EPA, 2003; Attachment 3-1). Each of these papers were reviewed and the studies were scored according to the Eco-SSL guidance (U.S. EPA, 2003; Attachment 3-2).

For LMW-PAHs, 16 studies received an Evaluation Score greater than ten. These studies are listed in Table 4.1. There are 11 studies eligible for Eco-SSL derivation that were used to derive the soil invertebrate Eco-SSL for PAHs (U.S. EPA, 2003; Attachment 3-2). The Eco-SSL is the geometric mean of the MATC and EC₁₀ values for four test species under different test conditions (pH and OM%) and is equal to 29 mg/kg dw.

For HMW-PAHs, six studies received an Evaluation Score greater than ten. These studies are listed in Table 4.2. There are six studies eligible for Eco-SSL derivation that were used to derive the soil invertebrate Eco-SSL for PAHs (U.S. EPA, 2003; Attachment 3-2). The Eco-SSL is the geometric mean of the MATC and EC₁₀ values for four test species under different test conditions (pH and OM%) and is equal to 18 mg/kg dw.

Table 3.1 Plant Toxicity Data - PAHs

Reference	IP Number	Study ID	PAH	Test Organism		Soil pH	OM %	Bio-availability Score	ERE	Tox Parameter	Tox Value-Soil Conc. (mg/kg dw)	Total Evaluation Score	Eligible for Eco-SSL Derivation?	Used for Eco-SSL?
Mitchell et al., 1988	15861	g	Anthracene	Oats	<i>Avena sativa</i>	5.5	2.0	2	GRO	EC ₅₀	30	15	N	N
Mitchell et al., 1988	15861	h	Anthracene	Cucumber	<i>Cucumis sativus</i>	5.5	2.0	2	GRO	EC ₅₀	720	15	N	N
Leyval and Binet, 1998	15848	c	Mixture	Perennial ryegrass	<i>Lolium perenne L.</i>	6.80	1.50	2	GRO	LOAEC	100	11	N	N
Mitchell et al., 1988	15861	a	Anthracene	Oats	<i>Avena sativa</i>	5.5	2.0	2	MOR	LC ₅₀	525	14	N	N
Mitchell et al., 1988	15861	b	Anthracene	Cucumber	<i>Cucumis sativus</i>	5.5	2.0	2	MOR	LC ₅₀	>1000	12	N	N
Mitchell et al., 1988	15861	c	Anthracene	Soybean	<i>Glycine max</i>	5.5	2.0	2	MOR	LC ₅₀	>1000	12	N	N
Mitchell et al., 1988	15861	d	Anthracene	Heath banksia	<i>Banksia ericifolia</i>	5.5	2.0	2	MOR	LC ₅₀	>1000	12	N	N
Mitchell et al., 1988	15861	e	Anthracene	She-oak	<i>Casuarina distyla</i>	5.5	2.0	2	MOR	LC ₅₀	>1000	12	N	N
Mitchell et al., 1988	15861	f	Anthracene	Yellow bloodwood	<i>Eucalyptus eximia</i>	5.5	2.0	2	MOR	LC ₅₀	>1000	12	N	N
Mitchell et al., 1988	15861	i	Anthracene	Soybean	<i>Glycine max</i>	5.5	2.0	2	GRO	EC ₅₀	>1000	15	N	N
Mitchell et al., 1988	15861	j	Anthracene	Heath banksia	<i>Banksia ericifolia</i>	5.5	2.0	2	GRO	EC ₅₀	>1000	15	N	N
Mitchell et al., 1988	15861	k	Anthracene	She-oak	<i>Casuarina distyla</i>	5.5	2.0	2	GRO	EC ₅₀	>1000	15	N	N
Mitchell et al., 1988	15861	l	Anthracene	Yellow bloodwood	<i>Eucalyptus eximia</i>	5.5	2.0	2	GRO	EC ₅₀	>1000	15	N	N

EC₅₀ = Effect concentration for 50% of test population

ERE = Ecologically relevant endpoint

GRO = Growth

LC₅₀ = Concentration lethal to 50% of test population

LOAEC = Lowest observed adverse effect concentration

N = No

OM = Organic matter content

Y = yes

Bioavailability Score described in *Guidance for Developing Eco-SSLs* (U.S. EPA, 2003)

Total Evaluation Score described in *Guidance for Developing Eco-SSLs* (U.S. EPA, 2003)

Table 4.1 Invertebrate Toxicity Data - Low Molecular Weight (LMW) PAHs

Reference	IP Number	Study ID	PAH	Test Organism		Soil pH	OM%	Bio-availability Score	ERE	Tox Parameter	Tox Value (Soil Conc at mg/kg dw)	Total Evaluation Score	Eligible for Eco-SSL Derivation?	Used for Eco-SSL?
Crouau et al., 1999	18893		Phenanthrene	springtail	<i>Folsomia candida</i>	6.0	10.0	1	REP	MATC	175	17	Y	Y
Sverdrup et al. 2001	20-6-1332	b	Fluoranthene	springtail	<i>Folsomia fimetaria L.</i>	6.2	2.8	0	REP	EC ₁₀	37	14	Y	Y
Sverdrup et al. 2001	20-6-1332	c	Phenanthrene	springtail	<i>Folsomia fimetaria L.</i>	6.2	2.8	0	REP	EC ₁₀	23	14	Y	Y
Sverdrup et al. 2001	20-6-1332	d	Fluorene	springtail	<i>Folsomia fimetaria L.</i>	6.2	2.8	0	REP	EC ₁₀	8	14	Y	Y
Sverdrup et al. 2002a	21-1-109	b	Fluoranthene	potworm	<i>Enchytraeus crypticus</i>	6.2	2.8	0	REP	EC ₁₀	15	14	Y	Y
Sverdrup et al. 2002a	21-1-109	c	Phenanthrene	potworm	<i>Enchytraeus crypticus</i>	6.2	2.8	0	REP	EC ₁₀	40	14	Y	Y
Sverdrup et al. 2002a	21-1-109	d	Fluorene	potworm	<i>Enchytraeus crypticus</i>	6.2	2.8	0	REP	EC ₁₀	25	14	Y	Y
Sverdrup et al. 2002b	21-3-489	b	Phenanthrene	springtail	<i>Folsomia fimetaria L.</i>	6.2	2.8	0	REP	EC ₁₀	9	14	Y	Y
Sverdrup et al. 2002c	21-9-1927	b	Fluoranthene	earthworm	<i>Eisenia veneta</i>	6.2	2.8	0	GRO	EC ₁₀	113	14	Y	Y
Sverdrup et al. 2002c	21-9-1927	c	Phenanthrene	earthworm	<i>Eisenia veneta</i>	6.2	2.8	0	GRO	EC ₁₀	25	14	Y	Y
Sverdrup et al. 2002c	21-9-1927	d	Fluorene	earthworm	<i>Eisenia veneta</i>	6.2	2.8	0	GRO	EC ₁₀	31	14	Y	Y
Geometric Mean											29			
Data Not Used to Derive Invertebrate Eco-SSL														
Neuhauser et al., 1985a	17707	a	Fluorene	earthworm	<i>Eisenia fetida</i>	6.0	10.0	1	MOR	LC ₅₀	173	15	N	N
Neuhauser et al., 1986	1214	a	Fluorene	earthworm	<i>Allolobophora tuberculata</i>	6.0	10.0	1	MOR	LC ₅₀	206	15	N	N
Neuhauser et al., 1986	1214	b	Fluorene	earthworm	<i>Eisenia fetida</i>	6.0	10.0	1	MOR	LC ₅₀	173	15	N	N
Neuhauser et al., 1986	1214	c	Fluorene	earthworm	<i>Eudrilus eugenia</i>	6.0	10.0	1	MOR	LC ₅₀	197	15	N	N
Neuhauser et al., 1986	1214	d	Fluorene	earthworm	<i>Perionyx excavatus</i>	6.0	10.0	1	MOR	LC ₅₀	170	15	N	N

ERE = Ecologically relevant endpoint
 LC₅₀ = Concentration lethal to 50% of test population
 LOAEC = Lowest observed adverse effect concentration
 MATC = Maximum acceptable toxicant concentration
 MOR = Mortality
 N = No

NOAEC = No observed adverse effect concentration
 OM = Organic matter content
 REP = Reproduction
 Y = Yes
 Bioavailability Score described in *Guidance for Developing Eco-SSLs* (U.S.EPA, 2003)
 Total Evaluation Score described in *Guidance for Developing Eco-SSLs* (U.S. EPA, 2003)

Table 4.2 Invertebrate Toxicity Data - High Molecular Weight (HMW) PAHs

Reference	IP Number	Study ID	PAH	Test Organism		Soil pH	OM%	Bio-availability Score	ERE	Tox Parameter	Tox Value (Soil Conc at mg/kg dw)	Total Evaluation Score	Eligible for Eco-SSL Derivation?	Used for Eco-SSL?
Brown et al. 2004	57-1675		Pyrene	earthworm	<i>Lumbricus rubellus</i>	NA	10.0	0	REP	MATC	80	11	Y	Y
Herbert et al. 2004	57-175	a	Pyrene	springtail	<i>Folsomia candida</i>	6.0	10.0	0	REP	MATC	10	13	Y	Y
Sverdrup et al. 2001	20-6-1332	a	Pyrene	springtail	<i>Folsomia fimetaria L.</i>	6.2	2.8	0	REP	EC ₁₀	10	14	Y	Y
Sverdrup et al. 2002a	21-1-109	a	Pyrene	potworm	<i>Enchytraeus crypticus</i>	6.2	2.8	0	REP	EC ₁₀	11	14	Y	Y
Sverdrup et al. 2002b	21-3-489	a	Pyrene	springtail	<i>Folsomia fimetaria L.</i>	6.2	2.8	0	REP	EC ₁₀	10	14	Y	Y
Sverdrup et al. 2002c	21-9-1927	a	Pyrene	earthworm	<i>Eisenia veneta</i>	6.2	2.8	0	GRO	EC ₁₀	38	14	Y	Y
Geometric Mean											18			

ERE = Ecologically relevant endpoint

GRO = Growth

LC₅₀ = Concentration lethal to 50% of test population

LOAEC = Lowest observed adverse effect concentration

MATC = Maximum acceptable toxicant concentration

N = No

OM = Organic matter content

REP = Reproduction

Y = Yes

Bioavailability Score described in *Guidance for Developing Eco-SSLs* (U.S.EPA, 2003)

Total Evaluation Score described in *Guidance for Developing Eco-SSLs* (U.S. EPA, 2003)

5.0 ECO-SSL FOR AVIAN WILDLIFE

The derivation of the Eco-SSL for avian wildlife was completed as two parts. First, the toxicity reference value (TRV) was derived according to the Eco-SSL guidance (U.S. EPA, 2003; Attachment 4-5). Second, the Eco-SSL (soil concentration) was back-calculated for each of three surrogate species based on the wildlife exposure model and the TRV (U.S. EPA, 2003).

The literature search completed according to the Eco-SSL guidance (U.S. EPA, 2003; Attachment 4-2) identified 5,478 papers with possible toxicity data for either avian or mammalian species. Of these papers, 5,432 papers were rejected for use as described in Section 7.5. Of the remaining papers, two contained data for avian test species. These papers were reviewed and the data were extracted and scored according to the Eco-SSL guidance (U.S. EPA, 2003; Attachment 4-3 and 4-4). The results of the data extraction and review are summarized in Appendix 5-1 for LMW-PAHs and Appendix 5-2 for HMW-PAHs. Within the results there are data available for only one species exposed to LMW-PAHs and one species exposed to HMW-PAHs. There were not enough data to derive TRVs for either class of PAHs.

6.0 ECO-SSL FOR MAMMALIAN WILDLIFE

The derivation of the Eco-SSL for mammalian wildlife was completed as two parts. First, the TRV was derived according to the Eco-SSL guidance (U.S. EPA, 2003; Attachment 4-5). Second, the Eco-SSL (soil concentration) was back-calculated for each of three surrogate species based on the wildlife exposure model and the TRV (U.S. EPA, 2003).

6.1 Mammalian TRV

The literature search completed according to the Eco-SSL guidance (U.S. EPA, 2003; Attachment 4-2) identified 5,478 papers with possible toxicity data for PAHs for either avian or mammalian species. Of these papers, 5,432 were rejected for use as described in Section 7.5. Of the remaining papers, 46 contained data for mammalian test species. These papers were reviewed and the data were extracted and scored according to the Eco-SSL guidance (U.S. EPA, 2003; Attachment 4-3 and 4-4). The results of the data extraction and review are summarized in Table 6.1 for LMW - PAHs and Table 6.2 for HMW - PAHs.. The complete results are provided in Appendix 6-1 for LMW-PAHs and Appendix 6.2 for HMW-PAHs.

Within the 46 papers there are 76 results for LMW - PAHs for biochemical (BIO), behavior (BEH), physiology (PHY), pathology (PTH), reproduction (REP), growth (GRO), and survival (MOR) endpoints with a total Data Evaluation Score >65 that were used to derive the TRV (U.S. EPA, 2003; Attachment 4-4). These data are plotted in Figure 6.1 and correspond directly with the data presented in Table 6.1. The NOAEL results for growth and reproduction are used to calculate a geometric mean NOAEL. This mean NOAEL is examined in relationship to the lowest bounded LOAEL for reproduction, growth, and survival to derive the TRV according to procedures in the Eco-SSL guidance (U.S. EPA, 2003; Attachment 4-5).

A geometric mean of the NOAEL values for growth and reproduction was calculated at 170 mg

PAHs/kg bw/day. However, this value is higher than the lowest bounded LOAEL for reproduction, growth, or mortality. Therefore, the TRV is equal to the highest bounded NOAEL below the lowest bounded LOAEL for reproduction, growth, or survival and is equal to 65.6 mg PAHs/kg bw/day.

There are 45 results for HMW - PAHs, for biochemical (BIO), behavior (BEH), physiology (PHY), pathology (PTH), reproduction (REP), growth (GRO), and survival (MOR) endpoints with a total Data Evaluation Score >65 that were used to derive the TRV (U.S. EPA, 2003; Attachment 4-4). These data are plotted in Figure 6.2 and correspond directly with the data presented in Table 6.2. The NOAEL results for growth and reproduction are used to calculate a geometric mean NOAEL. This mean NOAEL is examined in relationship to the lowest bounded LOAEL for reproduction, growth, and survival to derive the TRV according to procedures in the Eco-SSL guidance (U.S. EPA, 2003; Attachment 4-5).

A geometric mean of the NOAEL values for growth and reproduction was calculated at 18 mg PAHs/kg bw/day. However, this value is higher than the lowest bounded LOAEL for reproduction, growth, or mortality. Therefore, the TRV is equal to the highest bounded NOAEL lower than the lowest bounded LOAEL for reproduction, growth, or survival and is equal to 0.615 mg PAHs/kg bw/day.

6.2 Estimation of Dose and Calculation of the Eco-SSL

For each group of PAHs (LMW and HMW), three separate Eco-SSL values were calculated for mammalian wildlife, one for each of three surrogate species representing different trophic groups. The mammalian Eco-SSLs derived for PAHs were calculated according to the Eco-SSL guidance (U.S. EPA, 2003) and are summarized in Table 6.3 for LMW-PAHs and Table 6.4 for HMW-PAHs.

**Table 6.1 Mammalian Toxicity Data Extracted for Wildlife Toxicity Reference Value (TRV)
Low Molecular Weight Polynuclear Aromatic Hydrocarbons (LMW-PAHs)
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Result #	Reference	Ref No.	Test Organism	# of Conc/ Doses	Method of Analyses	Route of Exposure	Exposure Duration	Duration Units	Age	Age Units	Lifespan	Sex	Effect Type	Effect Measure	Response Site	NOAEL Dose (mg/kg bw/day)	LOAEL Dose (mg/kg bw/day)	Total
Biochemical (BIO)																		
1	Shopp et al, 1984	30980	Naphthalene	4	U	GV	14	d	6-7	w	JV	B	CHM	GBCM	SR	27.0	53.0	83
2	Verschuuren et al., 1976	29744	1-Naphthaleneacetic acid	4	U	FD	6	w	NR	NR	JV	M	ENZ	AHHD	LI	66.8	334	70
3	Knuckles et al., 2004	48537	Fluoranthene	4	UX	FD	90	d	9	w	JV	M	CHM	HEMT	BL	147	735	83
4	Poole and Buckley, 1989	26157	1-Naphthol	4	U	GV	90	d	6-7	w	JV	B	CHM	HMGL	BL	200		73
5	Shopp et al, 1984	30980	Naphthalene	4	U	GV	90	d	6-7	w	JV	F	CHM	CREA	SR		5.30	77
6	Ramesh et. al, 2000	32253	Fluoranthene	4	U	FD	90	d	6-7	w	JV	M	ENZ	AHHD	WO		157	74
7	Tao et al, 1991	28360	Naphthalene	2	U	GV	20	d	NR	NR	JV	F	CHM	PRTL	EY		700	77
8	Yamauchi et al, 1986	30470	Naphthalene	2	U	GV	4	d	NR	NR	JV	M	CHM	GBCM	SR		1000	77
9	Rao and Pandya, 1981	29132	Naphthalene	2	U	OR	10	d	NR	NR	JV	M	ENZ	GENZ	LI		1000	77
10	Kodama et al, 1974	31138	Naphthalene	2	U	GV	3	w	NR	NR	JV	NR	ENZ	GENZ	LI		1200	73
11	Srivastava and Nath, 1969	30130	Naphthalene	2	U	FD	5	d	NR	NR	NR	NR	ENZ	LADH	EY		2000	67
Behavior (BEH)																		
12	Navarro, et al, 1991	28943	Naphthalene	4	U	GV	9	d	8-10	w	GE	F	FDB	WCN	WO	50.0	150	86
13	Borzelleca, 1982	26048	Naphthalene	4	U	GV	60	d	NR	NR	AD	B	FDB	FCNS	WO	53.0	133	82
14	Verschuuren et al., 1976	29744	1-Naphthaleneacetic acid	4	U	FD	6	w	NR	NR	JV	M	FDB	FCNS	WO	66.8	334	73
15	Navarro et al, 1992	28813	Naphthalene	4	U	GV	13	d	6	mo	GE	F	FDB	FCNS	WO	120		73
16	Ramesh et. al, 2000	32253	Fluoranthene	4	U	FD	90	d	6-7	w	JV	M	FDB	FCNS	WO	157	735	81
17	Pharmakon Resesarch, 1986	26017	Naphthalene	4	U	GV	4	d	>=24	d	GE	F	FDB	FCNS	WO	200	400	86
18	Pharmakon Research, 1985	26016	Naphthalene	5	U	GV	7	d	>=24	w	GE	F	FDB	FCNS	WO	250	630	86
19	Anonymous, 1992	26028	Naphthalene	4	U	FD	4	w	NR	NR	JV	NR	FDB	FCNS	WO	294		68
20	Knuckles et al., 2004	48537	Fluoranthene	4	UX	FD	90	d	9	w	JV	M	FDB	FCNS	WO	735	1470	88
Physiology (PHY)																		
21	Anonymous, 1992	26028	Naphthalene	4	U	FD	4	w	NR	NR	JV	NR	PHY	FDCV	WO	294		68
Pathology (PTH)																		
22	Anonymous, 1992	26028	Naphthalene	4	U	FD	4	w	NR	NR	JV	NR	ORW	SMIX	AR	24.5	88.3	81
23	Shopp et al, 1984	30980	Naphthalene	4	U	GV	90	d	6-7	w	JV	F	ORW	ORWT	LI	53.0	133	86
24	Shopp et al, 1984	30980	Naphthalene	4	U	GV	14	d	6-7	w	JV	M	ORW	ORWT	TS	53.0	267	84
25	Verschuuren et al., 1976	29744	1-Naphthaleneacetic acid	4	U	FD	6	w	NR	NR	JV	M	ORW	SMIX	TY	66.8	334	73
26	Poole and Buckley, 1989	26157	1-Naphthol	4	U	GV	30	d	6-7	w	JV	M	HIS	GHIS	KI	100	200	86
27	Navarro et al, 1992	28813	Naphthalene	4	U	GV	13	d	6	mo	GE	F	ORW	SMIX	LI	120		80
28	Navarro, et al, 1991	28943	Naphthalene	4	U	GV	9	d	8-10	w	GE	F	ORW	ORWT	LI	450		80
29	Koch et al, 1977	26113	Naphthalene	2	U	GV	75	d	NR	NR	NR	NR	ORW	ORWT	EY	500		73
30	Koch et al, 1977	26113	Naphthalene	2	U	GV	75	d	NR	NR	NR	NR	ORW	ORWT	EY	500		73
31	Tao, et al, 1991	27906	Naphthalene	2	U	GV	90	d	NR	NR	JV	NR	HIS	GHIS	EY	700		71
32	Murata et al., 1997	48424	3-Methylnaphthalene	3	U	FD	81	w	6	w	JV	F	ORW	SMIX	KI		52.7	77
33	Knuckles et al., 2004	48537	Fluoranthene	4	UX	FD	90	d	9	w	JV	M	HIS	USTR	KI		147	82
34	Orzalesi, et al, 1994	28756	Naphthalene	2	U	GV	3	w	NR	NR	JV	M	HIS	GHIS	EY		495	80
35	Schmidt et al., 1990	31504	Naphthalene	2	U	FD	6	2	NR	NR	NR	F	HIS	USTR	EY		500	70
36	Tao et al, 1991	28360	Naphthalene	2	U	GV	20	d	NR	NR	JV	F	ORW	ORWT	EY		700	80
37	Pirie, 1968	28847	Naphthalene	2	U	GV	8	d	6-12	mo	JV	NR	HIS	GHIS	EY		1000	80
38	Rao and Pandya, 1981	29132	Naphthalene	2	U	OR	10	d	NR	NR	JV	M	ORW	SMIX	LI		1000	80
39	Srivastava and Nath, 1969	30130	Naphthalene	2	U	FD	5	d	NR	NR	NR	NR	HIS	GHIS	EY		2000	70
Reproduction (REP)																		
40	Navarro et al, 1992	28813	Naphthalene	4	U	GV	13	d	6	mo	GE	F	REP	PROG	WO	120		79
41	Shopp et al, 1984	30980	Naphthalene	4	U	GV	90	d	6-7	w	JV	M	REP	TEWT	TE	133		86
42	Navarro, et al, 1991	28943	Naphthalene	4	U	GV	9	d	8-10	w	GE	F	REP	GREP	WO	150	450	92
43	Pharmakon Research, 1985	26016	Naphthalene	5	U	GV	23	d	>=24	w	GE	F	REP	RSEM	WO	250	630	92
44	Shopp et al, 1984	30980	Naphthalene	4	U	GV	14	d	6-7	w	JV	M	REP	TEWT	TE	267		84
45	Anonymous, 1992	26028	Naphthalene	4	U	FD	4	w	NR	NR	JV	NR	REP	TEWT	TE	294		74
46	Pharmakon Resesarch, 1986	26017	Naphthalene	4	U	GV	23	d	>=24	w	GE	F	REP	PRWT	WO	400		86
47	Booth et al, 1983	1234	Naphthalene	2	U	GV	8	d	61-71	d	GE	F	REP	PROG	WO		300	86
48	Hardin, et al, 1987	1335	Naphthalene	2	U	GV	17	d	NR	NR	GE	F	REP	PROG	WO		300	86
Growth (GRO)																		
49	Navarro, et al, 1991	28943	Naphthalene	4	U	GV	9	d	8-10	w	GE	F	GRO	BDWT	WO	50.0	150	90
50	Germansky and Jamall, 1988	28793	Naphthalene	2	U	GV	2	w	NR	NR	JV	M	GRO	BDWT	WO	50.0		75
51	Murata et al., 1997	48424	2-Methylnaphthalene	3	U	FD	81	w	6	w	JV	M	GRO	BDWT	WO	52.7	110	68
52	Shopp et al, 1984	30980	Naphthalene	4	U	GV	14	d	6-7	w	JV	M	GRO	BDWT	WO	53.0	267	88
53	Verschuuren et al., 1976	29744	1-Naphthaleneacetic acid	4	U	FD	6	w	NR	NR	JV	M	GRO	BDWT	WO	65.6	328	82
54	Murata et al., 1997	48424	2-Methylnaphthalene	3	U	FD	81	w	6	w	JV	F	GRO	BDWT	WO	104		72
55	Navarro et al, 1992	28813	Naphthalene	4	U	GV	13	d	6	mo	GE	F	GRO	BDWT	WO	120		84
56	Shopp et al, 1984	30980	Naphthalene	4	U	GV	90	d	6-7	w	JV	B	GRO	BDWT	WO	133		84
57	Pharmakon Research, 1985	26016	Naphthalene	5	U	GV	12	d	>=24	w	GE	F	GRO	BDWT	WO	250	630	90
58	Anonymous, 1992	26028	Naphthalene	4	U	FD	4	w	NR	NR	JV	NR	GRO	BDWT	WO	294		81

**Table 6.1 Mammalian Toxicity Data Extracted for Wildlife Toxicity Reference Value (TRV)
Low Molecular Weight Polynuclear Aromatic Hydrocarbons (LMW-PAHs)
Page 2 of 2**

Result #	Reference	Ref No.	Test Organism	# of Conc/ Doses	Method of Analysis	Route of Exposure	Exposure Duration	Duration Units	Age	Age Units	Lifestage	Sex	Effect Type	Effect Measure	Response Site	NOAEL Dose (mg/kg bw/day)	LOAEL Dose (mg/kg bw/day)	Total	
59	Booth et al, 1983	1234	Naphthalene	2	U	GV	8	d	61-71	d	GE	F	GRO	BDWT	WO	300		82	
60	Pharmakon Resesarch, 1986	26017	Naphthalene	4	U	GV	12	d	>=24	w	GE	F	GRO	BDWT	WO	400		84	
61	Ramesh et. al, 2000	32253	Fluoranthene	4	U	FD	60	d	6-7	w	JV	M	GRO	BDWT	WO	725	1460	87	
62	Knuckles et al., 2004	48537	Fluoranthene	4	UX	FD	90	d	9	w	JV	M	GRO	BDWT	WO	735	1470	92	
63	Poole and Buckley, 1989	26157	1-Naphthol	4	U	GV	30	d	6-7	w	JV	B	GRO	BDWT	WO		50.0	84	
64	Hardin, et al, 1987	1335	Naphthalene	2	U	GV	17	d	NR	NR	GE	F	GRO	BDWT	WO		300	84	
65	Tao et al, 1991	28360	Naphthalene	2	U	GV	60	d	NR	NR	JV	F	GRO	BDWT	WO		700	84	
Survival (MOR)																			
66	Germansky and Jamall, 1988	28793	Naphthalene	2	U	GV	2	w	NR	NR	JV	M	MOR	MORT	WO	50.0		85	
67	Navarro et al, 1992	28813	Naphthalene	4	U	GV	13	d	6	mo	GE	F	MOR	MORT	WO	120		85	
68	Shopp et al, 1984	30980	Naphthalene	4	U	GV	90	d	6-7	w	JV	B	MOR	SURV	WO	133		85	
69	Booth et al, 1983	1234	Naphthalene	6	U	GV	8	d	61-71	d	JV	F	MOR	MORT	WO	250	500	91	
70	Pharmakon Research, 1985	26016	Naphthalene	5	U	GV	24	d	>=24	w	GE	F	MOR	MORT	WO	250	630	91	
71	Shopp et al, 1984	30980	Naphthalene	4	U	GV	14	d	6-7	w	JV	B	MOR	SURV	WO	267		76	
72	Anonymous, 1992	26028	Naphthalene	4	U	FD	4	w	NR	NR	JV	NR	MOR	MORT	WO	294		82	
73	Pharmakon Resesarch, 1986	26017	Naphthalene	4	U	GV	12	d	>=24	w	GE	F	MOR	MORT	WO	400		85	
74	Navarro, et al, 1991	28943	Naphthalene	4	U	GV	9	d	8-10	w	GE	F	MOR	MORT	WO	450		85	
75	Booth et al, 1983	1234	Naphthalene	2	U	GV	8	d	61-71	d	GE	F	MOR	MORT	WO		300	85	
76	Hardin, et al, 1987	1335	Naphthalene	2	U	GV	11	d	NR	mo	GE	F	MOR	MORT	WO		300	85	

AD = adult; AHHD = aryl hydrocarbon hydrolase; AR = adrenal; B = both; BDWT = body weight changes; BEH = behavior; BL = blood; bw = body weight; CHM = chemical changes; CREA = creatinine; d - day; DOPA = dopamine; ENZ = enzyme level changes; EY = eye; F = female; FCNS = food consumption; FD = food; FDB = feeding behavior; FDCV = feed conversion efficiency; GBCM = general biochemical changes; GE = gestation; GENZ = general enzyme changes; GHIS = general histology; GREP = general reproduction; GRO = growth; GRS = gross body weight changes; GV = gavage; HEMT = hematorcrit; HIS = histological changes; HMGL = hemoglobin; HRM = hormone changes; JV = juvenile; kg = kilograms; KI = kidney; LADH = ; L = liter; LI = liver; LOAEL = lowest observed adverse effect level; mo = months; M = male; M = measured; MOR = effects on mortality and survival; MORT = mortality; NOAEL = No Observed Adverse Effect Level; NR = Not reported; OR = other oral; ORW = organ weight changes; ORWT = organ weight changes; PHY = physiology; PL = plasma; PORP = porphyrin; PROG = progeny numbers/counts; PRTL = protein, total; PRWT = progeny weight; PTH = pathology; REP = reproduction; RSEM = resorbed embryo; SM = sexually mature; SMIX = weight relative to body weight; SR = serum; SURV = survival; TE = testes; TEWT = testes weight; TRII = triiodothyronine; TS = ; TY = ; U = unmeasured; UR = urine; USTR = ultrastructural changes; UX = measured but values not reported; w = weeks; WCON = water consumption; WO = whole organism; yr = year.

*NOAEL and LOAEL values that are equal and from the same reference represent different experimental designs.

**Table 6.2 Mammalian Toxicity Data Extracted for Wildlife Toxicity Reference Value (TRV)
High Molecular Weight Polynuclear Aromatic Hydrocarbons (HMW-PAHs)
Page 1 of 1**

Result #	Reference	Ref No.	Test Organism	# of Conc/ Doses	Method of Analyses	Route of Exposure	Exposure Duration	Duration Units	Age	Age Units	Lifestage	Sex	Effect Type	Effect Measure	Response Site	NOAEL Dose (mg/kg bw/day)	LOAEL Dose (mg/kg bw/day)	Total	
Biochemical (BIO)																			
1	De Jong et al, 1999	25983	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	5	U	GV	5	w	6	w	JV	M	CHM	HMGL	BL	2.11	7.04	81
2	Knuckles et al, 2001	25982	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	4	UX	FD	60	d	9	w	JV	M	CHM	HMCT	BL	4.90	49.0	86
3	Yamauchi et al, 1991	28204	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	3	U	GV	10	d	5	w	JV	M	ENZ	GSTR	LI	5.0	50.0	81
4	Burchiel et al, 1990	28439	7,12-Dimethylbenz(a)anthracene	Mouse (<i>Mus musculus</i>)	4	U	GV	14	d	10-11	w	JV	F	CHM	GBCM	SP		0.0970	77
5	Ramesh et al, 2000	32253	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	4	U	FD	90	d	6-7	w	JV	M	ENZ	AHHD	LI		5.39	74
6	Hood et al., 2003	48370	3-Methylcholanthrene	Mouse (<i>Mus musculus</i>)	5	U	FD	21	d	7	w	JV	M	HRM	TRII	SR		7.94	69
7	Bosveld, et al, 1996	27748	Benzo(a)pyrene	White toothed shrew (<i>Sorex araneus</i>)	3	U	FD	9	d	NR	NR	NR	F	ENZ	ECOD	LI		10.0	70
8	Reuber and Glover, 1969	30150	7,12-Dimethylbenz(a)anthracene	Rat (<i>Rattus norvegicus</i>)	2	U	FD	12	w	12	w	JV	M	CHM	GBCM	SR		20.7	70
9	Polidoro et al., 1985	30641	3-Methylcholanthrene	Guinea pig (<i>Cavia porcellus</i>)	2	U	FD	14	d	NR	NR	JV	F	ENZ	GLPX	LI		30.0	77
10	Das et al, 1994	27335	Benzanthrone	Guinea pig (<i>Cavia porcellus</i>)	2	U	GV	4	w	NR	NR	JV	M	CHM	HMGL	BL		50.0	77
Behavior (BEH)																			
11	Knuckles et al, 2001	25982	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	4	UX	FD	90	d	9	w	JV	M	FDB	FCNS	WO	49.0	98.0	91
12	Ramesh et al, 2000	32253	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	4	U	FD	90	d	6-7	w	JV	M	FDB	FCNS	WO	53.9	90.2	83
Physiology (PHY)																			
13	Lambelin et al. 1967	26033	6-Aminochrysene	Rat (<i>Rattus norvegicus</i>)	3	U	FD	360	d	1	mo	JV	M	PHY	FDCV	WO	24		68
14	Lambelin et al. 1967	26033	6-Aminochrysene	Rat (<i>Rattus norvegicus</i>)	3	U	FD	360	d	1	mo	JV	F	PHY	FDCV	WO	26.4		68
Pathology (PTH)																			
15	De Jong et al, 1999	25983	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	5	U	GV	5	w	6	w	JV	M	ORW	ORWT	TS	2.11	7.04	84
16	Gao et al., 2005	48343	7,12-Dimethylbenz(a)anthracene	Mouse (<i>Mus musculus</i>)	4	U	GV	5	d	8-10	w	JV	M	ORW	SMIX	SP	3.23	9.50	86
17	Yamauchi et al, 1991	28204	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	3	U	GV	10	d	5	w	JV	M	ORW	SMIX	LI	5.0	50.0	84
18	Bosveld, et al, 1996	27748	Benzo(a)pyrene	White toothed shrew (<i>Sorex araneus</i>)	3	U	FD	9	d	NR	NR	NR	F	GRS	BDWT	WO	10.0	100	77
19	Knuckles et al, 2001	25982	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	4	UX	FD	90	d	9	w	JV	M	ORW	SMIX	LI	49.0	98.0	91
20	Uno et al., 2006	48539	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	4	U	FD	18	d	NR	NR	JV	M	ORW	SMIX	LI	125		68
21	Seidel, 1977	25987	7,12-Dimethylbenz(a)anthracene	Mouse (<i>Mus musculus</i>)	2	U	GV	2	w	8-10	w	JV	F	ORW	ORWT	TS		0.140	80
22	Reuber and Glover, 1969	30150	7,12-Dimethylbenz(a)anthracene	Rat (<i>Rattus norvegicus</i>)	2	U	FD	12	w	12	w	JV	M	ORW	ORWT	TY		20.7	73
23	Das et al, 1994	27335	Benzanthrone	Guinea pig (<i>Cavia porcellus</i>)	2	U	GV	4	w	NR	NR	JV	M	ORW	SMIX	LI		50.0	80
Reproduction (REP)																			
24	Mackenzie and Angevine, 1981	26128	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	4	U	GV	9	d	NR	NR	GE	F	REP	PRWT	WO	10.0	40.0	90
25	Lambelin et al. 1967	26033	6-Aminochrysene	Rat (<i>Rattus norvegicus</i>)	3	U	FD	3	mo	1	mo	GE	F	REP	PROG	WO	13.3	26.4	89
26	Rigdon and Neal, 1965	26164	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	2	U	FD	17	d	NR	NR	LC	F	REP	PRWT	WO		45.9	79
Growth (GRO)																			
27	Culp et al., 1998	48317	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	4	M	FD	55	w	5	w	JV	B	GRO	BDWT	WO	3.09	12.4	86
28	Yamauchi et al, 1991	28204	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	3	U	GV	10	d	5	w	JV	M	GRO	BDWT	WO	5.0	50.0	88
29	Kristensen et al. 1995	2743	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	2	U	GV	9	d	9	w	GE	F	GRO	BDWT	WO	10.0		70
30	Lambelin et al. 1967	26033	6-Aminochrysene	Rat (<i>Rattus norvegicus</i>)	3	U	FD	360	d	1	mo	JV	F	GRO	BDWT	WO	11.8	24.0	87
31	Lambelin et al. 1967	26033	6-Aminochrysene	Rat (<i>Rattus norvegicus</i>)	3	U	FD	360	d	1	mo	JV	F	GRO	BDWT	WO	13.3	26.4	87
32	De Jong et al, 1999	25983	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	5	U	GV	2	w	6	w	JV	M	GRO	BDWT	WO	21.1	63.4	88
33	Gao et al., 2005	48343	7,12-Dimethylbenz(a)anthracene	Mouse (<i>Mus musculus</i>)	3	U	GV	5	d	8-10	w	JV	F	GRO	BDWT	WO	28.5		75
34	Rigdon et al, 1967	30203	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	4	U	FD	66	d	18-30	d	JV	NR	GRO	BDWT	WO	31.7		68
35	Knuckles et al, 2001	25982	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	4	UX	FD	60	d	9	w	JV	M	GRO	BDWT	WO	49.0	98.0	95
36	Ramesh et al, 2000	32253	Benzo(a)pyrene	Rat (<i>Rattus norvegicus</i>)	4	U	FD	60	d	6-7	w	JV	M	GRO	BDWT	WO	53.9	118	87
37	Uno et al., 2006	48539	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	4	U	FD	18	d	NR	NR	JV	M	GRO	BDWT	WO	125		72
38	Reuber and Glover, 1969	30150	7,12-Dimethylbenz(a)anthracene	Rat (<i>Rattus norvegicus</i>)	2	U	FD	12	w	12	w	JV	M	GRO	BDWT	WO		20.7	77
39	Rigdon and Neal, 1965	26164	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	2	U	FD	6	d	20	d	JV	M	GRO	BDWT	WO		27.3	78
40	Das et al, 1994	27335	Benzanthrone	Guinea pig (<i>Cavia porcellus</i>)	2	U	GV	3	w	NR	NR	JV	M	GRO	BDWT	WO		50.0	84
Survival (MOR)																			
41	Culp et al., 1998	48317	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	4	M	FD	65	w	5	w	JV	B	MOR	MORT	WO	0.615	3.07	87
42	Lambelin et al. 1967	26033	6-Aminochrysene	Rat (<i>Rattus norvegicus</i>)	3	U	FD	3	mo	1	mo	GE	F	MOR	MORT	WO	13.3	26.4	88
43	Rigdon and Neal, 1965	26164	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	2	U	FD	6	d	20	d	JV	M	MOR	MORT	WO	27.3		79
44	Rigdon et al, 1967	30203	Benzo(a)pyrene	Mouse (<i>Mus musculus</i>)	4	U	FD	77	d	18-30	d	JV	NR	MOR	MORT	WO	31.7		78

AD = adult; AHHD = aryl hydrocarbon hydrolase; B = both; BDWT = body weight changes; BEH = behavior; BL = blood; bw = body weight; CHM = chemical changes; d = day; ECOD = ethoxycoumarin O-deethylase; ENZ = enzyme level changes; F = female; FCNS = food consumption; FD = food; FDB = feeding behavior; FDCV = feed conversion efficiency; GBCM = general biochemical changes; GE = gestation; GLPX = glutathione peroxidase; GRO = growth; GRS = gross body weight changes; GSTR = glutathione S-transferase; GV = gavage; HA = hair; HE = heart; HIS = histological changes; HMCT = hematocrit; HMGL = hemoglobin; HRM = hormone changes; JV = juvenile; kg = kilograms; L = liter; LC = lactation; LI = liver; LOAEL = lowest observed adverse effect level; mo = months; M = male; M = measured; MOR = effects on mortality and survival; MORT = mortality; NOAEL = No Observed Adverse Effect Level; NR = Not reported; OR = other oral; ORW = organ weight changes; ORWT = organ weight changes; PHY = physiology; PROG = progeny numbers/counts; PRWT = progeny weight; PTH = pathology; REP = reproduction; SM = sexually mature; SMIX = weight relative to body weight; SP = spleen; SR = serum; TRII = tridithyronine; U = unmeasured; UX = measured but values not reported; w = weeks; WO = whole organism; yr = year.

*NOAEL and LOAEL values that are equal and from the same reference represent different experimental designs.

Table 6.3 Calculation of the Mammalian Eco-SSL for LMW-PAHs

Surrogate Receptor Group	TRV for PAHs (mg dw/kg bw/d) ¹	Food Ingestion Rate (FIR) ² (kg dw/kg bw/d)	Soil Ingestion as Proportion of Diet (P _s) ²	Concentration of PAHs in Biota Type (i) ^{2,3} (B _i) (mg/kg dw)	PAHs in Diet of Prey ⁴ (C _{diet})	Eco-SSL (mg/kg dw) ⁵
Mammalian herbivore (vole)	65.6	0.0875	0.032	$B_i = 2.09 * Soil_j$	NA	350
Mammalian ground insectivore (shrew)	65.6	0.209	0.030	$B_i = 3.04 * Soil_j$ where i = earthworms	NA	100
Mammalian carnivore (weasel)	65.6	0.130	0.043	$B_i = 0 * C_{diet}$ where i = mammals	0	1,200

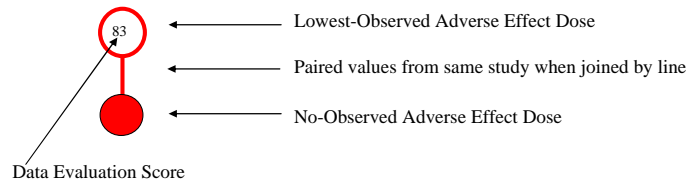
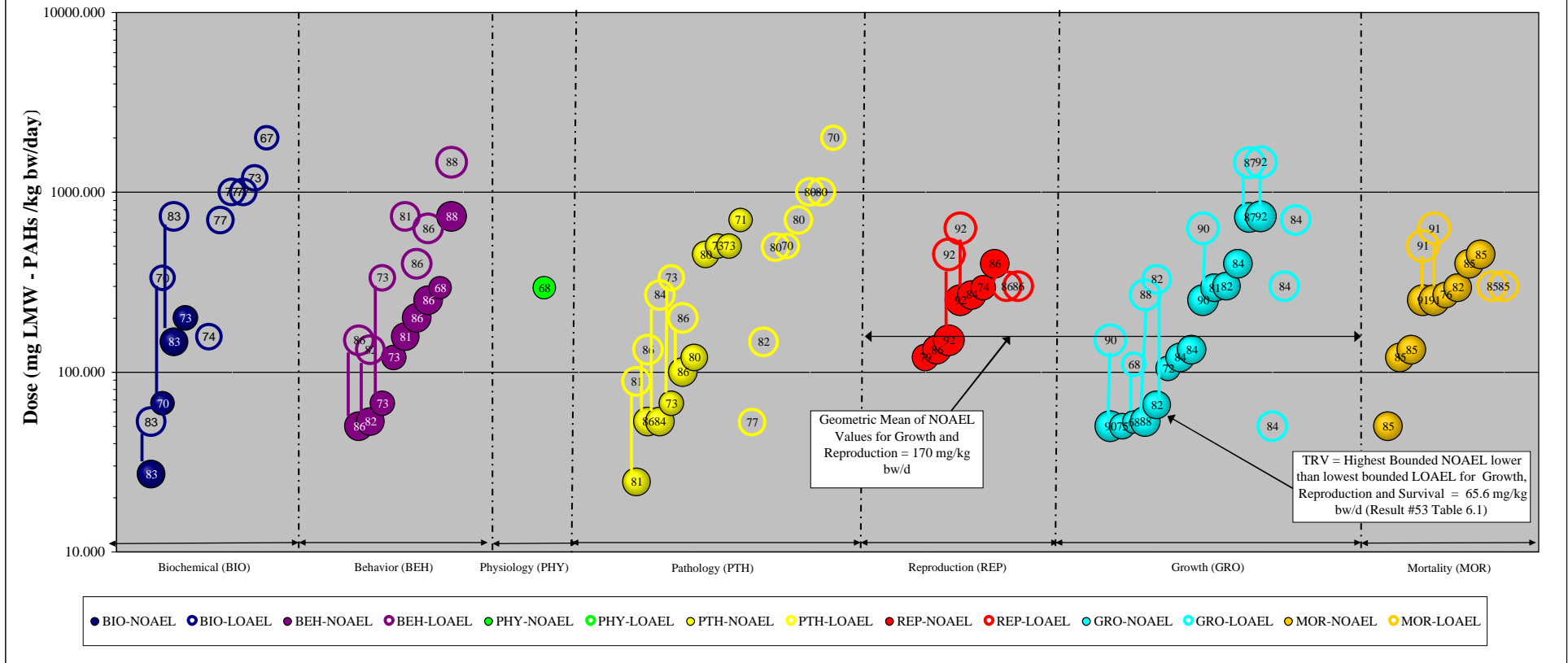
¹ The process for derivation of wildlife TRVs is described in Attachment 4-5 of U.S. EPA (2003).
² Parameters (FIR, P_s, B_i values, regressions) are provided in U.S. EPA (2003) Attachment 4-1 (revised February 2005).
³ B_i = Concentration in biota type (i) which represents 100% of the diet for the respective receptor.
⁴ C_{diet} = Concentration in the diet of small mammals consumed by predatory species (weasel).
⁵ HQ = FIR * (Soil_j * P_s + B_i) / TRV solved for HQ=1 where Soil_j = Eco-SSL (Equation 4-2; U.S. EPA, 2003).
 NA = Not Applicable
 BAF for earthworms is the median of values for individual PAHs in U.S. EPA (2003) Attachment 4-1 (revised February 2005).

Table 6.4 Calculation of the Mammalian Eco-SSL for HMW-PAHs

Surrogate Receptor Group	TRV for PAHs (mg dw/kg bw/d) ¹	Food Ingestion Rate (FIR) ² (kg dw/kg bw/d)	Soil Ingestion as Proportion of Diet (P _s) ²	Concentration of PAHs in Biota Type (i) ^{2,3} (B _i) (mg/kg dw)	PAHs in Diet of Prey ⁴ (C _{diet})	Eco-SSL (mg/kg dw) ⁵
Mammalian herbivore (vole)	0.615	0.0875	0.032	$\ln(B_i) = 0.9469 * \ln(Soil_j) - 1.7026$	NA	39
Mammalian ground insectivore (shrew)	0.615	0.209	0.030	$B_i = 2.6 * Soil_j$ where i = earthworms	NA	1.1
Mammalian carnivore (weasel)	0.615	0.130	0.043	$B_i = 0 * C_{diet}$ where i = mammals	0	110

¹ The process for derivation of wildlife TRVs is described in Attachment 4-5 of U.S. EPA (2003).
² Parameters (FIR, P_s, B_i values, regressions) are provided in U.S. EPA (2003) Attachment 4-1 (revised February 2005).
³ B_i = Concentration in biota type (i) which represents 100% of the diet for the respective receptor.
⁴ C_{diet} = Concentration in the diet of small mammals consumed by predatory species (weasel).
⁵ HQ = FIR * (Soil_j * P_s + B_i) / TRV solved for HQ=1 where Soil_j = Eco-SSL (Equation 4-2; U.S. EPA, 2003).
 NA = Not Applicable
 BAF for earthworms is the median of values for individual PAHs in U.S. EPA (2003) Attachment 4-1 (revised February 2005).

Figure 6.1 Mammalian TRV Derivation for Low Molecular Weight PAHs (LMW - PAHs)



Wildlife TRV Derivation Process

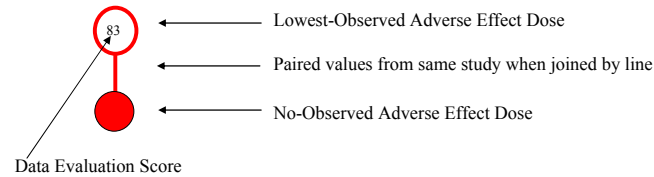
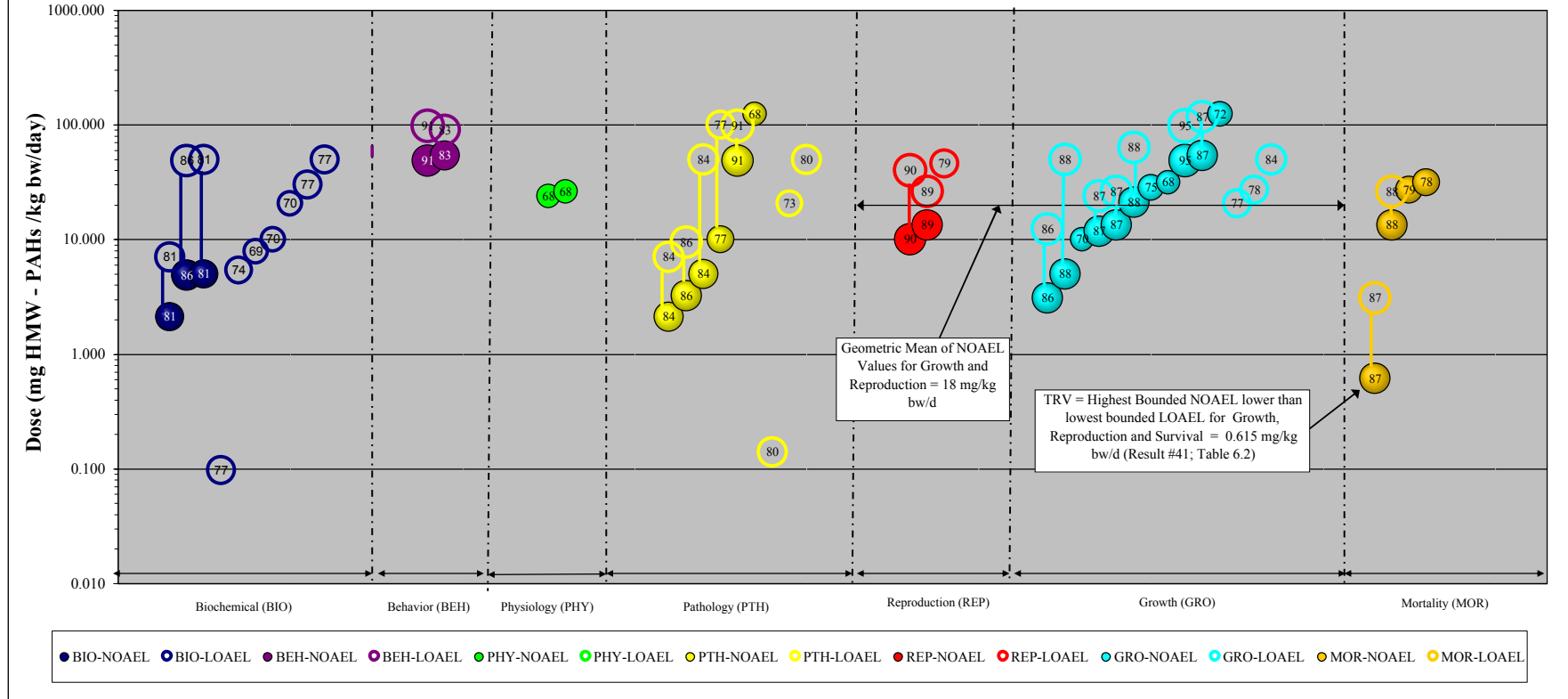
There are at least three results available for two test species within the growth, reproduction, and mortality effect groups. There are enough data to derive a TRV.

There are three NOAEL results available within the growth and reproduction effect groups for calculation of a geometric mean.

The geometric mean is equal to 170 mg LMW - PAHs/kg bw/d and is higher than the lowest bounded LOAEL for results within the reproduction, growth, and survival (MOR) effect groups.

The mammalian wildlife TRV for LMW - PAHs is equal to 65.6 mg/kg bw/day which is the highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival.

Figure 6.2 Mammalian TRV Derivation for High Molecular Weight PAHs (HMW - PAHs)



Wildlife TRV Derivation Process

There are at least three results available for two test species within the growth, reproduction, and mortality effect groups.

There are enough data to derive a TRV.

There are three NOAEL results available within the growth and reproduction effect groups for calculation of a geometric mean.

The geometric mean is equal to 18 mg HMW - PAHs/kg bw/d and is higher than the lowest bounded LOAEL for results within the reproduction, growth, and survival (MOR) effect groups.

The mammalian wildlife TRV for HMW - PAHs is equal to 0.615 mg/kg bw/day which is the highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survi

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Appendix 2-1

Summary of Peer Review

June 2007

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Summary of Peer Review of Draft Eco-SSL Document for PAHs

Introduction

The methodology for deriving Eco-SSLs was primarily designed for deriving soil concentrations for single compounds and not a group of compounds with multiple forms. When the current Eco-SSL methods are applied to polycyclic aromatic hydrocarbons (PAHs) as a group with data for all individual compounds considered together, the results for derivation of a wildlife toxicity reference value (TRV) is a focus on the most toxic PAH compound. There is no consideration of the relative toxicity of less toxic compounds. For plants and soil, the focus is on the geometric mean of values across all PAH compounds.

In August of 2006, EPA sought a peer-review of the Eco-SSL methodology as to its applicability for derivation of values for PAHs as group of compounds with multiple forms. Five peer reviewers were identified who are experienced with either the toxicity of PAHs and/or risk assessment of these substances. The peer reviewers were provided with a package for review that included the draft Eco-SSL document for PAHs, an overview description of the Eco-SSL effort, internet links to the Eco-SSL guidance documents, a brief description of the literature review method and results and a list of the PAHs considered in the Eco-SSL effort. The peer reviewers were provided with a list of five charge questions to consider in their review of the Eco-SSL PAH document. The questions as stated were:

- 1) *Is it reasonable for EPA to use the most toxic PAH compounds in the derivation of a TRV (used to derive the Eco-SSL) for screening purposes? Or should TRVs (and Eco-SSLs) be derived for individual PAH compounds? If so, what would be the recommendation(s) for addressing individual PAH compounds for which toxicity data are not available?*
- 2) *Are the methods used for human health risk assessment in the use of toxicity equivalency factors for carcinogenicity developed sufficiently that they can be used in some manner for the derivation of TRVs for wildlife? Are there possible alternative methods for relative toxicity? If so, are the toxicity data available for PAHs (Tables 5.1 and 6.1 in the document) sufficient to implement a relative toxicity approach?*
- 3) *Is it reasonable for EPA to average across endpoints for individual PAH compounds in the derivation of an Eco-SSL for plants and/or soil invertebrates? Or should values be calculated for individual PAH compounds?*
- 4) *Modeling PAH exposure and comparing the estimated dose to a TRV is problematic in the calculation of the Eco-SSL in that the TRV may reflect a different mixture of PAH compounds than the estimated dose. For example, the TRV may reflect pyrene (the most toxic) and the modeled dose is an uptake factor or equation using data for several PAH compounds (including pyrene). Is it appropriate to have different congeners in the exposure and effects sides of the HQ equations that generate the Eco-SSL.*

- 5) *In the derivation of the Eco-SSLs for PAHs, EPA considered data for PAHs and PAH derivatives but did not include data for halogenated PAHs or heterocyclic PAHs. Are these inclusions and limitations appropriate?*

The peer review packages were delivered to reviewers in August of 2006 and four of the five reviewers returned comments in August and September of 2006. A Summary Report of the peer review and results was issued in September of 2006. The purpose of this memorandum is to make recommendations concerning changes to the draft Eco-SSL document for PAHs based on the results of the peer review. The memorandum is divided into two parts. The first summarizes the peer review results and the second lists the changes made to the draft document as a result of the peer review. The full report on the peer review process and results (USEPA, 2006) is available on the Eco-SSL web site at www.epa.gov/ecotox/ecossl.

Summary of the Peer Review Results

- *Use the Most Toxic PAH Compounds to Derive a TRV.* The reviewers were divided on the use of all PAH data to derive one toxicity reference value (TRV) versus derivation of values for individual PAHs. Half considered the current approach reasonable based on the limited amount of toxicity information available and the need to be conservative and use of the values as screening levels. However, segregation of data into low and high molecular weights was suggested as an alternative approach. The other half considered the approach not acceptable and were concerned that the values would be too conservative. Another concern was grouping all PAHs together when they vary widely in physical/chemical properties which indicates different environmental and biological behaviors. This second half advocated derivation of values for each individual PAH or groups of PAHs based on boiling point fractions.
- *Use of Toxicity Equivalency Approach.* Most reviewers agreed, in general, that the use of toxicity equivalency factors (TEFs) of some sort would be appropriate. However, most agreed that application of this approach would be prohibitive due to a lack of available data. Some provided datasets as examples however these were limited to the aquatic environment and in-vitro effects. One reviewer did not recommend the use of TEFs for a screening value and believed they should be considered later in the risk assessment process.
- *Average Across Individual PAHs for Plant and Soil Invertebrate Eco-SSL.* Most reviewers agreed it was appropriate to average across results for individual PAHs. However, segregation of data into low and high molecular weights was suggested as an alternative approach.
- *Modeling PAH Exposure.* The reviewers response to this issue was the same as that for derivation of wildlife TRVs. One half agreed it was appropriate to group PAHs together

even though the mixture may or may not be equal to that reflected in the TRV. The other half advocated derivation of Eco-SSLs for individual PAHs.

- *Should Data be included for Halogenated PAHs or Heterocyclic PAHs.* In general, the reviewers agreed it was reasonable to exclude halogenated PAHs but it may be appropriate to include heterocyclic PAHs.
- *Additional Comment.* An additional comment outside the framed questions was received from one reviewer. The comment concerned the assumption that bioaccumulation of PAHs in small mammal tissues is zero (diet for carnivores). The reviewer states that mammals and other vertebrates metabolize PAHs very efficiently but can bioaccumulate free (unmetabolized) PAHs in muscle, particularly under conditions of chronic exposure and could contribute to carnivore exposure. The reviewer points to a reference that shows PAH accumulation in the muscle of fish and shellfish. The reviewer suggests that the data supporting this assumption be briefly described.

Apparent Consensus

The apparent consensus among the peer review comments is that grouping both toxicity and exposure data into two classes based on molecular weight is a reasonable approach. Although it would be ideal to use a toxicity equivalency approach in developing values, this is not possible due to limitations of the existing data. Grouping PAHs into the two classes (low and high molecular weight) is an apparent means to address the differences in physical/chemical properties of individual PAHs which influence toxicity and environmental fate.

Changes to the Draft Eco-SSL Document for PAHs

- The introduction was expanded to describe the peer review process and results and to also describe the relative strength of the TRV and Eco-SSLs. The revised introduction acknowledges that PAHs are group of individual chemicals and that the approach taken to derive Eco-SSLs for them was different. The approach used is contrasted with the approach used for other chemicals.
- This peer review summary report was added to the document as an Appendix. The full report was provided on the web site.
- The data included remained limited to only PAHs and PAH derivatives. PAHs (CASRN: 130498-29-2) are defined as a class of organic substances made up of carbon and hydrogen atoms grouped into at least two condensed aromatic ring structures. PAH derivatives are PAHs having an alkyl or other radical attached to a ring. Heterocyclic aromatic compounds (HACs) will not be included. Although the peer reviewers suggest that it is appropriate to include these chemicals, the literature search procedures used for identification of both plant and soil invertebrate and wildlife toxicity data for PAHs were

not inclusive of HACs. HACs include PAHs having any one carbon atom in a ring replaced by a nitrogen, oxygen, or sulfur atom (<http://toxnet.nlm.nih.gov>).

- Eco-SSLs were calculated for two classes of PAHs (high and low molecular weights). Low molecular weight compounds are defined as PAHs and PAH derivatives composed of fewer than four rings and high molecular weight compounds are defined as those with four or more rings. Similarly, wildlife TRVs were also derived separately for the two classes. The current regression model used to predict the transfer of PAHs from soils to plant foliage was also segregated into two classes (Attachment 4-1 of the Eco-SSL guidance).

References

United States Environmental Protection Agency (USEPA). 2006. *Summary of Peer Review Comments Draft Eco-SSL Document for Polycyclic Aromatic Hydrocarbons (PAHs)*. September 25, 2006. Prepared by Syracuse Research Corporation, Denver, Colorado under contract to Wilson Environmental Labs, Duluth, Minnesota for the USEPA National Health and Ecological Effects Research Laboratory (NHEERL), Mid-Continent Ecology Division- Duluth (MED-Duluth).



Appendix 5-1

*Avian Toxicity Data Extracted and Reviewed for Wildlife Toxicity
Reference Value (TRV) - LMW PAHs*

June 2007

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**Appendix 5.1 Avian Toxicity Data Extracted for Wildlife Toxicity Reference Value (TRV)
Low Molecular Weight Polynuclear Aromatic Hydrocarbons (LMW - PAHs)**

Result #	Ref	Reference	Chemical Form	MW%	Test Species	Exposure														Effects						Conversion to mg/kg bw/day			Result		Data Evaluation Score													
						# of Conc/ Doses	Conc/ Doses	Conc/Dose Units	Wet Weight Reported?	Percent Moisture	Application Frequency	Method of Analyses	Route of Exposure	Exposure Duration	Duration Units	Age	Age Units	Lifestage	Sex	Control Type	Test Location	General Effect Group	Effect Type	Effect Measure	Response Site	Study NOAEL	Study LOAEL	Body Weight Reported?	Body Weight in kg	Ingestion Rate Reported?	Ingestion Rate in kg/day or L/day	NOAEL Dose (mg/kg/day)	LOAEL Dose (mg/kg/day)	Data Source	Dose Route	Test Concentrations	Chemical form	Dose Quantification	Endpoint	Dose Range	Statistical Power	Exposure Duration	Test Conditions	Total
Behavior																																												
1	27393	Landis Assoc.Inc, 1985	Naphthalene	100	Bobwhite (<i>Colinus virginianus</i>)	7	0/316/562/1000/1780/3160/5620	mg/kg diet	N	na	ADL	U	FD	5	d	13	d	JV	B	V	Lab	BEH	FDB	FCNS	WO	5620		Y	0.03400	Y	0.01000	1653		10	10	5	10	7	4	4	1	10	7	68
Growth																																												
2	27393	Landis Assoc.Inc, 1985	Naphthalene	100	Bobwhite (<i>Colinus virginianus</i>)	7	0/316/562/1000/1780/3160/5620	mg/kg diet	N	na	ADL	U	FD	5	d	13	d	JV	B	V	Lab	GRO	GRO	BDWT	WO	5620		Y	0.03400	Y	0.01000	1653		10	10	5	10	7	8	4	1	10	7	72
Survival																																												
3	27393	Landis Assoc.Inc, 1985	Naphthalene	100	Bobwhite (<i>Colinus virginianus</i>)	7	0/316/562/1000/1780/3160/5620	mg/kg diet	N	na	ADL	U	FD	5	d	13	d	JV	B	V	Lab	MOR	MOR	MORT	WO	5620		Y	0.03400	Y	0.01000	1653		10	10	5	10	7	9	4	10	10	7	82

All abbreviations and definitions used in coding studies are available from Attachment 4-3 of the Eco-SSL guidance (U.S. EPA 2003).

Duplicate values for NOAELs and LOAELs for the same reference represent results from different experimental designs.



Appendix 5-2

*Avian Toxicity Data Extracted and Reviewed for Wildlife Toxicity
Reference Value (TRV) - HMW - PAHs*

June 2007

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**Appendix 5.2 Avian Toxicity Data Extracted for Wildlife Toxicity Reference Value (TRV)
High Molecular Weight Polynuclear Aromatic Hydrocarbons (HMW - PAHs)**

Result #	Ref	Reference	Chemical Form	MW%	Test Species	Exposure																Effects						Conversion to mg/kg bw/day		Result		Data Evaluation Score													
						# of Conc/ Doses	Conc/ Doses	Conc/Dose Units	Wet Weight Reported?	Percent Moisture	Application Frequency	Method of Analyses	Route of Exposure	Exposure Duration	Duration Units	Age	Age Units	Lifestage	Sex	Control Type	Test Location	General Effect Group	Effect Type	Effect Measure	Response Site	Study NOAEL	Study LOAEL	Body Weight Reported?	Body Weight in kg	Ingestion Rate Reported?	Ingestion Rate in kg/day or L/day	NOAEL Dose (mg/kg/day)	LOAEL Dose (mg/kg/day)	Data Source	Dose Route	Test Concentrations	Chemical form	Dose Quantification	Endpoint	Dose Range	Statistical Power	Exposure Duration	Test Conditions	Total	
Biochemical																																													
1	27747	Trust et al, 1994	7,12- Dimethylbenz(a)anthracene	100	European Starling (<i>Sturnus vulgaris</i>)	4	0/10/25/60	mg/kg bw/d	N	na	DLY	U	GV	5	d	NR	NR	AD	B	C	Lab	BIO	CHM	PRTL	PL	60		N	0.08470	N	0.011667	60.0		10	8	10	10	10	10	1	4	10	6	4	73
2	27747	Trust et al, 1994	7,12- Dimethylbenz(a)anthracene	100	European Starling (<i>Sturnus vulgaris</i>)	3	0/2/20	mg/kg bw/d	N	na	DLY	U	GV	5	d	9	d	JV	B	C	NR	BIO	ENZ	AATT	PL	2	20	Y	0.05500	N	0.00881	2.0	20.0	10	8	10	10	10	10	1	8	10	10	4	81
Pathology																																													
5	27747	Trust et al, 1994	7,12- Dimethylbenz(a)anthracene	100	European Starling (<i>Sturnus vulgaris</i>)	3	0/2/20	mg/kg bw/d	N	na	DLY	U	GV	5	d	9	d	JV	B	C	NR	PTH	ORW	ORWT	BU	2	20	N	0.05500	N	0.00881	2.0	20.0	10	8	10	10	10	4	8	10	10	4	84	
Growth																																													
7	27747	Trust et al, 1994	7,12- Dimethylbenz(a)anthracene	100	European Starling (<i>Sturnus vulgaris</i>)	3	0/2/20	mg/kg bw/d	N	na	DLY	U	GV	5	d	9	d	JV	B	C	NR	GRO	GRO	BDWT	WO	2	20	Y	0.05500	N	0.00881	2.0	20.0	10	8	10	10	10	8	8	10	10	4	88	

All abbreviations and definitions used in coding guides are available from Attachment 4-3 of the Eco-SSL guidance (U.S. EPA 2003).

Duplicate values for NOAELs and LOAELs for the same reference represent results from different experimental designs.



Appendix 6-1

*Mammalian Toxicity Data Extracted and Reviewed for Wildlife
Toxicity Reference Value (TRV) - LMW PAHs*

June 2007

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Appendix 6-2

*Mammalian Toxicity Data Extracted and Reviewed for Wildlife
Toxicity Reference Value (TRV) - HMW - PAHs*

June 2007

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**Appendix 6.2 Mammalian Toxicity Data Extracted for Wildlife Toxicity Reference Value (TRV)
High Molecular Weight Polynuclear Aromatic Hydrocarbons (HMW-PAHs)
Page 2 of 2**

Result #	Ref No.	Ref	Chemical Form	MW %	Test Species	Exposure																	Effects					Conversion to mg/kg bw/day				Result		Data Evaluation Score											
						Phase #	# of Conc/ Doses	Conc/ Doses	Conc/Dose Units	Wet Weight Reported?	Percent Moisture	Application Frequency	Method of Analyses	Route of Exposure	Exposure Duration	Duration Units	Age	Age Units	Lifestage	Sex	Control Type	Test Location	General Effect Group	Effect Type	Effect Measure	Response Site	Study NOAEL	Study LOAEL	Body Weight Reported?	Body Weight in kg	Ingestion Rate Reported?	Ingestion Rate in kg or L/day	NOAEL Dose (mg/kg/day)	LOAEL Dose (mg/kg/day)	Data Source	Dose Route	Test Concentrations	Chemical form	Dose Quantification	Endpoint	Dose Range	Statistical Power	Exposure Duration	Test Conditions	Total
48	26164	Rigdon and Neal, 1965	Benzo(a)pyrene	100	Mouse (<i>Mus musculus</i>)	2	2	0/0.25	mg/g	NR	na	ADL	U	FD	6	d	20	d	JV	M	V	Lab	BEH	FDB	FCNS	WO	0.25		Y	0.0110	Y	0.0012	27.3		10	10	5	10	7	4	4	1	10	4	65
49	48370	Hood et al., 2003	3-Methylcholanthrene	100	Mouse (<i>Mus musculus</i>)	1	5	0/62.5/125/250/500	mg/kg diet	NR	na	ADL	U	FD	21	d	7	w	JV	M	V	Lab	PTH	ORW	ORWT	LI	500		Y	0.0316	N	0.004015	63.5		10	10	5	5	10	4	4	1	10	4	63
50	48539	Uno et al., 2006	Benzo(a)pyrene	100	Mouse (<i>Mus musculus</i>)	1	4	0/1.25/12.5/125	mg/kg bw/d	NR	na	ADL	U	FD	18	d	NR	NR	JV	M	V	Lab	BIO	ENZ	AATT	BL	125		Y	0.024	N	0.0032025	125		10	10	5	10	10	1	4	1	10	4	65
27	28203	Holladay and Smith, 1994	Benzo(a)pyrene	100	Mouse (<i>Mus musculus</i>)	1	4	0/50/100/150	mg/kg bw/d	NR	na	DLY	U	GV	5	d	NR	NR	GE	F	V	Lab	REP	REP	OHIS	PY		50	N	0.03530	N	0.00439772		50.0	10	8	10	10	10	10	4	10	10	4	86

All abbreviations and definitions used in coding studies are available from Attachment 4-3 of the Eco-SSL guidance (U.S. EPA 2003).
Duplicate values for NOAELs and LOAELs for the same reference represent results from different experimental designs.